12 GROUNDWATER

In parallel with the preparation of the Draft EIS, and subsequent to its submission, significant additional work has been completed on the groundwater systems of the Stuart Shelf and surrounds. This work has assisted in gaining a broader understanding of the Stuart Shelf groundwater system, its relationship to other aquifer systems, and in clarifying the potential impacts of the proposed expansion on groundwater, both in the vicinity of the operation and on a regional scale. Some of the material presented in the responses to Draft EIS submissions in the following sections is complex, but a number of broad conclusions can be drawn and these are provided in this introductory section to the chapter. This section provides a context for the overall groundwater response and shows that the outcomes of the additional studies support the conclusions drawn in the Draft EIS.

The Stuart Shelf aquifers are shown to be a part of a low-flow system, with total flow less than 4 ML/d. They are, in turn, surrounded by large, high-flow systems, including the Arckaringa/Boorthanna aquifers to the west, aquifers associated with Lake Torrens and recharge from the Flinders Ranges to the east, and the very large, high-flow system of the Great Artesian Basin (GAB) to the north. Importantly, the GAB can be shown to be separated and distinct from the aquifers of the Stuart Shelf and Arckaringa Basin.

The groundwater of the GAB is chemically distinct from that of the Stuart Shelf, and the water is derived from separate sources. In addition, the GAB aquifers are separated from the Stuart Shelf by the very low permeability sediments of the Adelaide Geosyncline and Torrens Hinge Zone, a groundwater divide approximately 80 km to the north of Olympic Dam and an extensive evaporative groundwater discharge zone that is aligned with the southwestern extent of the artesian GAB. They are further separated from the Arckaringa Basin by the presence of this same extensive evaporative groundwater discharge zone. Elevated heads in the Arckaringa/Boorthanna aquifers relative to the Stuart Shelf, and recharge, would provide inflow to compensate for the small projected long-term pit inflow.

The estimated long-term inflow to the pit, post-closure, is relatively minor in the context of the high-flow systems bounding the Stuart Shelf and the associated potential buffering effects. The resulting drawdown impacts are therefore also predicted to be minor, both to third party users and also at the important Yarra Wurta spring to the east.

The modelling of drawdown associated with the expanded operation has been very conservative and, whilst considered unlikely, conceivable impacts are possible at Yarra Wurta spring and to a lesser extent at third party groundwater extraction wells. These impacts may only materialise after a very long time, in excess of 500 years post-closure. For third party users, a potential impact has been identified in two bores to the west of the operation, with drawdown of up to 2 m at 19 Mile Bore and less than 1 m at Loch Well, although this will be mitigated by the likelihood these supplies draw on perched aquifers and not the regional water table aquifer. The long term drawdown at Yarra Wurta spring is predicted to be about 1 m, but it is likely that spring flow will be buffered by a number of factors not taken into account in the modelling. These include structural controls known to exist between the mine and the spring, the effect of storage buffering by Lake Torrens, and groundwater levels around the lake edge that are approximately 2 m above the elevation of the spring vents. In addition, the spring flow is quite possibly sourced from the north-east, rather than from the west in the direction of the mine.

While the magnitude of inflow to the pit is small in the context of the regional groundwater system, it has been shown to act as an effective sink for any seepage from both the tailings storage facility (TSF) and rock storage facility (RSF). The results of an extensive four-year study of the existing TSF have shown that there is sufficient capacity within the first 2 to 3 m of underlying sediments and Andamooka Limestone above the water table to effectively neutralise and attenuate the seepage associated with the expanded operation. Nevertheless, all seepage is predicted to remain within 1.5 km of the system and is ultimately captured by the drawdown cone associated with the final pit.

The conclusions drawn are based on the results of a number of assessment programs, both local and regional. Among the more significant items are:

- the installation of an additional 75 groundwater wells throughout the Stuart Shelf, in six separate areas of investigation
- the installation of multiple nested piezometers for the assessment of aquifer response

- the definition of groundwater contours for each aquifer unit
- three regional water quality surveys
- characterisation of groundwater salinity and associated density contrasts
- definition of the Lake Torrens brine wedge
- a major study to characterise the neutralisation and attenuation of TSF and RSF seepage.

Updates have also been made to the groundwater numerical model to incorporate:

- refined modelling properties and grid, including inflow based on results from the calibrated Prominent Hill Mine Regional Groundwater Model (Aquaterra 2009)
- extended sensitivity analyses of various scenarios
- the addition of multiple nodes to represent the GAB
- aquifer testing results into the model calibration
- confirmation that model calibration statistics are appropriate.

12.1 CONCEPTUAL GROUNDWATER MODEL

12.1.1 MODELLING

Issue:

Clarification and substantiation was sought regarding some aspects of the conceptual hydrogeological model presented in Chapter 12 of the Draft EIS and accompanying appendices, in particular:

- the barrier between the Great Artesian Basin (GAB) and Stuart Shelf, with a specific request for the presentation of a hydrogeological cross-section from Olympic Dam to Billa Kalina Springs
- the inferred geological and hydrogeological interfaces between the Stuart Shelf, GAB, Torrens Hinge Zone and Adelaide Geosyncline, including inferred groundwater flow behaviour and hydraulic separateness
- the hydrochemical distinctness of individual aquifers
- inferences of linkages between the Arckaringa Basin (Boorthanna Formation) and Stuart Shelf groundwater systems
- the presence of the Andamooka Palaeochannel in the mining lease area
- observed groundwater system response to the existing mining operation and inferences that can be drawn regarding the predicted response for the proposed expansion.

Submissions: 1 and 2

Response:

Each of the specific issues raised above are addressed under separate sub-headings below and supported by Appendices F1, F2 and F3 of the Supplementary EIS. The conceptual groundwater model has also been reviewed and accepted by Golder Associates Pty Ltd and provided in Appendix F of the Supplementary EIS.

Barriers to groundwater flow between the Stuart Shelf and the Great Artesian Basin (GAB)

The groundwater systems of the Stuart Shelf and the GAB (in this area represented by the artesian sections of the Eromanga Basin aquifers) are separated by two primary hydrogeological controls. One is a groundwater divide located north of the Andamooka Limestone and the other is the Arckaringa Basin groundwater system located west-north-west of the Stuart Shelf.

Figures 12.1a, 12.1b and 12.2 show the location of the groundwater divide, with the location being derived from available groundwater level data provided in Appendix F2 of the Supplementary EIS, as well as topography and the outcrop of low permeability Adelaide Geosyncline rocks. The interpreted location of this groundwater divide is also shown on Figure 12.12 of the Draft EIS and is supported in the peer reviewed publications of Kellet and others (1999) and Waterhouse and others (2002). This groundwater divide occurs in a 20 to 40 km wide zone of low permeability Proterozoic rocks around 80 km north of Olympic Dam, and is interpreted as extending almost as far west as the Billa Kalina Fault System (see Figure 12.5). North of this divide, an extensive (regional) evaporative groundwater discharge zone further separates the artesian GAB from the Stuart Shelf groundwater system.

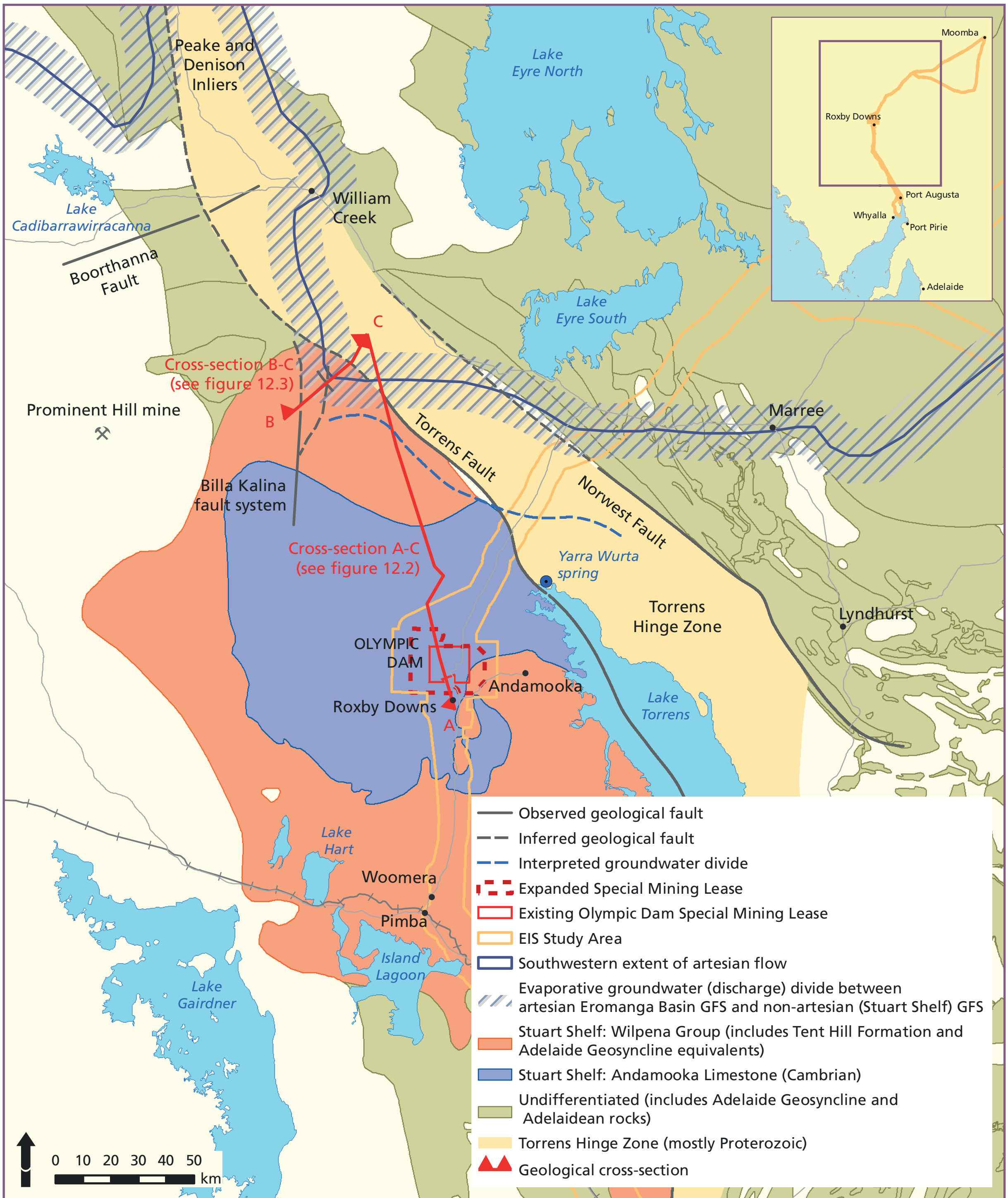


Figure 12.1a Geological setting of the Stuart Shelf

Around 100 km north west of Olympic Dam, in a lithologically and structurally complex area, Arckaringa Basin sediments come into contact with artesian GAB aquifers. The regional evaporative groundwater discharge zone also occurs in this area, as shown on Figure 12.3 (see also the detailed description in Sections 3.3 and 3.4 of Appendix F1 of the Supplementary EIS). Along with geological structure, this discharge zone also serves to separate the artesian GAB from other groundwater systems to the west and southwest.

Therefore, the potential for the proposed open pit mine to affect the GAB, either during the operational phase or in the long term after closure, is considered to be extremely unlikely given the hydraulic barriers that separate the Stuart Shelf from the GAB.

Geological and hydrogeological interfaces, including inferred groundwater flow behaviour and hydraulic separateness

The geological and hydrogeological setting of the broader Olympic Dam region were presented in detail in Section 12.3 and Appendix K1 of the Draft EIS. Geological cross-sections were presented for the northern Stuart Shelf and southern GAB (being the

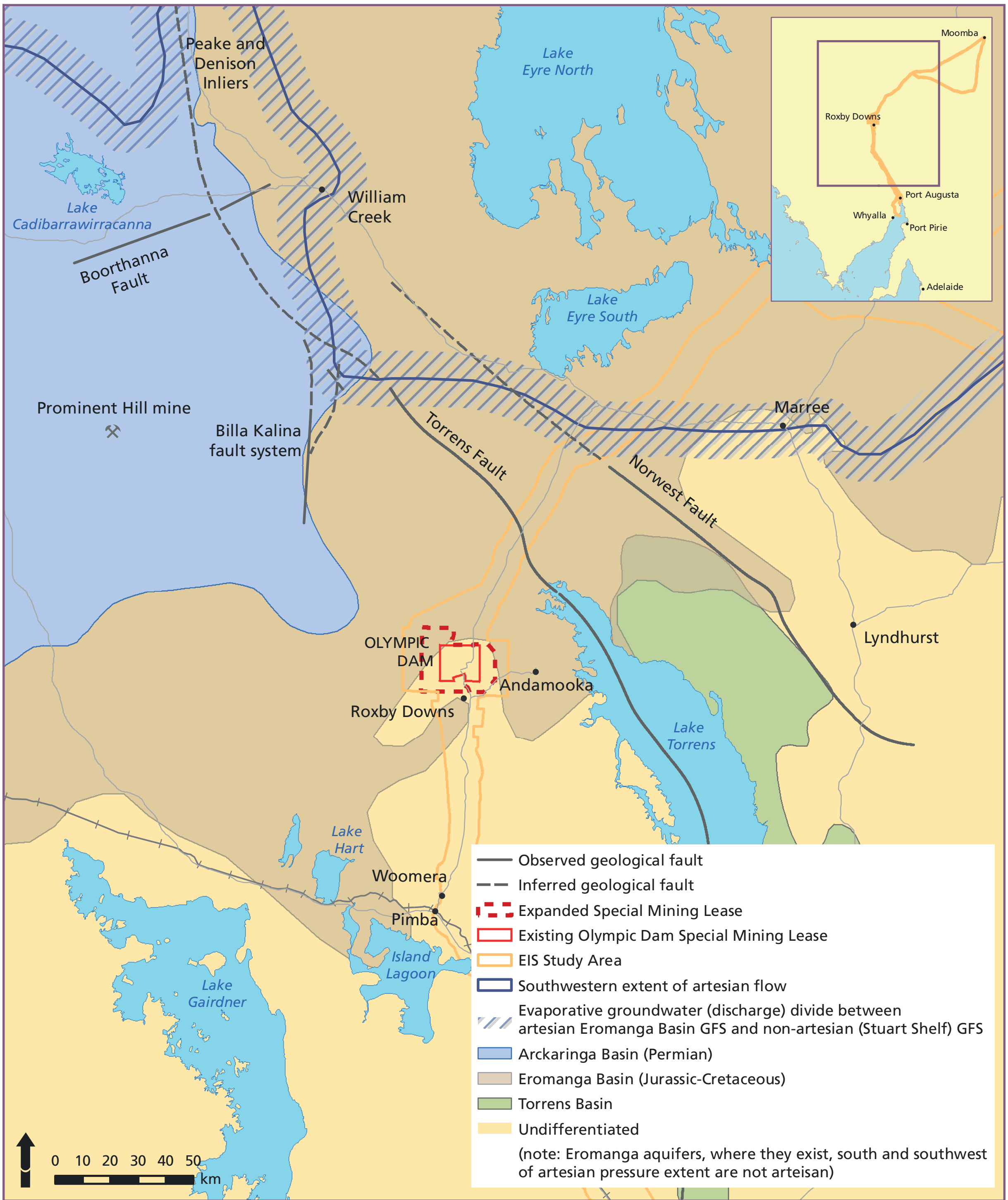


Figure 12.1b Geological setting of the Arckaringa Basin and Eromanga Basin

artesian portion of the Eromanga Basin) in Figure 12.6 of the Draft EIS, and for the northern Stuart Shelf and westerly extent of the Adelaide Geosyncline in Figure 12.7 of the Draft EIS.

Figures 12.1a and 12.1b of the Supplementary EIS present a locality plan showing the spatial extent of key lithologies for the broader region.

To further establish the geological setting of the broader region and, in particular, the hydrostratigraphic relationships between the Stuart Shelf, Arckaringa Basin and GAB, two additional geological cross-sections are presented for the northern Stuart Shelf and the south-westerly extent of the GAB (see Figure 12.2), and for the eastern extent of the Arckaringa Basin and the GAB (see Figure 12.3). The cross-sections have been prepared based on available geological drill hole database information and 1:250,000 geological maps as detailed in Section 3.4 of Appendix F1 of the Supplementary EIS.

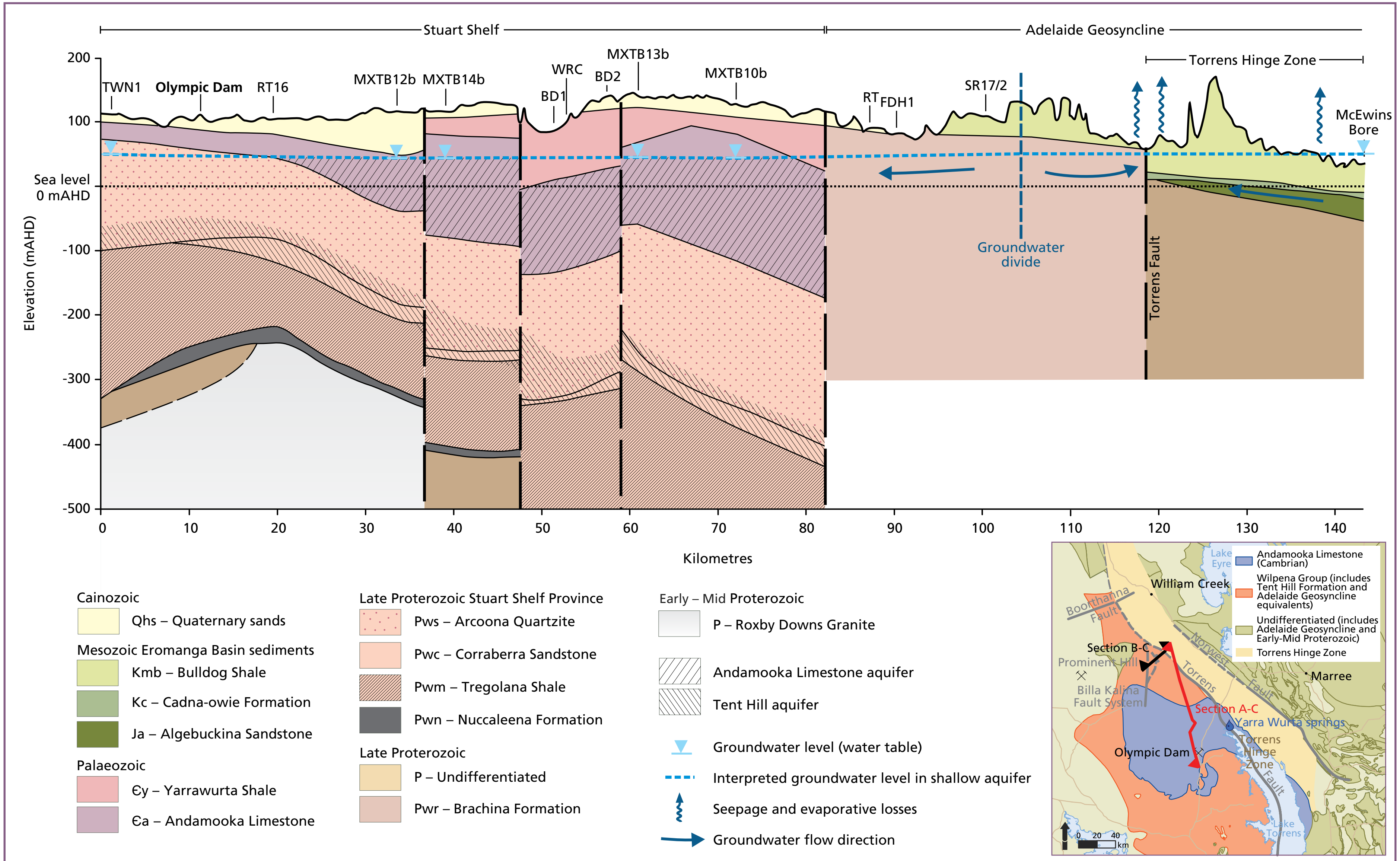


Figure 12.2 Cross-section A-C showing interpreted hydrostratigraphic and structural relationships north of Olympic Dam toward Billa Kalina spring

The Neoproterozoic rocks of the Stuart Shelf and the Adelaide Geosyncline abut each other along the Torrens Fault and the Billa Kalina Fault System (see Figure 12.2). Consistent with descriptions presented in Chapter 12 and Appendix K1 of the Draft EIS, the Torrens Hinge Zone represents an extensive zone of faulting and deformation that separates the undeformed sedimentary rocks of the Stuart Shelf and the folded sedimentary rocks of the Adelaide Geosyncline (Preiss 1987).

Figure 12.2 shows:

- The northern limit of Stuart Shelf rocks appear to be structurally controlled, and Adelaide Geosyncline rocks (or their equivalents) extend south of the Torrens Fault.
- Between the northern margin of the Stuart Shelf and the Torrens Fault, Adelaide Geosyncline rocks lie close to the surface, separating Stuart Shelf rocks from GAB sediments (i.e. the Cadna-owie Formation and Algebuckina Sandstone).

Shallow remnant Eromanga Basin sediments (i.e. the Bulldog Shale and patches of lag cobbles derived from it), occur sporadically and discontinuously over parts of the northern Stuart Shelf and the Torrens Hinge Zone. Further north into the GAB, the Bulldog Shale forms the extensive confining unit that overlies the deeper artesian Eromanga Basin aquifer.

As shown on Figure 3.11 of the Supplementary EIS, northwest, near Billa Kalina springs, Proterozoic basement strata are overlain by Permian sediments of the Arckaringa Basin, which are in turn overlain by Eromanga Basin sediments. Although some Arckaringa Basin sediments do occur between the Billa Kalina fault system and the Torrens Fault, the available data suggest the sediments are separated from overlying GAB sediments by the low permeability Stuart Range Formation (of the Arckaringa Basin) (see Section 3.4 of Appendix F1 of the Supplementary EIS for further details).

Results of analysis of aquifer testing data are presented in Section 3.4 of Appendix F1. Other testing data were also collected during studies for the proposed expansion as well as other regional studies (e.g. Douglas and Howe 2009; Howe et al. 2008; AGC 1982; WMC Resources 1997; and other references cited in Appendix K1 of the Draft EIS). Hydraulic testing undertaken at the location of monitoring wells screening Adelaide Geosyncline rocks of the Torrens Hinge Zone show the rocks have very low permeability in comparison to the Stuart Shelf aquifers and the artesian Eromanga (GAB) aquifers, as shown on Figure 12.4 and detailed further in Section 3.4 of Appendix F1 of the Supplementary EIS. Table 12.1 presents a summary of the key hydrostratigraphic units of the broader region.

Table 12.1 Summary of regional hydrostratigraphy

Geological Domain	Age	Aquifer	Aquitard
Stuart Shelf	Adelaidean–Cambrian	Andamooka Limestone Tent Hill Aquifer[1]	Yarloo Shale Arcoona Quartzite (Upper Part) Tregolana Shale Woomera Shale
Adelaide Geosyncline	Adelaidean	None Identified In Study Area	ABC Range Quartzite Brachina Formation Amberoona Formation
Arckaringa Basin	Permian	Boorthanna Formation	Stuart Range Formation
Eromanga Basin	Jurassic–Mesozoic	Cadna–owie Formation Algebuckina Sandstone	Bulldog Shale
Pirie-Torrens Basin	Quaternary–Tertiary	Tertiary sediments	Quaternary sediments

[1] Incorporating the Corraberra Sandstone and lower Arcoona Quartzite.

The three dominant groundwater flow systems (GFS) in the broader region of Olympic Dam are shown in Figure 12.5 and are described as:

- the regional-scale Arckaringa–Stuart Shelf GFS, which incorporates the aquifers of the Stuart Shelf itself (the Tent Hill aquifer and the Andamooka Limestone aquifer) as well as the connected aquifers of the neighbouring (upstream) Arckaringa Basin (the Boorthanna aquifer) to the west
- the regional-scale artesian Eromanga GFS, comprising the aquifers of the Eromanga Basin where they are artesian north of Olympic Dam
- the intermediate to regional-scale Torrens Basin GFS, comprising Tertiary sedimentary aquifers beneath and immediately east of Lake Torrens and Proterozoic fractured rock aquifers of the western Flinders Ranges.

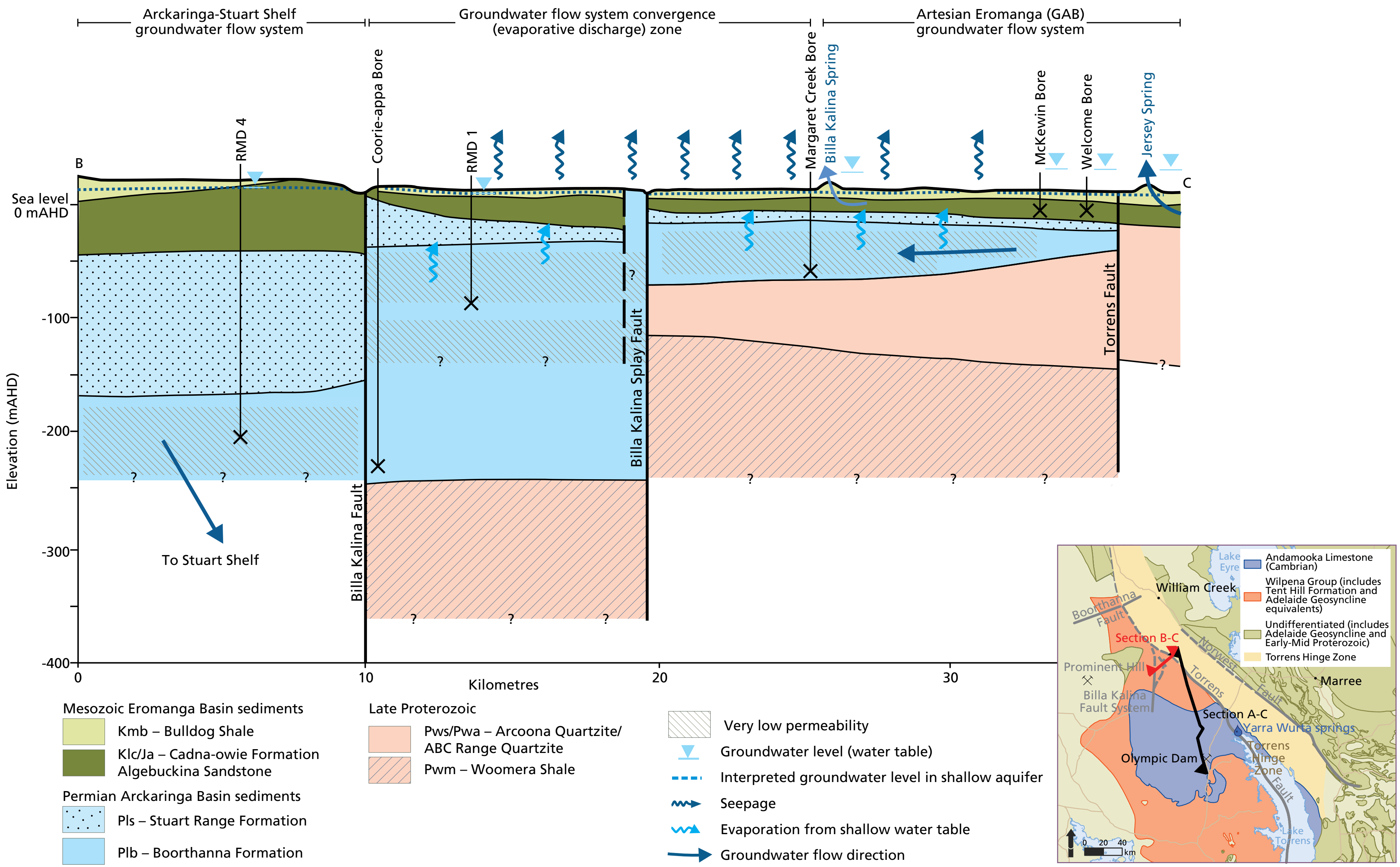


Figure 12.3 Cross-section B-C showing interpreted hydrostratigraphic and structural relationships from the Arckaringa Basin through to the Eromanga Basin

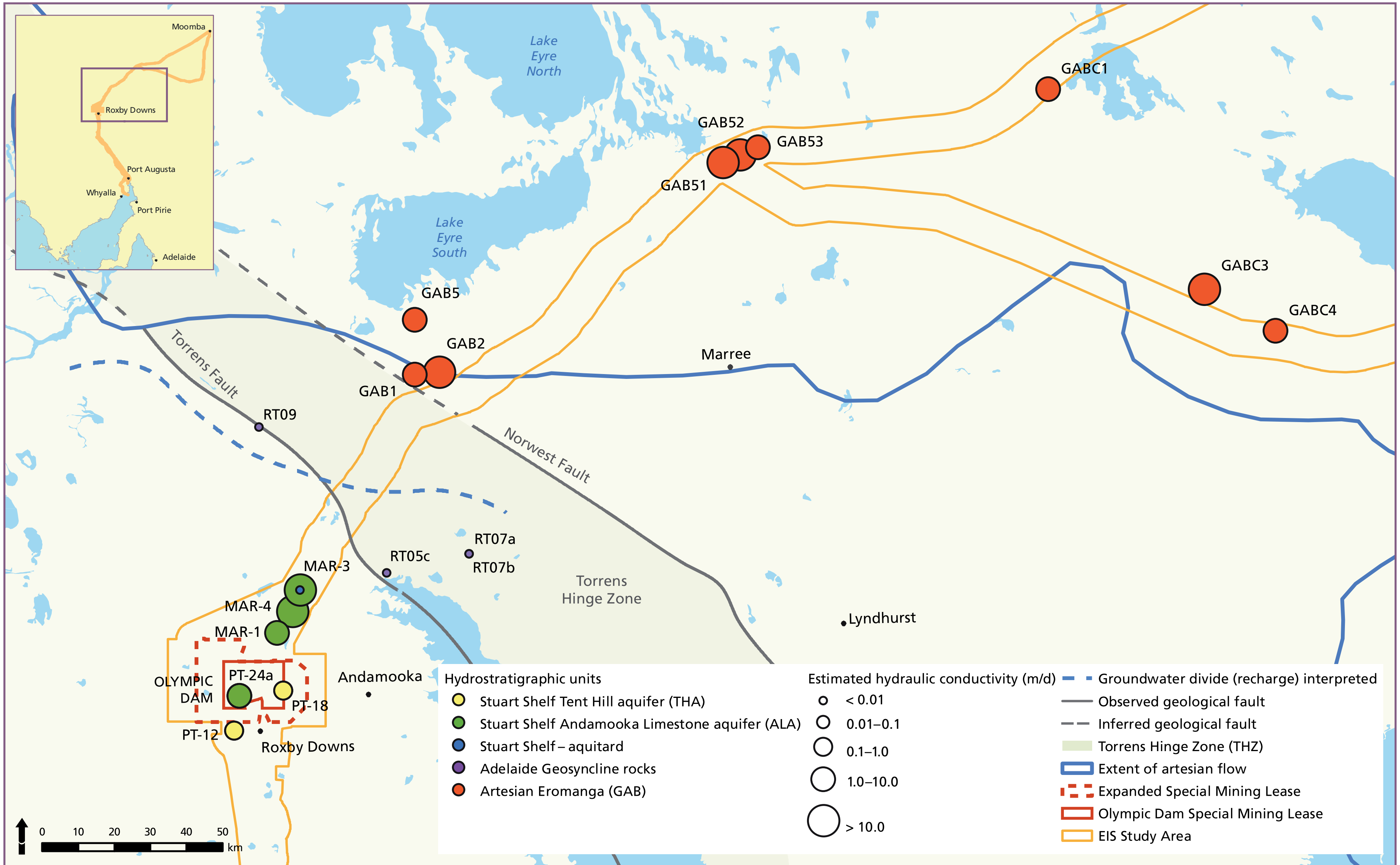


Figure 12.4 Spatial distribution of aquifer permeability data

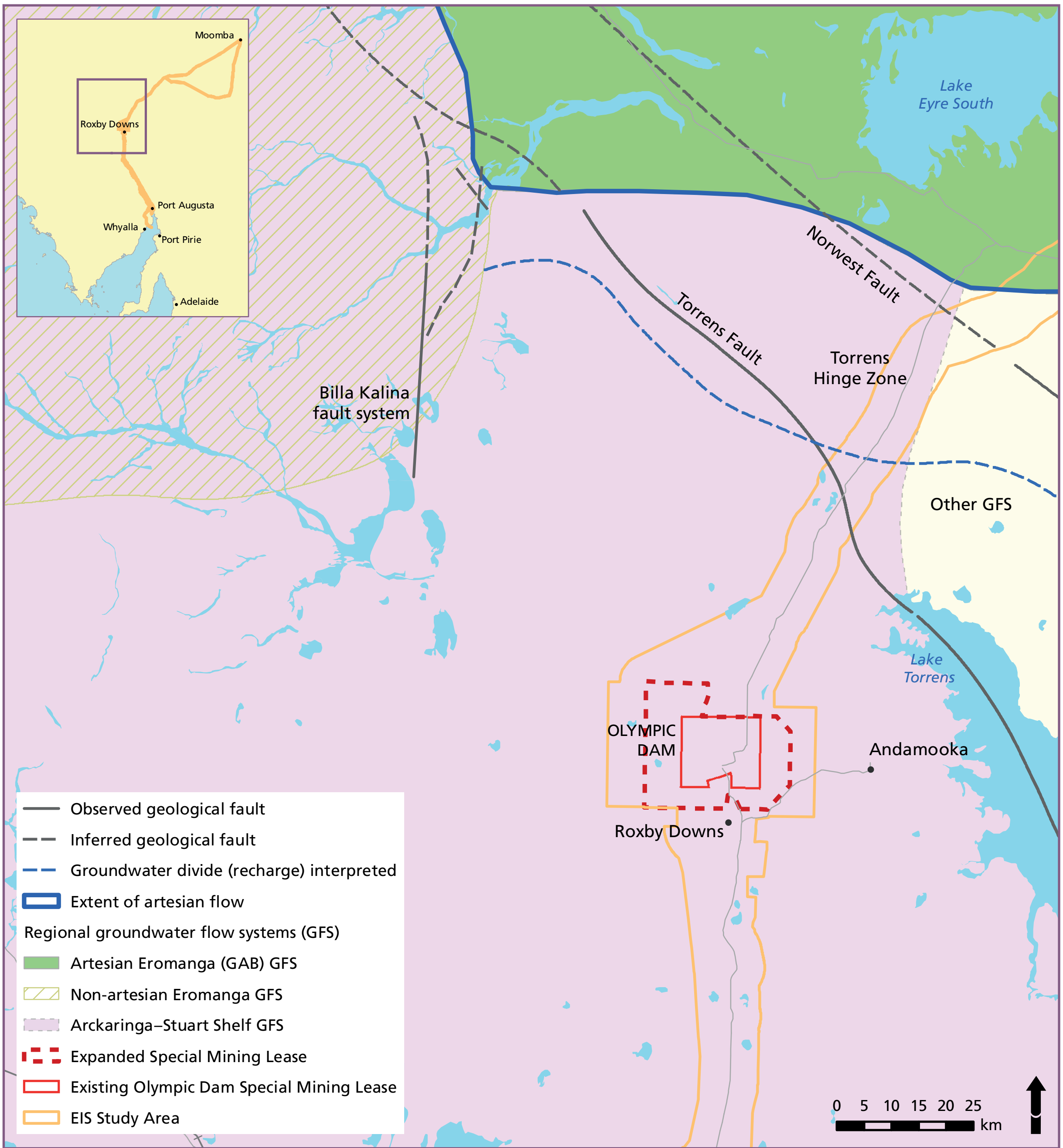


Figure 12.5 Regional groundwater flow systems (GFS)

Hydrogeochemical distinctness of individual aquifers

Regional scale interactions between groundwater flow systems

Hydrogeochemical data, including salinity concentrations and major ion concentrations (as presented in Section 3.5 of Appendix F1 and Attachments to Appendix F2 of the Supplementary EIS), support the notion that the aquifers of the Arckaringa Basin and Stuart Shelf do not interact with those of the artesian Eromanaga GFS, and comprise a single regional-scale GFS.

Figure 12.6 of the Supplementary EIS presents a Piper tri-linear plot that compares major ion concentrations in groundwater sampled from the different aquifers of the broader region. The plot shows a different speciation between the artesian Eromanga GFS groundwaters and other groundwaters in the region. Figure 12.7 presents groundwater salinity concentrations against Australian Map Grid Eastings. The data are interpreted to show that Boorthanna aquifer groundwaters (sampled from the upstream component of the Arckaringa–Stuart Shelf GFS) are quite distinct from artesian Eromanga GFS groundwaters, including those sampled from the GAB springs and artesian wells around the Billa Kalina springs located more than 100 km north-west of Olympic Dam, as shown on Figures 12.1 and 12.2.

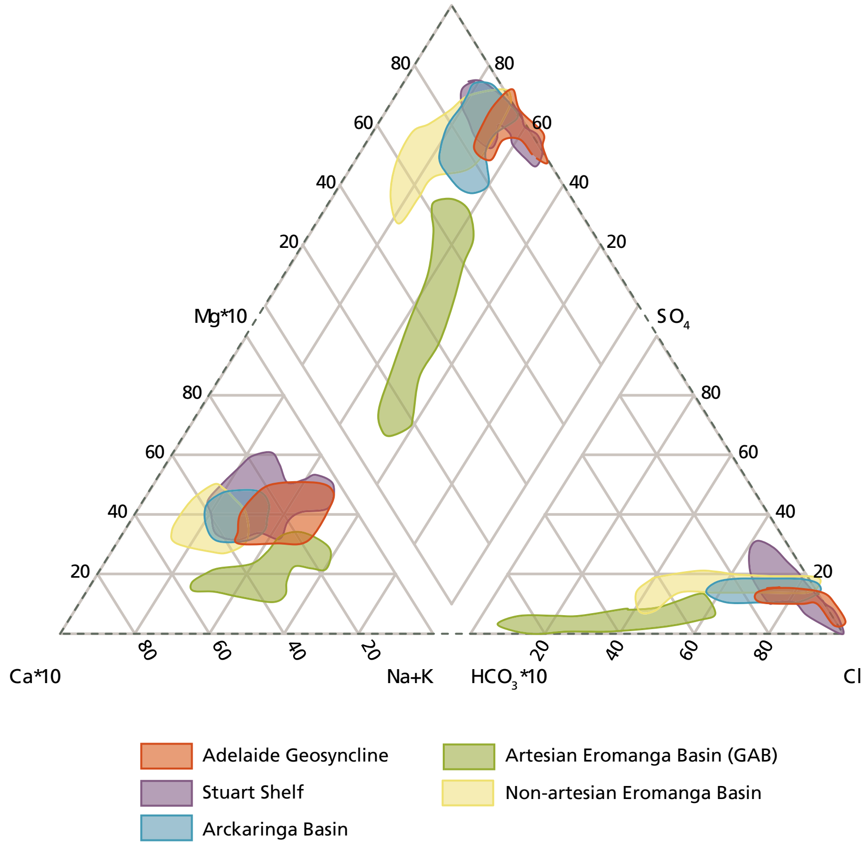
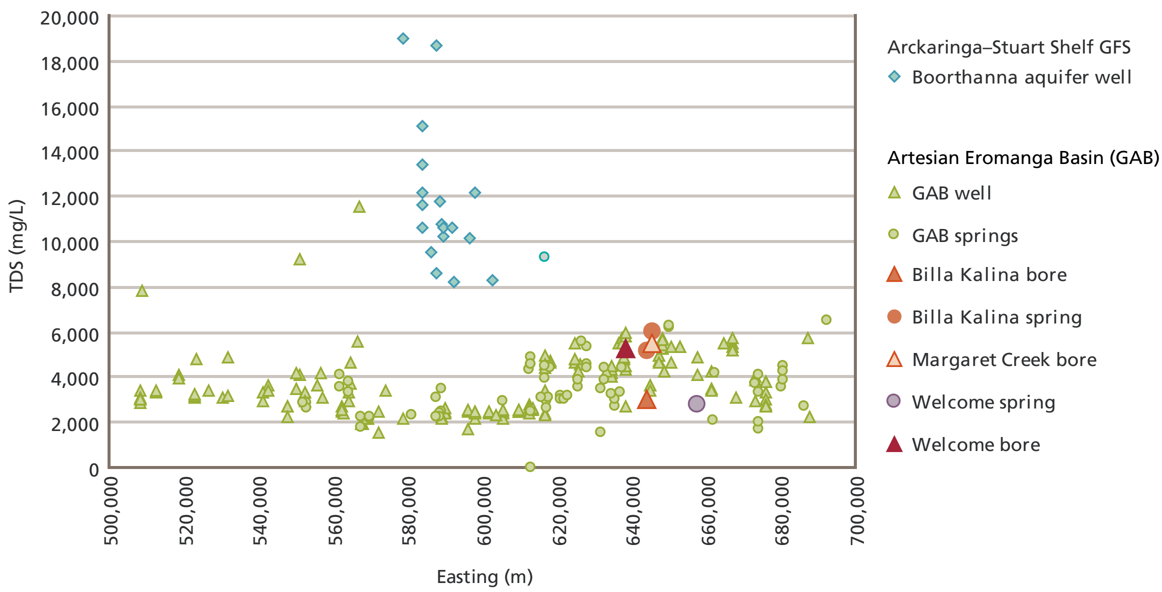


Figure 12.6 Piper tri-linear plot showing regional major ion data for different groundwater systems



GFS: Groundwater flow system

Figure 12.7 Salinity concentrations for the Boorthanna aquifer and the artesian Eromanga (GAB) aquifers

Linkages between the Arckaringa Basin and Stuart Shelf groundwater systems

Groundwater data showing a regional hydraulic gradient extending from the Boorthanna aquifer in the west, to the east across the Stuart Shelf, strongly support the notion that the aquifers are in hydraulic connection and form a single regional groundwater flow system.

A large dataset of groundwater level/potentiometric data, covering the area of greatest predicted change in water level, has been collected for the Stuart Shelf aquifers as a result of an extensive groundwater investigation program conducted by BHP Billiton since 2005 (refer Appendix K1 and K2 of the Draft EIS; and Figure 3.1 in Appendix F1 and Appendix F2 of the Supplementary EIS). These data have been used to prepare Figure 12.8 of the Supplementary EIS showing regional water table contours overlaid on the dominant geological provinces.

The groundwater level/potentiometric data presented in Figure 12.8 show there is a regional hydraulic gradient extending from the Boorthanna aquifer to the east across the Stuart Shelf. This gradient supports the notion that the Boorthanna aquifer (of the Arckaringa Basin) and the aquifers of the Stuart Shelf are in hydraulic connection and form a single regional GFS, as described above. Available hydrogeochemical data support this conclusion.

As was described in Section 12.3.3 of the Draft EIS and shown on Figure 12.8 of the Supplementary EIS, Olympic Dam lies on the southern margins of the south Andamooka Limestone Aquifer (ALA) (further south, the ALA becomes largely unsaturated). Also shown on Figure 12.8 is the interpreted alignment of the groundwater divide that separates the primary aquifers of the Arckaringa–Stuart Shelf GFS from the GAB GFS.

Andamooka Palaeochannel in the mining lease area

The Andamooka Palaeochannel referenced in Appendix K1 of the Draft EIS is inferred from mapping, and landform that resembles a surface drainage along the northern margin of the Arcoona Plateau approximately 30 km south-east of the expanded SML.

Geophysical surveys undertaken by BHP Billiton, supported by drilling programs, suggest the drainage alignment is a structurally controlled feature within Stuart Shelf rocks, and is not associated with Tertiary sediments that infill palaeodrainages elsewhere on the Gawler Craton. It lies outside the predicted zone of influence of the mine pit post-closure at 2550 (as discussed in Section 12.2.1 of the Supplementary EIS) and is not considered to be an aquifer nor a significant groundwater feature within the Stuart Shelf. As such, the feature would not be affected by, or have unique implications for, the proposed mining operation in terms of groundwater levels or groundwater quality.

Groundwater system response to current mining activities and inferences for the proposed expansion

The response of the Stuart Shelf groundwater system around the SML to the existing operation was described in Section 12.4 and Appendix K1 of the Draft EIS. The observed responses to Tent Hill Aquifer (THA) drainage into the underground workings over the previous 30 years, since the Whenan Shaft intersected the water table, shows drawdown extending some 10 km from the underground workings (see Figure 12.9 for two THA well hydrographs).

The cone of depression that has formed around the underground workings after some 30 years of mining activity at Olympic Dam is broadly symmetrical. The proposed expansion would represent an additional drainage area which, in the regional setting, would not greatly increase the rate of regional drawdown during the operational mine life. Further numerical modelling undertaken since the publication of the Draft EIS and detailed in Appendix F4 of the Supplementary EIS confirms this, with the predicted 10 m drawdown contour for the Tent Hill Aquifer (THA) changing little between 2050 (end of mining) and 2150, as shown on Figures 12.10a and 12.10b, respectively. Drawdown contours for the Andamooka Limestone Aquifer (ALA) are also shown as Figures 12.11a and 12.11b.

Drawdown development in the THA north of the existing operation is thought to be constrained by leakage from the overlying Andamooka Limestone Aquifer (ALA) and propagates to the south-east, where the ALA is absent and all water is sourced from the THA, which has less storage capacity than the ALA. It is expected that drawdown development from the proposed mine pit and the effect of mine water affecting activities, including additional recharge introduced from the proposed tailings storage facility (see Appendix F5 of the Supplementary EIS) and rock storage facility (see Appendix F7 of the Supplementary EIS) would be similarly controlled. Modelling predictions detailed in Appendix F7 of the Supplementary EIS support this understanding.

Local scale interactions between aquifers of the Stuart Shelf

Density corrected groundwater head data show that near-hydrostatic conditions exist in shallow and deep aquifers of the Stuart Shelf, suggesting there is little vertical movement between the aquifers, as detailed further in Section 6.3 of Appendix F1 of the Supplementary EIS. A slight downward hydraulic gradient between the shallower and deeper aquifers is evident in the area of the Special Mining Lease. A slight upward hydraulic gradient exists between the deeper and shallower aquitards and aquifers closer to Lake Torrens, consistent with the lake and its margins being a regional groundwater discharge feature. This is supported by investigations reported in Section 3 of Appendix F1 of the Supplementary EIS, specifically Figure 3.5 and data presented in Attachment A.

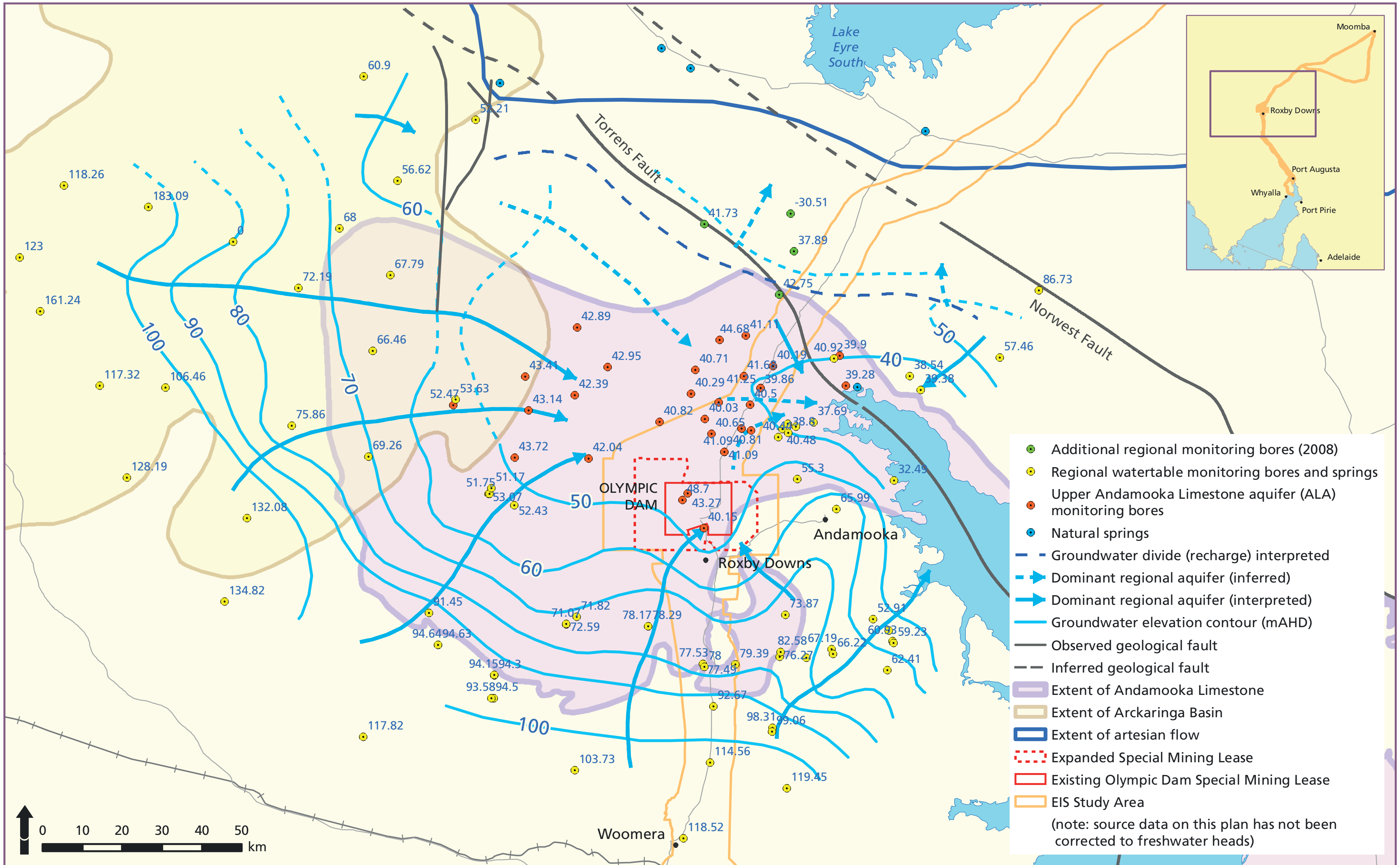


Figure 12.8 Interpreted regional watertable contours of the Arckaringa–Stuart Shelf groundwater flow system (GFS) overlain on geological provinces

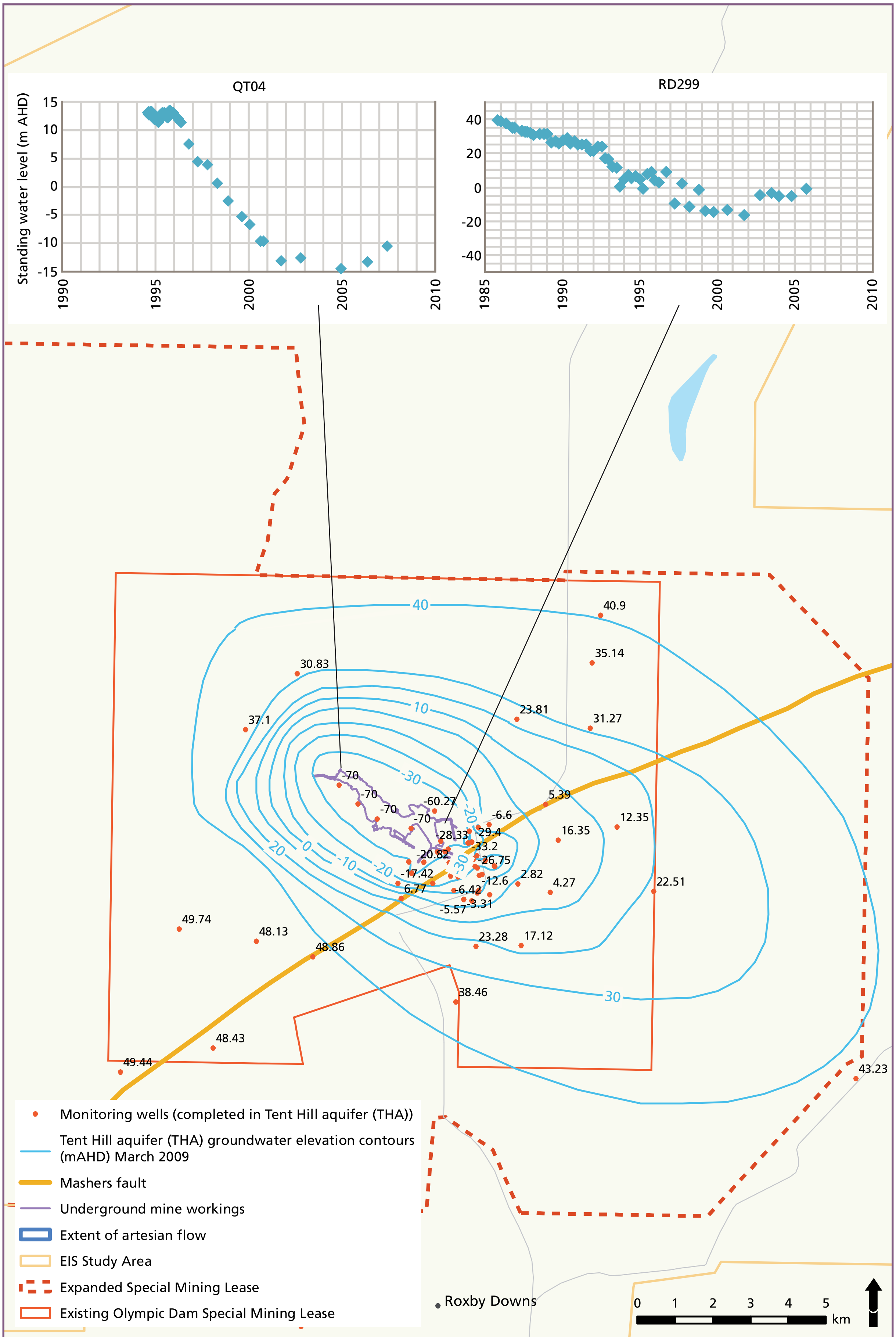


Figure 12.9 Interpreted Tent Hill aquifer (THA) groundwater elevation contours

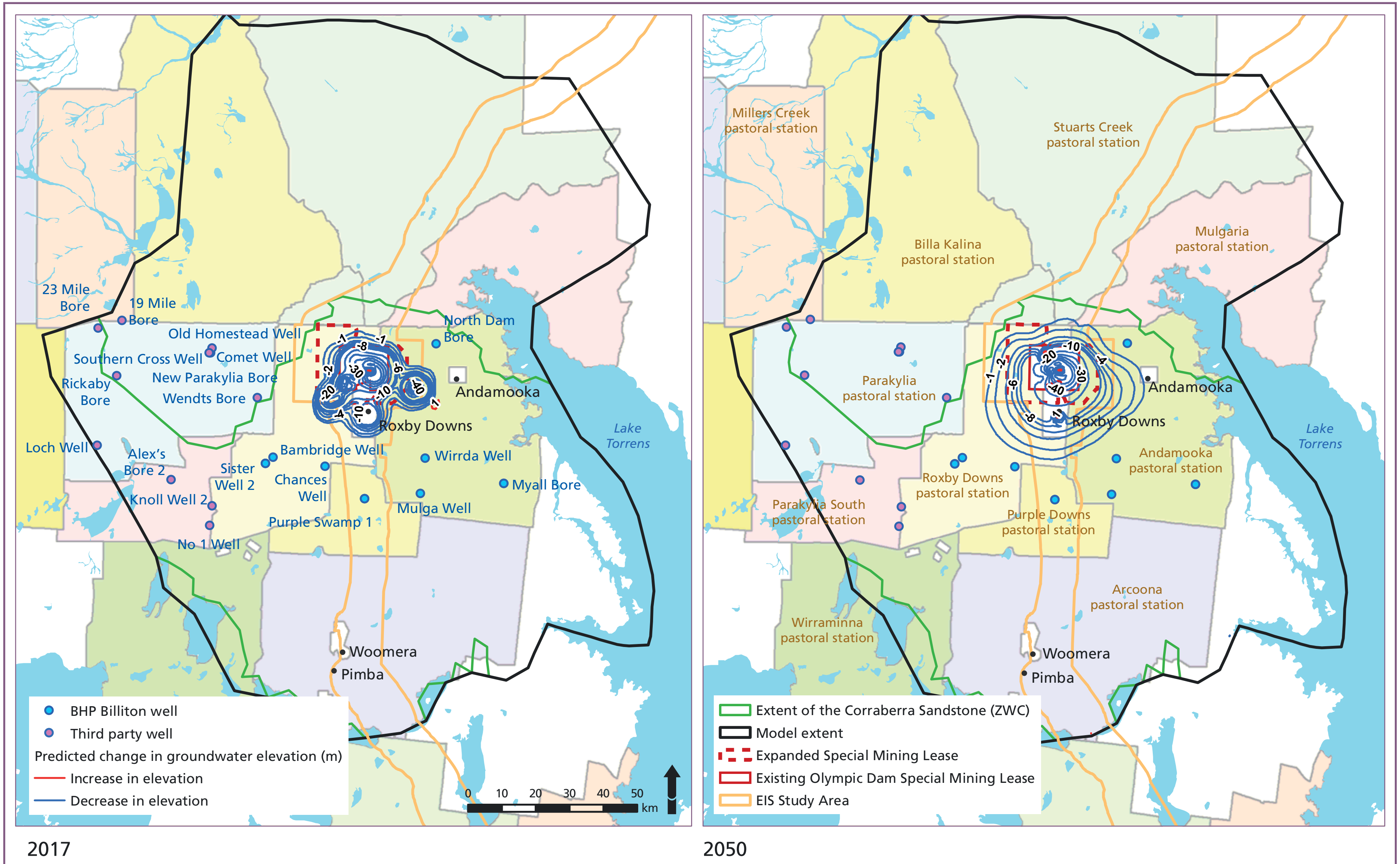


Figure 12.10a Predicted drawdown in the Tent Hill aquifer from the updated groundwater model

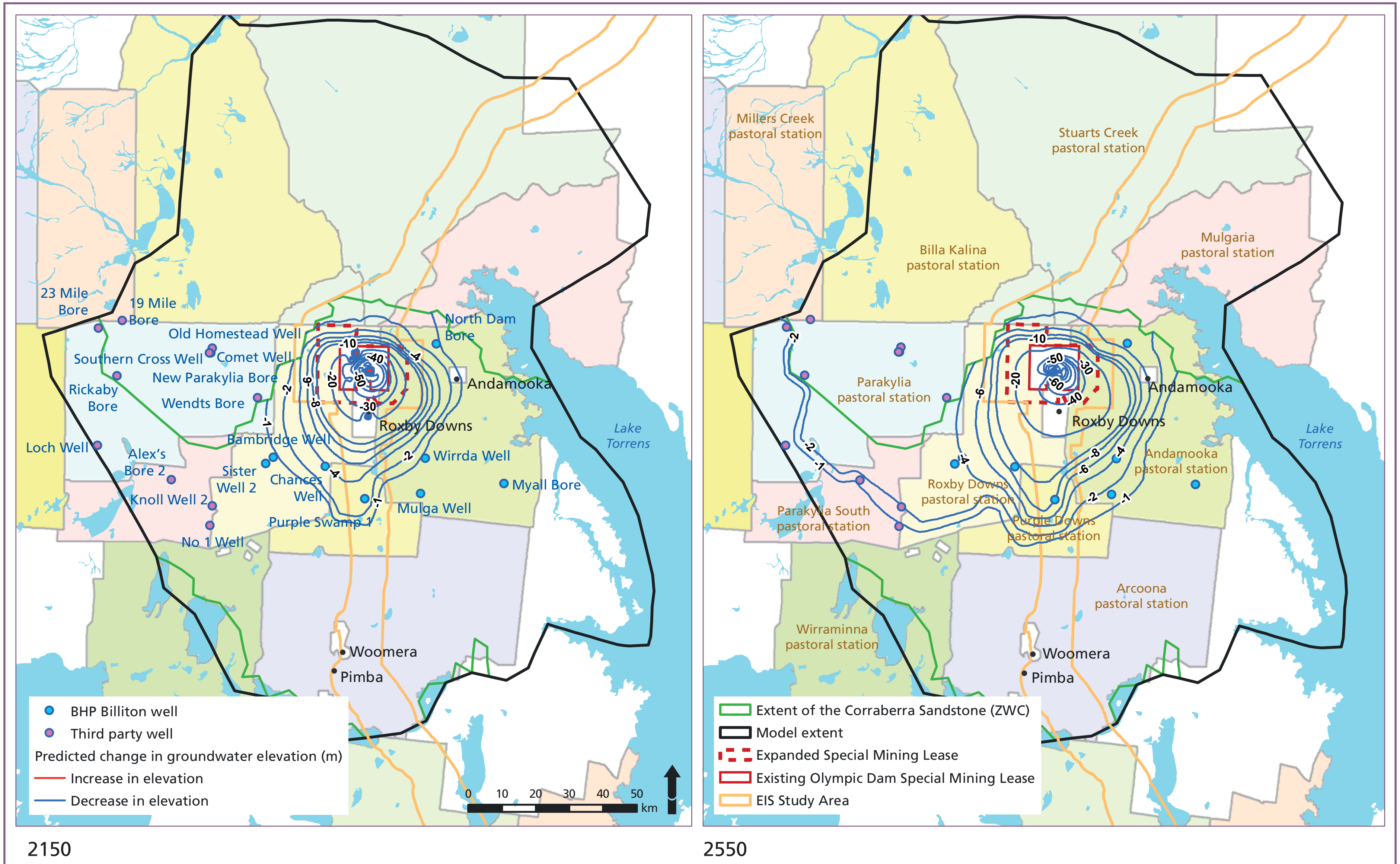


Figure 12.10b Predicted drawdown in the Tent Hill aquifer from the updated groundwater model

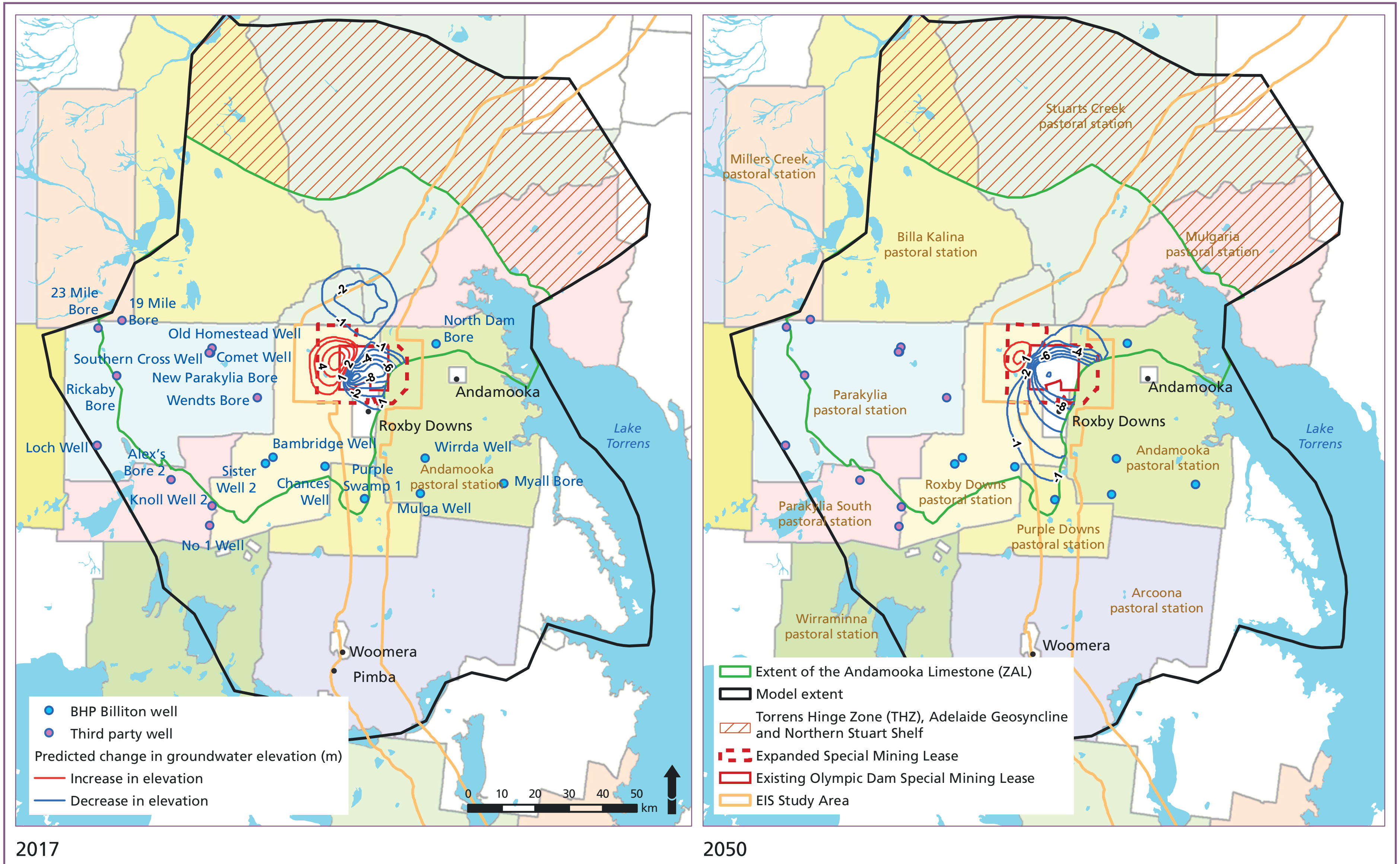


Figure 12.11a Predicted drawdown and mounding in the Andamooka Limestone (ZAL) aquifer from the updated groundwater model

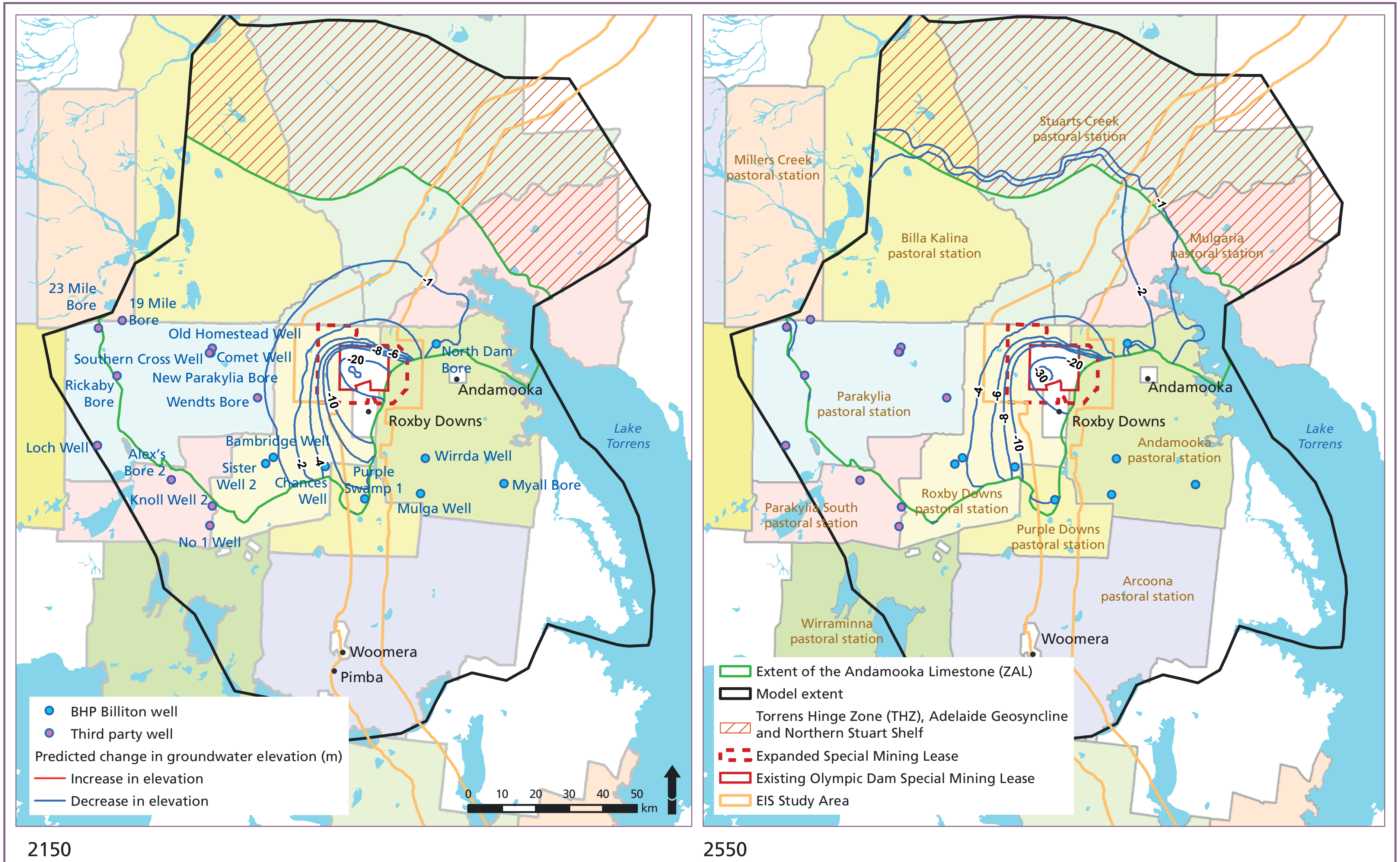


Figure 12.11b Predicted drawdown and mounding in the Andamooka Limestone (ZAL) aquifer from the updated groundwater model

12.1.2 WATER QUALITY

Issue:

Clarification was sought on the:

- representativeness of groundwater quality analytical data
- water quality usage of potentially impacted aquifers according to ANZECC water quality guidelines.

Submissions: 1 and 2

Response:

Representative status for groundwater quality analytical data

The water sampling protocols adopted for the groundwater studies undertaken for the proposed Olympic Dam expansion environmental studies are consistent with industry practice in terms of the methods of sample collection, preservation and shipment, holding times, and analysis by NATA-registered laboratories.

Comprehensive regional baseline groundwater sampling events were undertaken in 2006 (refer Appendix K3 of the Draft EIS) and 2008 (see Attachment C, Appendix F2 of the Supplementary EIS). The sampling events for various groundwater drilling programs undertaken since 2005 are summarised in Appendix F2 of the Supplementary EIS. Details of the manner in which water samples were collected and submitted for laboratory testing are also presented in Appendix F2.

Although some water samples reported elevated total suspended solids, the water quality data are considered representative of *in situ* groundwater, as detailed in Section 5 of Appendix F1 of the Supplementary EIS.

Beneficial use categories (ANZECC) of regional groundwater resources

As was discussed in Section 12.3.4 and further detailed in Appendix K3 of the Draft EIS, groundwater quality in the vicinity of Olympic Dam, in aquifers that may be potentially impacted by the proposed expansion, is highly saline and does not support any of the environmental value categories defined by ANZECC (2000).

A large set of groundwater quality data has been collated for the Stuart Shelf aquifers and compared against a number of national and jurisdictional guidelines to assess beneficial use categories for the different aquifers occurring in the broader region (including ANZECC guidelines). A summary of the dataset is presented as Table 12.2, with supporting data included in Appendix F2 of the Supplementary EIS. Apart from the artesian Eromanga Basin, average groundwater salinity concentrations regardless of the aquifer from which samples were sourced are saline, with groundwater salinities typically ranging above 10,000 mg/L.

Table 12.2 Groundwater quality data summary (as TDS mg/L), including beneficial use categories

Aquifer	Number of wells	Mean (TDS) (mg/L)	Beneficial use[1]	TDS (mg/L)			
				Min	Max	Mean	Median
Stuart Shelf (ALA)[2]	49	68,817	None	13,550	260,500	68,817	32,100
Stuart Shelf (THA)[2]	22	61,607	None (r)[3]	10,741	211,500	61,607	42,683
Adelaide Geosyncline[4]	6	100,433	None	28,500	248,500	100,433	67,300
Arckaringa Basin (Boorthanna aquifer) [2]	54	18,715	None (s, r)[3]	5,800	56,100	18,715	11,550
Non-artesian Eromanga Basin	24	11,372	s, r (i, none)[3]	1,484	37,000	11,372	8,048
Artesian Eromanga Basin (GAB wells)	16	4,709	s, r (i)[3]	2,262	5,965	4,709	5,163

1 Beneficial uses: I = Irrigation for agriculture, parks and gardens (limit = 3,500 mg/L; Vic EPA 1997). S = Stock watering (limit = 10,000 mg/L for sheep without loss of production; ANZECC/ARMCANZ, 2000). R = Recreation (limit = 13,000 mg/L; Vic EPA, 1997).

2 Arckaringa–Stuart Shelf GFS.

3 In localised parts of aquifer system (as indicated by specific wells).

4 Torrens Hinge Zone.

For the Arckaringa–Stuart Shelf GFS, reported groundwater salinity concentrations range from 6,000 mg/L to more than 200,000 mg/L. In the flow system, groundwater becomes progressively more saline to the east, and hypersaline groundwater (brine) occurs at depth in both the Andamooka Limestone and Tent Hill aquifers closer to Lake Torrens (as discussed further in Section 12.1.3 of the Supplementary EIS).

Groundwater from only two groundwater flow systems (the non-artesian and artesian Eromanga (GAB) aquifers), report brackish (i.e. salinity concentrations of less than 5,000 mg/L) to saline water quality. The non-artesian Eromanga (GAB) aquifer reports salinity concentrations ranging from around 1,500 to more than 35,000 mg/L, while the range for artesian Eromanga (GAB) aquifer groundwater is around 2,000 to 6,000 mg/L.

An assessment of the overall beneficial use of the regional aquifers, adopting the mean of salinity concentrations for sampled groundwater (see Table 12.2), and based on criteria formulated by ANZECC/ARMCANZ (2000), SA EPA (2003) and Victorian EPA (1997) indicates that:

- The Stuart Shelf (Andamooka Limestone and Tent Hill) aquifers have no current beneficial use other than for possible industrial purposes.
- The Adelaide Geosyncline aquitards (the rocks in the THZ north of Olympic Dam) cannot be considered as aquifers. Any minor quantities of groundwater that might be available locally have no current beneficial use other than for possible industrial purposes.
- To the extent that it has been investigated, average groundwater salinity data for Boorthanna aquifer groundwater (of the Arckaringa Basin) typically has no current beneficial use other than for possible industrial purposes. Some locations report stockwater quality groundwater.
- The non-artesian Eromanga (GAB) aquifer has beneficial use in terms of stockwater supplies and recreation use, but not in terms of potable or irrigation use.
- The GAB aquifer has beneficial use in terms of stockwater supplies and recreation use, but not in terms of potable or irrigation use. However, as demonstrated above, the proposed open pit mine would have no impact on the GAB aquifers.

12.1.3 INTERACTION WITH LAKE TORRENS

Issue:

Clarification was sought on how the Lake Torrens brine interface would respond to the proposed groundwater changes noted in the Draft EIS.

Submission: 1

Response:

Numerical modelling has shown that operation of the proposed Motherwell saline water supply wellfield (which would draw water from the ALA) is likely to have the greatest influence on regional groundwater drawdowns of all the mine water affecting activities, and has the potential for vertical displacement of deeper brines during the operation of the wellfield and mine. The influence of the mine pit becomes important post-closure, but this is unlikely to significantly alter the vertical position of the brine interface.

Brine body underlying Lake Torrens

Chapter 12 and Appendix K1 of the Draft EIS identified the existence of a brine wedge in groundwater in the lower part of the ALA to the west of Lake Torrens. The Draft EIS provided a discussion of the effects of this brine in relation to regional groundwater movement towards its discharge at the margins of Lake Torrens, consistent with the conclusions of Schmid (1985) and Johns (1968) (see Section 6.2 of Appendix F1 of the Supplementary EIS). The numerical groundwater flow modelling presented in the Draft EIS, and refined in Appendix F4 of the Supplementary EIS, adopted reduced ALA transmissivity near Lake Torrens to replicate groundwater flow conditions and the shallowing of the brine interface in the aquifer.

For clarification, further explanation of brine occurrence beneath Lake Torrens and its influence on regional groundwater flow patterns in the Stuart Shelf aquifers is discussed here and detailed in Section 6 of Appendix F1 of the Supplementary EIS.

The brine has developed as a result of the long-term evaporative concentration of shallow saline groundwater and incident rainfall over Lake Torrens, with the main source of this groundwater being from east of the lake (Schmid 1985; Johns 1968). Both Schmid and Johns have concluded there is minimal movement of groundwater into the lake sediments from the west (i.e. from the Arckaringa–Stuart Shelf GFS).

Groundwater wells installed across much of the eastern portion of the Stuart Shelf have encountered a groundwater salinity interface (halocline) within the ALA (see Section 6 of Appendix F1 of the Supplementary EIS). This interface represents a contrast between hypersaline waters of the lower ALA, which originates as a result of density-driven brine discharge from aquifers in the Tertiary sediments beneath Lake Torrens moving outward and beneath the less saline groundwater of the upper ALA flowing from the west toward Lake Torrens. Closer to Lake Torrens, the Tent Hill aquifer also shows evidence of brine discharge from the lake sediments.

Figure 12.12 presents a schematic west-east aligned cross-section of the Stuart Shelf, conceptually showing how the brine causes saline groundwater flowing towards Lake Torrens to be driven upwards as a result of density differences, thereby reducing the effective transmissivity of the ALA throughflow component from the west by around 50%.

Freshwater corrected hydraulic heads and vertical gradients for the ALA at various nested groundwater monitoring sites show the lower (hypersaline) and upper (saline) ALA are close to equilibrium at most sites (as discussed in Section 6 of Appendix F1 of the Supplementary EIS), suggesting that under current conditions there is little potential for vertical interaction between the aquifers.

Andamooka Limestone aquifer brine response to the proposed expansion

The results of recently completed numerical modelling of the proposed mine expansion, as discussed in Section 12.2 of the Supplementary EIS, have been used to assess the potential response of the brine at the base of the Andamooka Limestone north of Olympic Dam and north-west of the northern tip of Lake Torrens to the water-affecting activities of the proposed expansion. Details of the analysis are presented in Section 5.4 of Appendix F1 of the Supplementary EIS.

Numerical modelling (see Section 12.2 and Appendix F4 of the Supplementary EIS) has shown that the operation of the proposed Motherwell saline water supply wellfield (which would draw water from the ALA) is likely to have the greatest influence on regional groundwater drawdowns and the potential for vertical displacement of deeper brines during operation of the wellfield. The influence of the open pit becomes important post-closure, but this is unlikely to significantly alter the vertical position of the brine interface as the pit would drain the base of the ALA in the vicinity of the mine.

The analysis of the vertical displacement of brine (discussed in detail in Section 6 of Appendix F1 of the Supplementary EIS) considers those areas where brine occurrence is most significant (i.e. where the Andamooka Limestone is deepest to the northwest of the northern tip of Lake Torrens). The analysis of a monitoring site used as a proxy for assessing possible effects (monitoring site PT66, north west of the northern extent of Lake Torrens) indicates that there is the potential for upward brine displacement of around 17 m (at the end of operation of the Motherwell Wellfield i.e. 2017) based on drawdown predictions presented in Appendix F4 and analytical modelling results assuming freshwater corrected heads (Section 6.3 of Appendix F1 of the Supplementary EIS). Post-closure, as a result of the effect of vertical downward gradient potential from the ALA to the THA in response to mine pit inflows (see discussion above and Section 6.4 of Appendix F1 of the Supplementary EIS) it is very probable that there would be an upward displacement of the brine interface.

12.1.4 Hazard and risk

Issue:

An assessment was sought of conceivable impacts of risk events on regional groundwater-related values. In particular, concerns were raised about groundwater-related values including groundwater-dependent ecosystems, groundwater flow regimes, groundwater availability and Lake Torrens hydrology.

Submission: 1

Response:

Given the timeframe before which impacts on these groundwater-related values may be realised, and the potential for other influences to affect the groundwater system over the long term, these issues are addressed using the risk assessment framework presented in the Draft EIS (refer Section 26.2 and Appendix C for details).

A water supply risk assessment was undertaken and specifically considered:

- the consequences of drawdown on mound springs (note that this risk assessment was conducted in relation to a borefield extension option which is not part of the final proposal)
- the risks of incorrectly modelling drawdown on Yarra Wurta spring
- a complete subsection on secondary supply – local saline aquifers.

The mining risk assessment considered the risk of the open pit cutting the local aquifer and impacting on the springs.

The construction and gas pipeline risk assessments considered direct impacts on the mound springs.

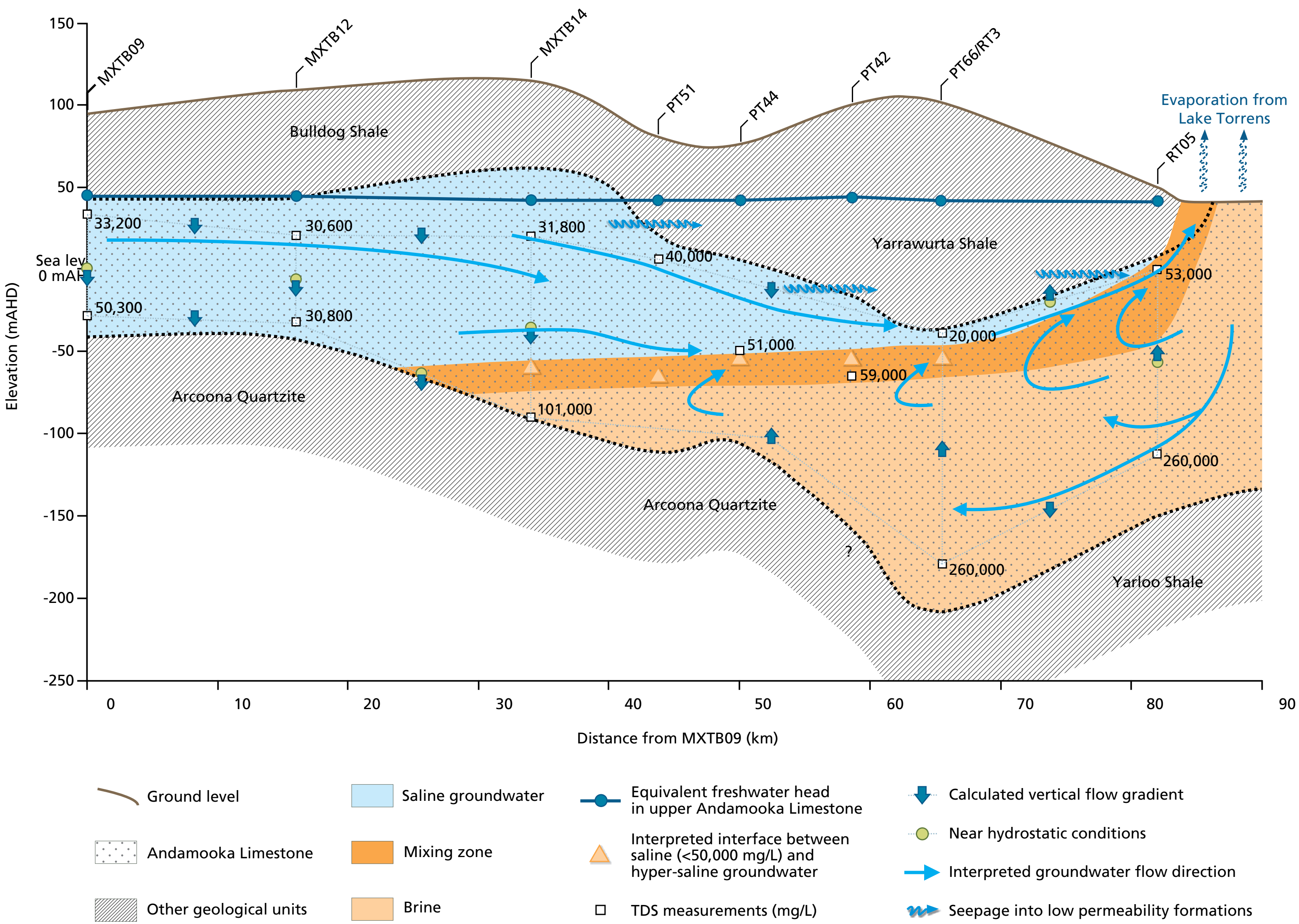


Figure 12.12 Hydrostratigraphic cross-section through the Andamooka Limestone aquifer (ALA) showing the interface between Lake Torrens brine and saline regional groundwaters

The outcomes of the risk assessments were:

- the risk rating for impact on the assessed groundwater-dependent ecosystems is 'high' (representing a 'possible' likelihood and a 'moderate' consequence)
- the risk rating for impact on the assessed flow regimes and groundwater availability is also 'high' (representing a 'rare' likelihood and a 'major' consequence).

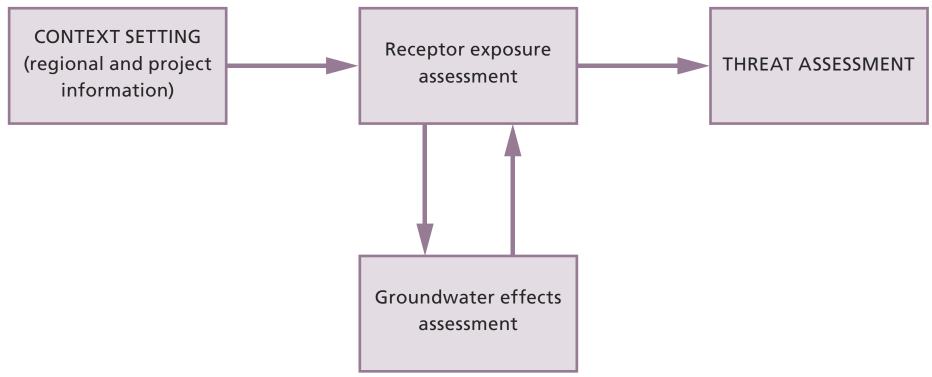
As discussed in Section 1.6.2 and illustrated in Figure 1.11 of the Draft EIS, a 'high' risk is considered to be a tolerable risk, although 'high' risks are considered to be key project risks and require active control through specific management measures. In this instance, groundwater levels in wells would be monitored near the open pit and at regular intervals from the open pit to determine the extent and timing of drawdown compared with that of the modelled predictions. The monitoring program would be reported through the Environmental Management Program, as discussed in Section 26.3 of the Draft EIS.

It is noted that additional groundwater modelling has occurred since the publication of the Draft EIS. However, due to the nature of risk assessments, these additional studies do not alter the risk ratings as discussed above. The additional modelling does, however, provide an opportunity to review the impact assessment for groundwater values. The assessment was undertaken in a manner consistent with that proposed for the National Water Commission's 'Framework for assessing cumulative effects of mining on groundwater' as presented in Figure 12.13 of the Supplementary EIS (Howe et al. 2010). The key findings in relation to impact assessment with respect to the values noted above are (see Section 7 of Appendix F1 of the Supplementary EIS for further details):

Coorlay Lagoon fills after major storms and run-off, and then slowly empties. The lack of salt on its bed suggests the lagoon is disconnected from the groundwater system except as an intermittent source of recharge. As such, it is highly unlikely that ecosystems associated with Coorlay Lagoon are dependent on regional groundwater, which is saline (>30,000 mg/L TDS) and, as a result, unsuitable for plant use. These ecosystems are more likely to be dependent on surface water. The potential impact to the Coorlay Lagoon environmental receptor is categorised as negligible, representing no detectable impact.

- With regard to the potential for impact at Yarra Wurta spring, the precautionary approach has been applied and the impact is categorised as moderate, reflecting the potential for a long-term impact to a common receiver. Drawdown is not expected to extend as far as the spring during the life of the mine. A worst-case modelling scenario predicts, 500 years after mine closure, a drawdown of up to 3 m. However, a number of factors, either singly or combined, may significantly reduce the predicted drawdown and were deliberately omitted from the worst-case modelling scenario (discussed in Appendix F3 of the Supplementary EIS):
    - It is likely that most groundwater flows to the spring from the north-east or discharges upward from the confined Tertiary aquifer of the Torrens Basin. In the model, however, no hydraulic restriction was used for other directions.
    - It is possible that there is sufficient structural disruption in the Torrens Hinge Zone to impede the development of drawdown across that zone (Johns 1968 and Schmid 1985). No such barriers were modelled.
    - The sedimentary aquifers beneath Lake Torrens are likely to be more extensive than modelled. These sediments have a high storage capacity and are recharged from substantial groundwater throughflow generated from the western Flinders Ranges (Johns 1968 and Schmid 1985). Evaporative discharge of groundwater and surface water from the lake bed is the dominant discharge mechanism controlling the Lake Torrens water balance. Any potential drawdown from the pit void would be offset by reduced evaporative losses from Lake Torrens. The numerical model does not include this storage buffer capacity.
    - The discharge level of the spring is at approximately the same level as the lake bed. Groundwater monitoring data from a nearby bore to the west indicates an approximate 2 m head buffer to the spring.
    - Lake Torrens floods episodically, and may take years to dry out. To be conservative, such raised water levels in the lake are not modelled. These floods appear to have a great importance in the lake's long-term water balance and lake-groundwater interactions.
    - The single worst-case prediction of drawdown of up to 3 m has to be considered in the context of it being 500 years into the future (1 m reduction was shown from base-case modelling). This timeframe carries uncertainties in prediction that are difficult to describe or to quantify. Sensitivity analysis was carried out as part of the numerical modelling (see Appendix F4) to capture many of these uncertainties.
    - No historical data about the behaviour or permanence of Yarra Wurta spring exists. However, based on-site observations and the geological history of the area, they are likely to be permanent at a time scale of thousands of years, if not longer. This interpretation suggests that the springs are likely to continue discharging for thousands of years, although it is possible that climate change may affect them and they may, in the past, have had intermittent periods without discharge.

- The Prominent Hill mine water supply wellfield draws water from the Boorthanna Formation aquifer, a deep, confined aquifer in the Arckaringa Basin. Numerical groundwater flow modelling (see Section 12.2 and Appendix F4 of the Supplementary EIS) shows that drawdowns arising from the operation of the proposed Stuart Shelf saline water supply wellfield and mine pit dewatering systems would not propagate as far as the Boorthanna aquifer over the planned life of the Prominent Hill mine. As such, the predicted impact to the Prominent Hill operation is categorised as negligible, representing no detectable impact.
- Numerical modelling indicates the groundwater divide and low-permeability rocks of the Torrens Hinge Zone that separate the Arckaringa–Stuart Shelf GFS from the artesian Eromanga GFS will prevent impact to GAB springs.



Source: After Howe et al. 2010

Figure 12.13 Groundwater impact assessment framework

12.2 NUMERICAL GROUNDWATER MODEL

12.2.1 MODELLING

Issue:

Clarification and substantiation was sought on the numerical groundwater model. Specific issues raised were:

- inclusion of the detailed review of the draft report undertaken by Golder Associates Pty Ltd
- provision of the model details to the SA EPA for assessment and review
- clarification and substantiation of the hydraulic characteristics used in the model
- provision of sensitivity analysis of changes in boundary conditions at the Arckaringa Basin and sensitivity analysis of the particle tracking, including discussion of the implications for pollution fate and transport
- substantiation of the statistical robustness, including provision of spatial distribution of errors, and transient calibration statistics
- discussion of, and to ensure that, the recalibrated model achieves acceptable scaled root mean square errors
- incorporation of the worst-case scenario, which would represent a significant decline in inflow to the western inflow zone
- incorporation of monitored changes in groundwater heads at Prominent Hill and the potential consequences of the effects of the pit lake on groundwater flow from the Arckaringa Basin on groundwater users outside the modelled zone
- discussion of the sensitivity analysis of the particle tracking and the implications on local plume movement from the tailings storage facility
- discussion of the implications of seepage modelling if allowing for an inactive tailings storage facility cell
- provision of modelling results at finer time-steps and with smaller drawdown contours
- extension of model domain to include the GAB aquifers
- provision of verifications and calibrations for all aquifers using the recalibrated model, including provision of monitored pump test time series data
- extension of model scenarios to reach steady state of a minimum of 1,000 years
- estimation of the likely impacts of the changed groundwater flow patterns on the mass water balance, including Lake Torrens.

Submissions: 1 and 2

Response:

The groundwater modelling undertaken and provided as Appendix K6 of the Draft EIS has been updated since the publication of the Draft EIS. The original groundwater model was reviewed by Golder Associates Pty Ltd. Dr Jan Vermaak stated in the peer review letter of testimony:

> 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.

The numerical groundwater model has been updated and progressed since the Golder Associates Pty Ltd review in November 2008 and the publication of the Draft EIS. The changes requested by Golder Associates Pty Ltd would not materially change the results of the numerical model provided as Appendix K6 of the Draft EIS. The updated model has also been reviewed and accepted by Golder Associates Pty Ltd and provided in Appendix F of the Supplementary EIS.

With regard to provision of the model, these models are particularly complex and therefore BHP Billiton and the specialist consultants working on their behalf extend an invitation to the submitters to view the model in operation and discuss any issues or concerns.

Updated numerical groundwater model

A three-dimensional numerical groundwater flow model was constructed by BHP Billiton Olympic Dam Corporation Pty Ltd (BHP Billiton) for the Draft EIS. The objectives, conceptualisation and construction of the Draft EIS groundwater model (referred to in this document as the original groundwater model) were described in full in Appendix K6 of the Draft EIS.

In response to submissions received, the original groundwater model has been updated (referred to in this document as the updated groundwater model) using hydrogeological data collected since the original groundwater model was constructed (see Appendix F1 of the Supplementary EIS for details). No major variations to the original conceptualisation were required in light of this additional information.

The updated groundwater model has been recalibrated, and the predictive and sensitivity scenarios described in the original groundwater model report have been rerun. In order to address specific comments raised, additional description and sensitivity runs have also been undertaken. The objectives of the updated groundwater model remain the same as those of the original model. The updated groundwater model report is provided as Appendix F4 of the Supplementary EIS. It describes the adjustments made, the calibration of the model and the detailed results of the prediction and sensitivity analyses. A summary is provided below which is relevant to the issues raised above.

Clarification and substantiation of hydraulic characteristics used in the model

Table 12.3 summarises the available measured hydraulic parameters for the Stuart Shelf lithologies (see Appendix F4 of the Supplementary EIS for further detail). Figures 12.14 to 12.19 present the locations and results of the tests. Additional data collected since the submission of the Draft EIS, which target the geological units found to the north of the Stuart Shelf (the Torrens Hinge Zone and Adelaide Geosyncline), are also included in these figures and are detailed in Appendix F2 of the Supplementary EIS.

Some minor variations to the original calibration were required during the process of updating the model. Table 12.4 presents the parameters used in the updated model, which are presented in further detail in Appendix F4 of the Supplementary EIS.

Table 12.3 Summary of measured hydraulic parameters in the Stuart Shelf

Lithology	Hydraulic conductivity (m/d)			Specific storage (m^{-1})		
	No. of tests	Minimum	Maximum	No. of Tests	Minimum	Maximum
THZ and Adelaide Geosyncline	4	1×10^{-4}	6×10^{-3}	0	n.a.	n.a.
Bulldog and Yarra Wurta Shale	3	4×10^{-2}	1×10^{0}	0	n.a.	n.a.
Andamooka Limestone	34	1×10^{-1}	$7 \times 10^{+2}$	11	1×10^{-6}	2×10^{-3}
Yarloo Shale	0	n.a.	n.a.	0	n.a.	n.a.
Arcoona Quartzite*	18	5×10^{-4}	2×10^{-1}	0	n.a.	n.a.
Corraberra Sandstone*	51	6×10^{-4}	$3 \times 10^{+1}$	9	1×10^{-6}	6×10^{-4}
Tregolana Shale	7	2×10^{-4}	2×10^{-2}	0	n.a.	n.a.

Note: There are no measured specific yield values.
* Corraberra Sandstone and Arcoona Quartzite together constitute the Tent Hill Formation.

Table 12.4 Calibrated model parameters (updated model)

Lithology/feature	Kh (m/d)	Kv (m/d)	Ss (m-1)	Sy (%)
Alluvial sediments	$2 \times 10^{0} – 9 \times 10^{-6}$	$2 \times 10^{-1} – 9 \times 10^{-6}$	1×10^{-6}	7.5
THZ/Adelaide Geosyncline*	9×10^{-6}	9×10^{-6}	$5 \times 10^{-4} – 1 \times 10^{-6}$	1.0–7.5
Andamooka Limestone	$2 \times 10^{+1} – 9 \times 10^{-1}$	$2 \times 10^{0} – 9 \times 10^{-2}$	$1 \times 10^{-4} – 5 \times 10^{-4}$	7.5
Brine	1×10^{-0}	1×10^{-1}	5×10^{-4}	7.5
Yarloo Shale	$9 \times 10^{-3} – 9 \times 10^{-4}$	$9 \times 10^{-4} – 7 \times 10^{-5}$	5×10^{-6}	1.0
Arcoona Quartzite	9×10^{-4}	$9 \times 10^{-5} – 9 \times 10^{-6}$	5×10^{-6}	1.0
Corraberra Sandstone	2×10^{-1}	2×10^{-2}	5×10^{-5}	1.0
Tregolana Shale/Basement	9×10^{-6}	9×10^{-6}	1×10^{-6}	1.0

* THZ/Adelaide Geosyncline Kh and Kv values have not been altered from those used in the Draft EIS, however, a sensitivity analysis with K values above the upper range measured (9×10^{-3} m/d) was also undertaken and the results of both runs were very similar.

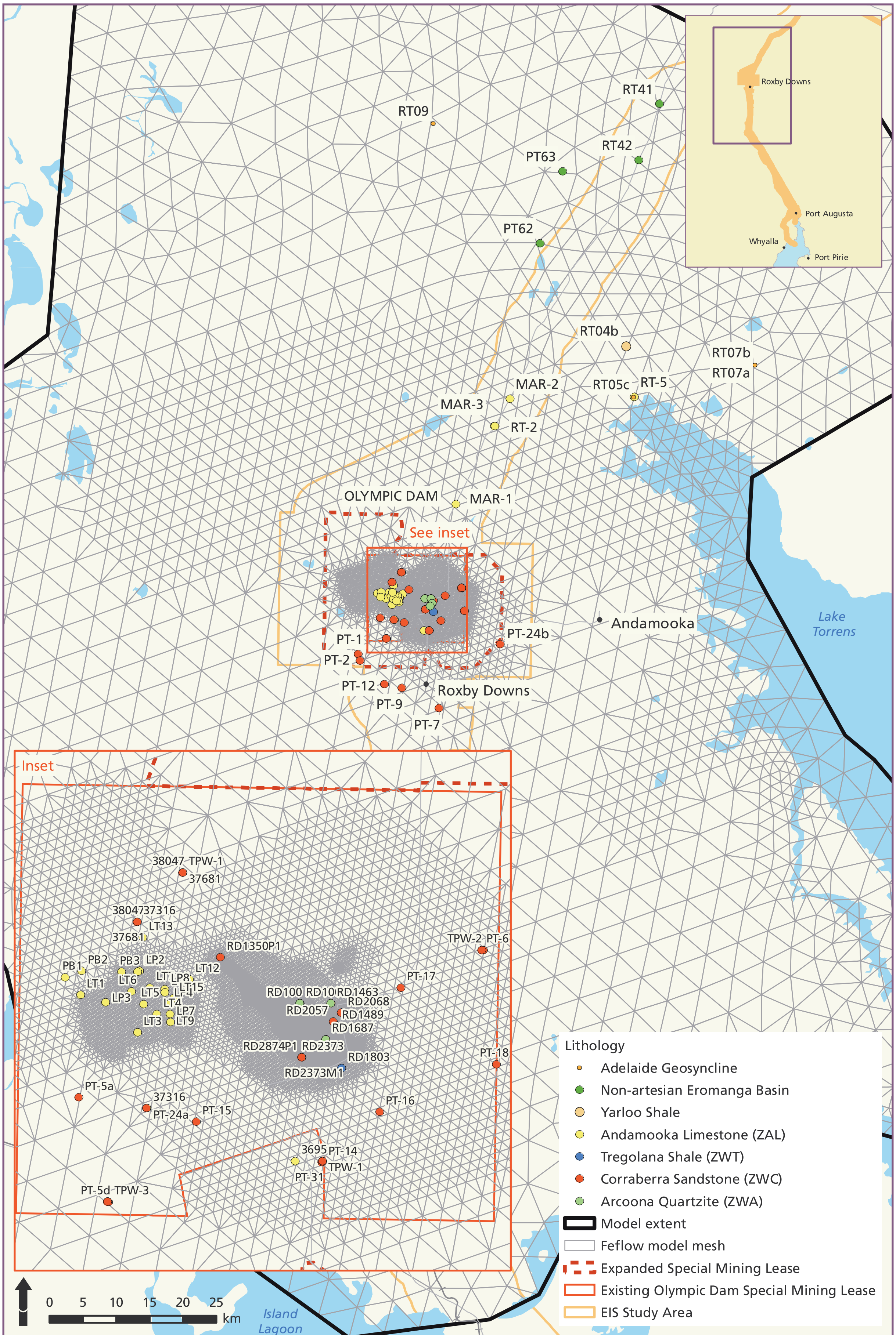


Figure 12.14 Location of measured hydraulic conductivity

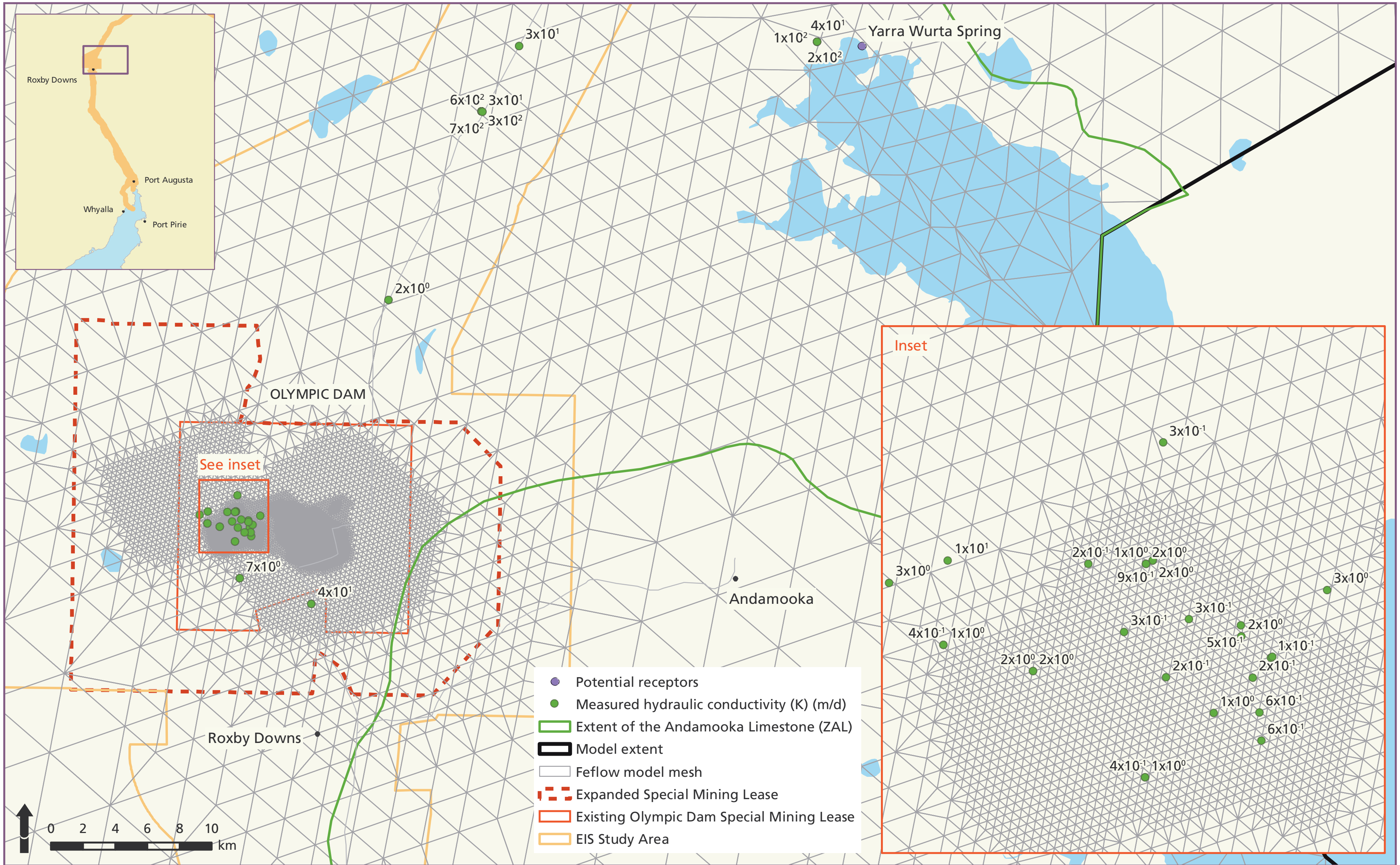


Figure 12.15 Measured hydraulic conductivity in the Andamooka Limestone (ZAL)

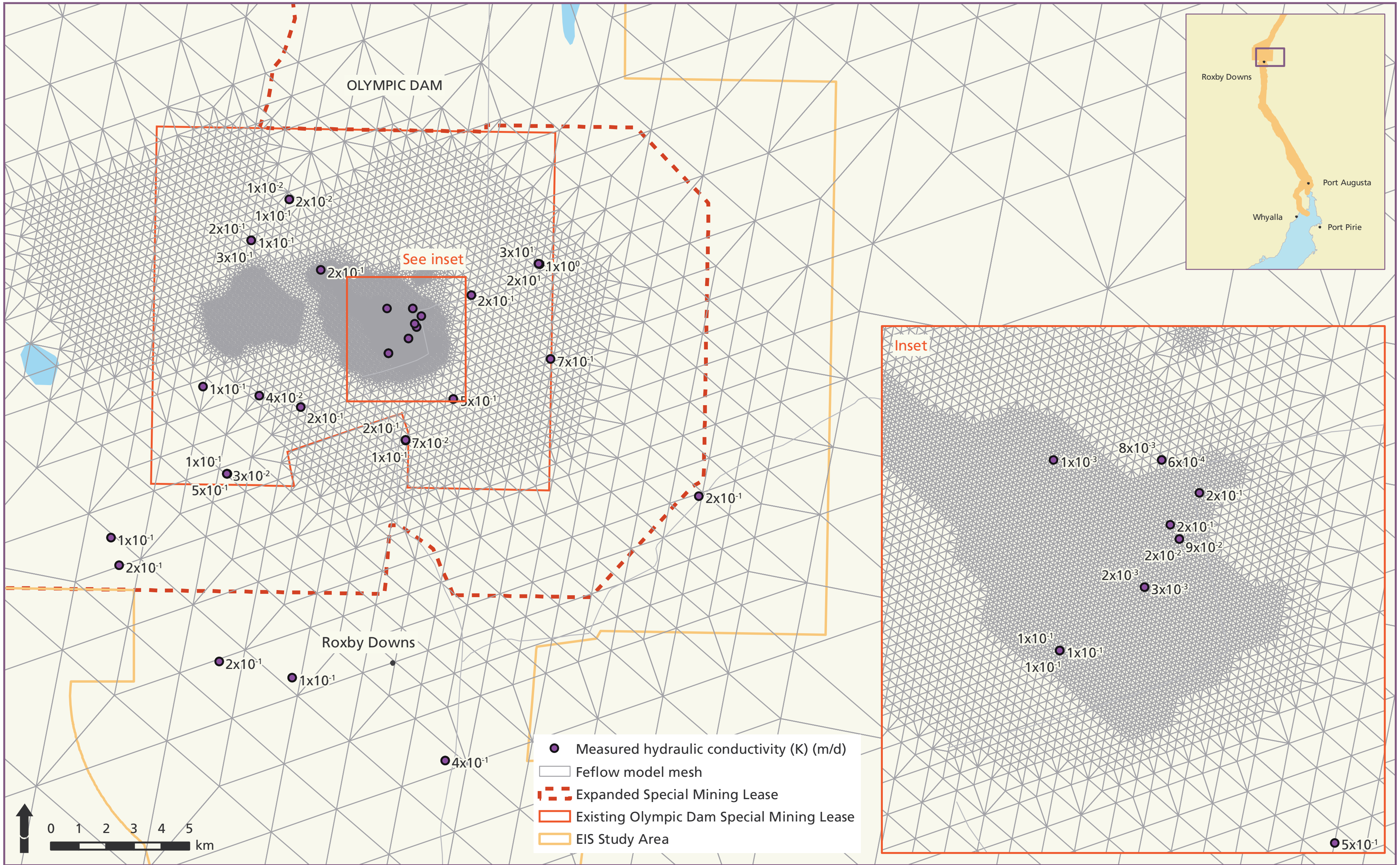


Figure 12.16 Measured hydraulic conductivity in the Corraberra Sandstone (ZWC)

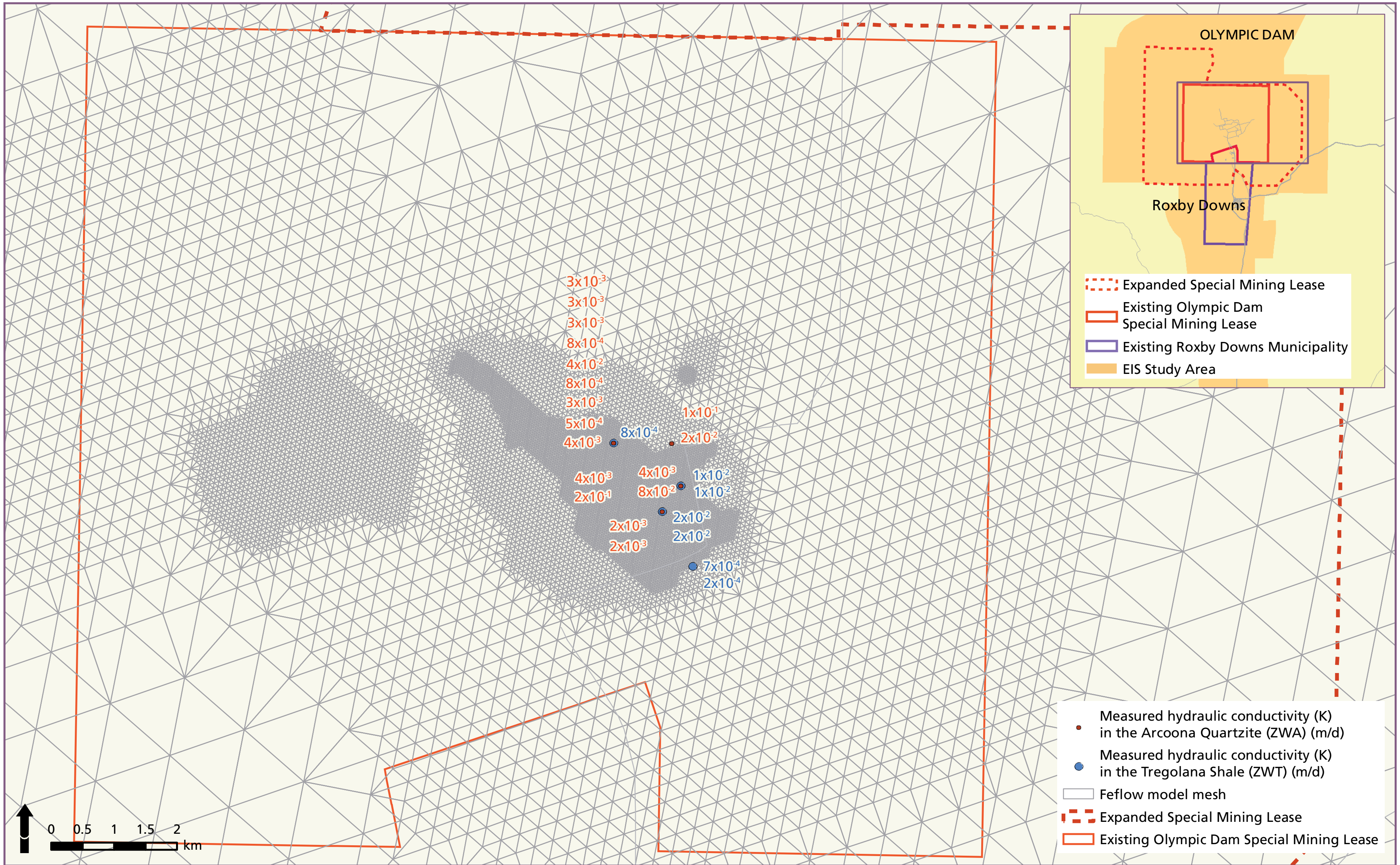


Figure 12.17 Measured hydraulic conductivity in the Arcoona Quartzite (ZWA) and Tregolana Shale (ZWT)

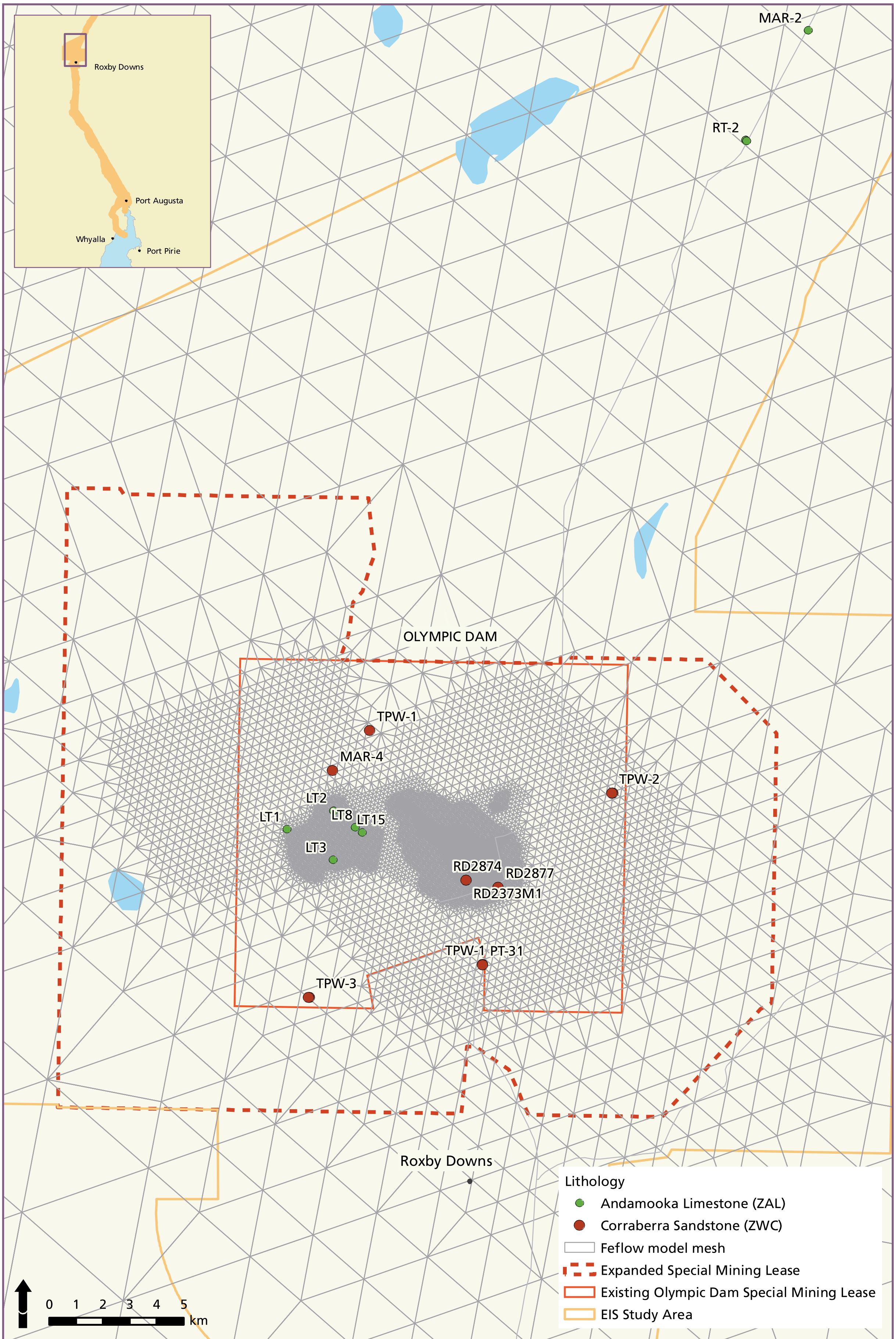


Figure 12.18 Location of measured specific storage

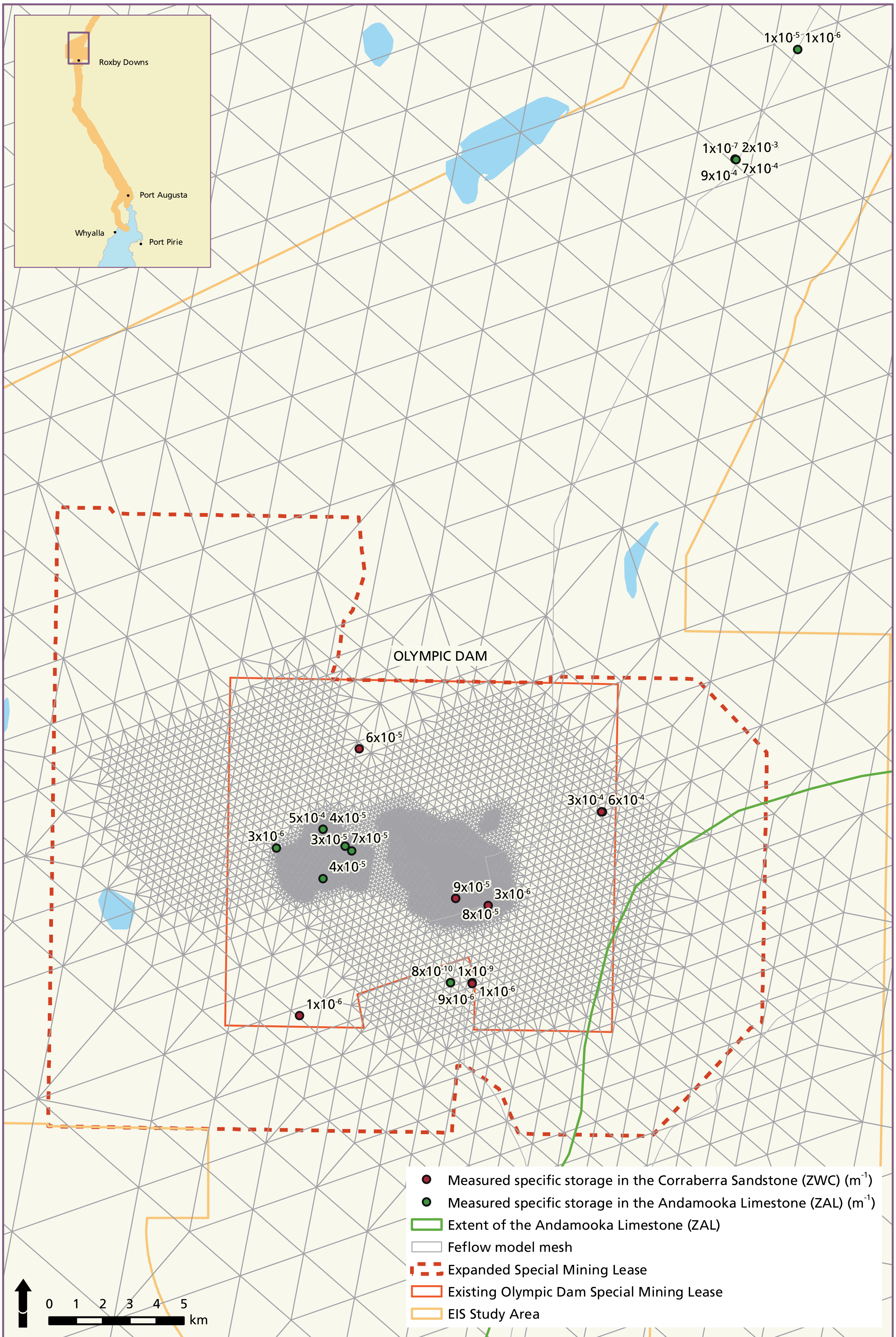


Figure 12.19 Measured specific storage of the Andamooka Limestone (ZAL) and Corraberra Sandstone (ZWC)

Sensitivity analysis of changes in boundary conditions at the Arckaringa Basin and sensitivity analysis of the particle tracking

Hydraulic conductivity ranges

The groundwater model explored a range of hydraulic conductivities of the aquifers and aquitards. As noted in Appendix K6 of the Draft EIS, two sensitivity analyses were undertaken that explicitly considered the variation of hydraulic conductivity of key units on model predictions. These analyses were:

- the hydraulic conductivity (horizontal and vertical) of the Corraberra Sandstone was multiplied by 2.5
- the hydraulic conductivity (horizontal and vertical) of the Torrens Hinge Zone (THZ) and Adelaide Geosyncline was increased by three orders of magnitude.

The sensitivity analyses were repeated in the updated model and a number of additional analyses have been undertaken. Sensitivities represent the likely range of hydraulic parameters encountered during testing. Those related specifically to hydraulic conductivity were:

- The presence of a high horizontal hydraulic conductivity region in the THZ and Adelaide Geosyncline. This sensitivity scenario was undertaken to allow for the unlikely situation whereby an enhanced hydraulic connection exists in the THZ and Adelaide Geosyncline. By assuming a higher-permeability channel between the Stuart Shelf and Eromanga Basin (Great Artesian Basin) this represents a worst-case scenario in terms of hydraulic connection and long-term drawdown. In this sensitivity analysis, the horizontal hydraulic conductivity was increased by four orders of magnitude, from $1x10^{-10}$ m/s ($8.6x10^{-6}$ m/d) to $1x10^{-6}$ m/s ($8.6x10^{-2}$ m/d) in model Layers 1 and 2 (which present a combined thickness of up to 200 m in this area), in the vicinity of boreholes PT63, RT41 and PT62 in the THZ and Adelaide Geosyncline. These holes intersect discontinuous remnants of Eromanga Basin sediments, which present a higher hydraulic conductivity than the THZ rocks that underlie them.
- Increased vertical hydraulic conductivity of the Arcoona Quartzite (ZWA) and therefore increased connection between the Andamooka Limestone (ZAL) and the Corraberra Sandstone (ZWC). This represents a scenario whereby leakage is significantly greater than what has been calibrated regionally. The value over the full extent of the ZWA was increased by two orders of magnitude, from $1x10^{-10}$ m/s ($8.6x10^{-6}$ m/d) to $1x10^{-8}$ m/s ($8.6x10^{-4}$ m/d).

The four sensitivity analyses were rerun with the updated groundwater model and the results from the four runs described above are:

- Increased hydraulic conductivity of the ZWC – the most significant effect is seen in the ZWC, where predicted drawdown 500 years post-closure is about 30 m greater in the area of the open pit, and at least 1 m greater over the majority of the northern and central extent of the ZWC. In the ZAL, the predicted drawdown is up to 20 m greater in the area of the open pit and about 2 m greater in the regional ZAL. At the northern extent of Lake Torrens predicted drawdown is between 1 and 2 m.
- Increased hydraulic conductivity of the THZ and Adelaide Geosyncline – 500 years post-closure this has insignificant effect in the THZ and Adelaide Geosyncline or anywhere else in the model domain.
- Increased hydraulic conductivity of the THZ and Adelaide Geosyncline in a specific region to the north-west to simulate preferential flow pathways – there are no discernible differences in predicted drawdown compared to the lower hydraulic conductivity base case.
- Increased vertical hydraulic conductivity of the ZWA – the predicted drawdown 500 years post-closure is greater in both the ZWC and ZAL. The difference is more pronounced in the ZAL, where predicted drawdown in the vicinity of the open pit increases by over 30 m. Regionally within the ZAL, the predicted drawdown is between 2 and 4 m greater.

The sensitivity analyses included parameter variations that are considered to be at the maximum of what can be expected for the Stuart Shelf hydrostratigraphic units. The results of the analyses show that even when the upper bound values of hydraulic conductivity are used for the THZ and Adelaide Geosyncline units, the predictions in these areas and in the model domain in general remain relatively unchanged.

The analysis also shows that the model predictions are sensitive to variations in the horizontal hydraulic conductivity of the ZWC and the vertical hydraulic conductivity of the ZWA. In both cases, additional drawdown of around 2 m is predicted over the regional extent of the ZAL. However, the predicted drawdown to the north of the ZAL (including in the THZ and Adelaide Geosyncline) is relatively unchanged.

Modelling of flow in fractured media

The original and updated groundwater model assumes porous media flow. No attempt was made to simulate groundwater flow in fractured media in either the original groundwater model or the updated groundwater model. As stated in Appendix K6 of the Draft EIS, the inclusion of regional or sub-regional structures was not considered possible because:

> ... there is little evidence (with the exception of Mashers Fault around the mine area) to suggest regional or sub-regional scale faults or structures. While these structures have been mapped from regional and local geophysics, there is little observation data to base these on.

Only the location of the Mashers Fault Zone (MFZ) has been described with any certainty but this is true only within the Olympic Dam Special Mining Lease. As stated in Appendix K6 of the Draft EIS, the MFZ was not included in the modelling on a regional scale because:

> ... 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.

Furthermore, observations from the existing underground operation indicate a sub-radial drawdown response on a sub-regional scale (see Figure 12.20 of the Supplementary EIS), validating to some extent the assumption that on a regional scale, groundwater behaviour is similar to that of a porous flow medium. This approach is defined by Bear (1972) as the Representative Elementary Volume (REV) of a given porous medium. Within each REV it is '... required that the solid matrix and pore space be distributed throughout the domain occupied by a porous medium ...', whereby there is a step from the '... microscopic scale at which we consider what happens at each point within a phase inside each pore...' to the '... macroscopic level of a continuum at which only averaged phenomena are considered.'

Based on the observations above, an attempt to simulate fracture flow in the regional Stuart Shelf model would have increased the level of uncertainty and is therefore considered inappropriate.

Density contrasts

As was discussed in Section 12.1.1 and noted in Appendix K1 of the Draft EIS, and Appendix F1 of the Supplementary EIS, geochemical analysis of groundwater has shown that the salinity of the major aquifers in the study area is variable. Salinity in the Andamooka Limestone and the Tent Hill Formation typically ranges between 20,000 and 75,000 mg/L. It is only in the area around Lake Torrens that salinities reach above 200,000 mg/L.

The general variation in salinity observed in the aquifers was not considered to have a major bearing on the groundwater flow system of the Stuart Shelf and the available data are insufficient to enable suitable configuration and calibration of a three-dimensional, regional scale, variable density groundwater flow model.

However, the density contrast between the saline water body and the hypersaline water body (e.g. salinity greater than 200,000 mg/L) extending out from beneath Lake Torrens was considered significant and was represented implicitly in the numerical model (as described in Appendix K6 of the Draft EIS). Further studies undertaken for the Supplementary EIS have confirmed these findings and have provided additional information to allow for the refinement of the positioning of the low hydraulic conductivity model cells (see Appendix F1 of the Supplementary EIS for details). The numerical representation of this feature has been adjusted, with the revised model set-up, calibration, detailed results and sensitivity analyses presented in Appendix F4 of the Supplementary EIS.

Substantiation of statistical robustness including provision of the spatial distribution of errors and transient calibration statistics

The root mean square (RMS) and the scaled root mean square (SRMS) for the calibrated steady state model as a whole and the individual Andamooka Limestone (ZAL), Corraberra Sandstone (ZWC) and Arcoona Quartzite (ZWA) layers was provided in Appendix K6 of the Draft EIS. The following explanation was given for the spatial distribution of errors in the steady state model.

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. While 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.

For the calibrated time variant model, observed and simulated hydrographs at several key locations were provided and discussed in the Draft EIS and associated appendix. However, the time variant observations are distributed almost entirely in the Olympic Dam Special Mining Lease and a discussion of the spatial distribution of the errors in the time variant model is therefore restricted.

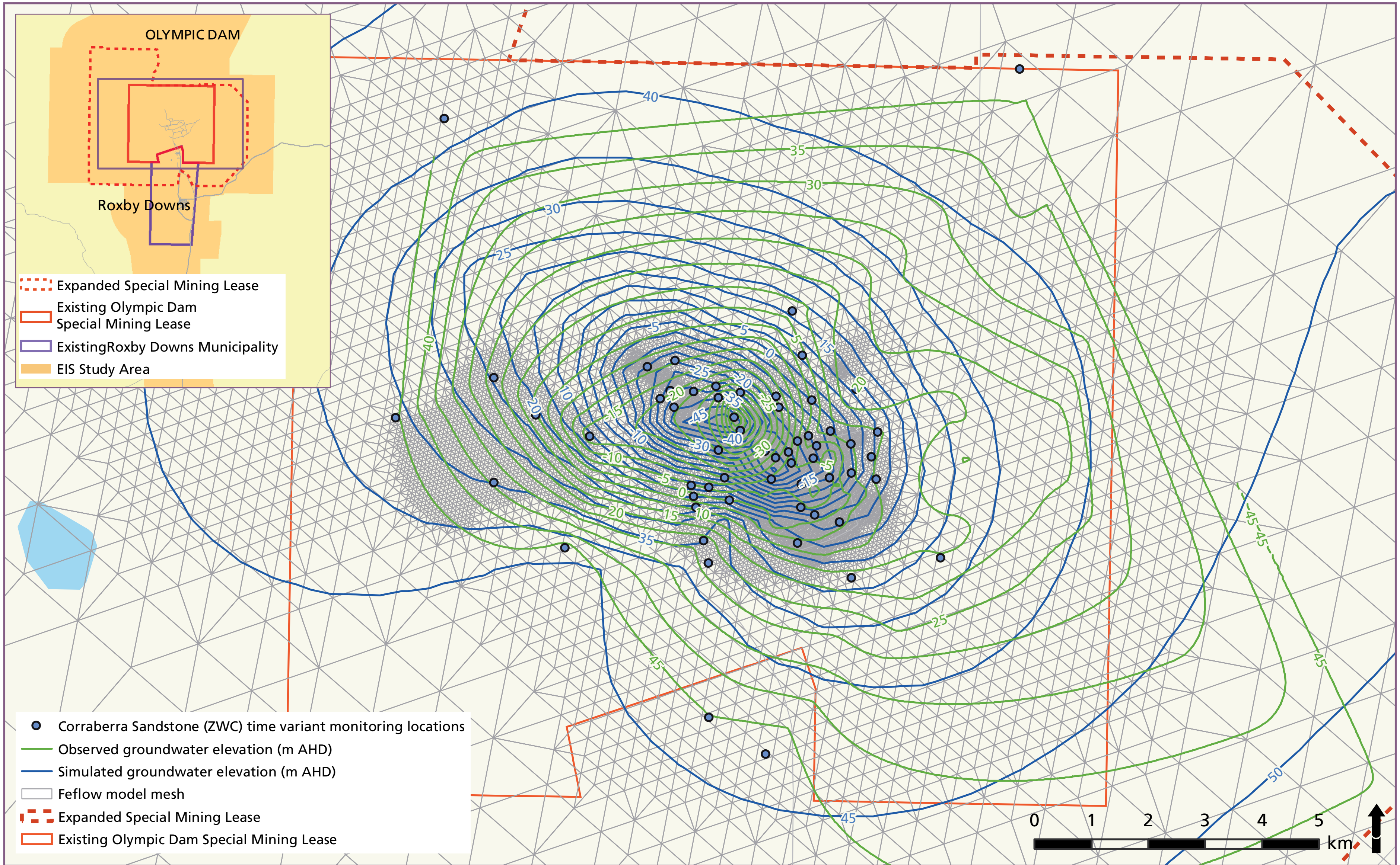


Figure 12.20 Observed and simulated groundwater elevations in the Corraberra Sandstone (ZWC) in 2008

Updating the model to support the Supplementary EIS has involved some changes to the model mesh and boundary conditions, and as a result of the expansion of the calibration dataset, the calibration has been revisited. The spatial distribution of the errors in the updated groundwater model is summarised below.

A statistical comparison of the steady state observed and simulated groundwater elevations produces an SRMS of 12.2% (see Table 12.5). The calculated SRMS is 9.5% for the Torrens Hinge Zone (THZ), 17% for the ZAL, 22.2% for the ZWA and 19.5% for the ZWC.

Table 12.5 Steady state model calibration statistics

Observation set	Number of observations	Variation in observed data (m)	Mean residual (m)	RMS (m)	SRMS (%)
All observations	125	102.5	8.2	12.5	12.2
THZ only	8	56.9	5.1	6.6	9.5
ZAL only	62	54.8	5.2	7.7	17.0
ZWA only	38	90.4	16.4	20.1	22.2
ZWC only	17	14.1	3.8	2.8	19.5

The spatial distribution of these errors in the model domain is detailed in Appendix F4 of the Supplementary EIS and is summarised as:

ZAL: the residuals are highest to the south and south-west and in an area to the north-east of Olympic Dam. In these areas a residual of over 10 m was observed. The modelled groundwater elevation is generally lower than measured to the south and south-west and higher than observed to the north and north-east. In the central areas of the model the residuals are generally <5 m and modelled elevations are higher than measured.

ZWC: the ZWC observations are clustered around the centre of the model, in the vicinity of Olympic Dam. Residuals are generally low (<2 m) but increase slightly to the east (maximum 5.7 m).

- THZ: the residuals are high throughout the THZ as the observed values show significant variability (minimum 17 mAHD, maximum 87 mAHD) over a small area. The high variability in the observed values, however, results in a low calculated SRMS.
- ZWA: the most significant residuals (maximum 40 m) are found in the ZWA. As with the ZAL, towards the centre of the model the residuals tend to be lower, and towards the south and north they tend to be higher due to the greater variability in hydraulic conditions.

As the time variant historical observations are considerably more complex but have no regional significance in terms of the calibration they are not discussed here. A full description is provided however (including all time variant observed and simulated hydrographs) in Appendix F4 of the Supplementary EIS.

Discussion of, and to ensure that, the recalibrated model achieves acceptable scaled root mean square errors

Table 12.6 presents a summary of the data and the calibration statistics of the updated groundwater model for the time variant simulated and observed groundwater heads.

Table 12.6 Time variant model calibration statistics – absolute values

Observation set	Number of observations	Variation in observed data (m)	Mean residual (m)	RMS (m)	SRMS (%)
All long term	6,615	169	3.7	10.1	6.0
ZAL long term	3,888	39.3	6.3	7.9	20.2
ZWC long term	2,727	147.6	8.8	12.5	8.5

The time variant calibration statistics show that the SRMS calculated against the combined long-term groundwater head observations in the ZWC and ZAL is 8.5% and 20.2% respectively; this is considered acceptable for the scale the model represents. The greatest error is contributed by the ZAL dataset. This reflects observations that both the response and absolute groundwater heads in the ZAL show significant variability within short distances. Several factors may contribute to this observed variation, however it is likely that this high SRMS is controlled primarily by three factors:

- karstic and fracture dominated flow in the ZAL, resulting in significant heterogeneity and anisotropy that produces large spatial variability of hydraulic parameters at a local scale, but not at a regional scale
- non-uniform leakage (spatially and over time) from the tailings storage facility and balance ponds
- conversion of saline groundwater heads to freshwater head equivalents for the deep bores.

The RMS and SRMS adjusted to consider drawdown (or mounding) for the calibrated time variant model are presented in Table 12.7. In this analysis only the change in values over the calibration period is considered as opposed to a comparison of absolute values over the period (Table 12.8). This provides a better statistical indication of the quality of the calibration against the trends in the observed behaviour (or in other words the response of the groundwater system to stress).

Table 12.7 Time variant model calibration statistics – magnitude of changes

Observation set	Variation in observed data (m)	Mean residual (m)	RMS (m)	SRMS (%)
All long term	131.8	3.6	7.1	5.4
ZAL long term	26.5	1.8	2.9	11.1
ZWC long term	131.8	6.3	10.5	7.9

Table 12.7 shows that the time variant model calibration returns a SRMS of 5.4% when the entire long-term dataset is used. This is considered to be acceptable. The analysis also shows that a significant proportion of the SRMS in the ZAL comes from errors in the absolute groundwater head rather than the groundwater response. When the groundwater response is used to calculate SRMS, the resultant value is 11.1%, rather than 20.2% as calculated from the absolute values.

Introducing additional complexity to the model to achieve a lower calibrated scaled root mean square (SRMS) was also considered inappropriate because:

- it places too much reliance on a single measure of calibration performance
- it places too much emphasis on a statistics-based calibration
- it still doesn’t guarantee that the solution is unique
- it would give the impression that the model predictions are more accurate than is realistically possible.

Incorporation of the worst-case scenario, which would represent a significant decline in inflow to the western inflow zone

As was noted in Appendix K6 of the Draft EIS, a sensitivity analysis was run that considered a reduction of inflow into the Stuart Shelf model from the Arckaringa Basin. In this scenario the constant head boundaries were replaced with constant flux boundaries and the flux reduced by 15% from that predicted by steady state constant heads. Within the timeframes of the predictive modelling (500 years), there was no discernible difference observed between the results of this sensitivity run and the base-case predictive model.

In the updated groundwater model, inflow was based on results from the calibrated Prominent Hill Mine Regional Groundwater Model (Aquaterra 2009) and was set at 740 m^3/d. This is significantly lower than the value of 3,060 m^3/d used in the Draft EIS model and the value of 2,142 m^3/d provided by the previous Prominent Hill model (Aquaterra 2007). The rate of 740 m^3/d is therefore considered to be a conservative value.

As a consequence of this change to the model boundary conditions and other modifications to the Draft EIS model, an additional sensitivity analysis has been undertaken. The sensitivity looks at the effect of reducing inflow from this boundary and the change this may have on the model predictions. The reduction in flow that has been simulated in the sensitivity analysis was based on the Prominent Hill model results (Aquaterra 2009). Aquaterra (2009) predicted a 13% reduction, yet the sensitivity included a reduction of 50%, which is proportionally much higher compared to the Prominent Hill model. This higher reduction has been included as a conservative approach. Again, even after 500 years post-closure there is no significant difference between the results of this scenario and that of the base case (see Figures 12.21 and 12.22 of the Supplementary EIS).

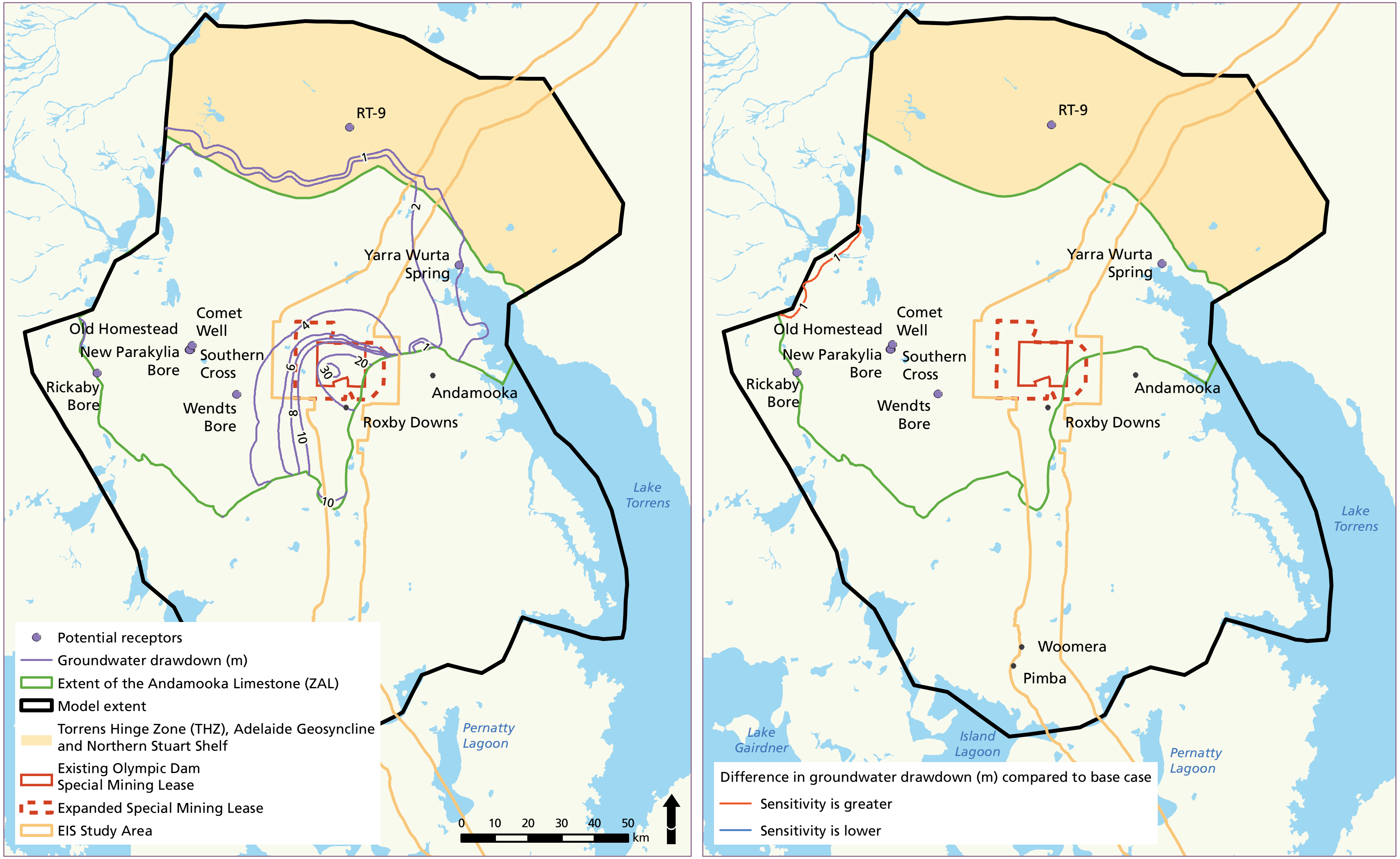


Figure 12.21 Andamooka Limestone (ZAL) predictions from ‘Declining inflow from Arckaringa Basin’ sensitivity (run X)

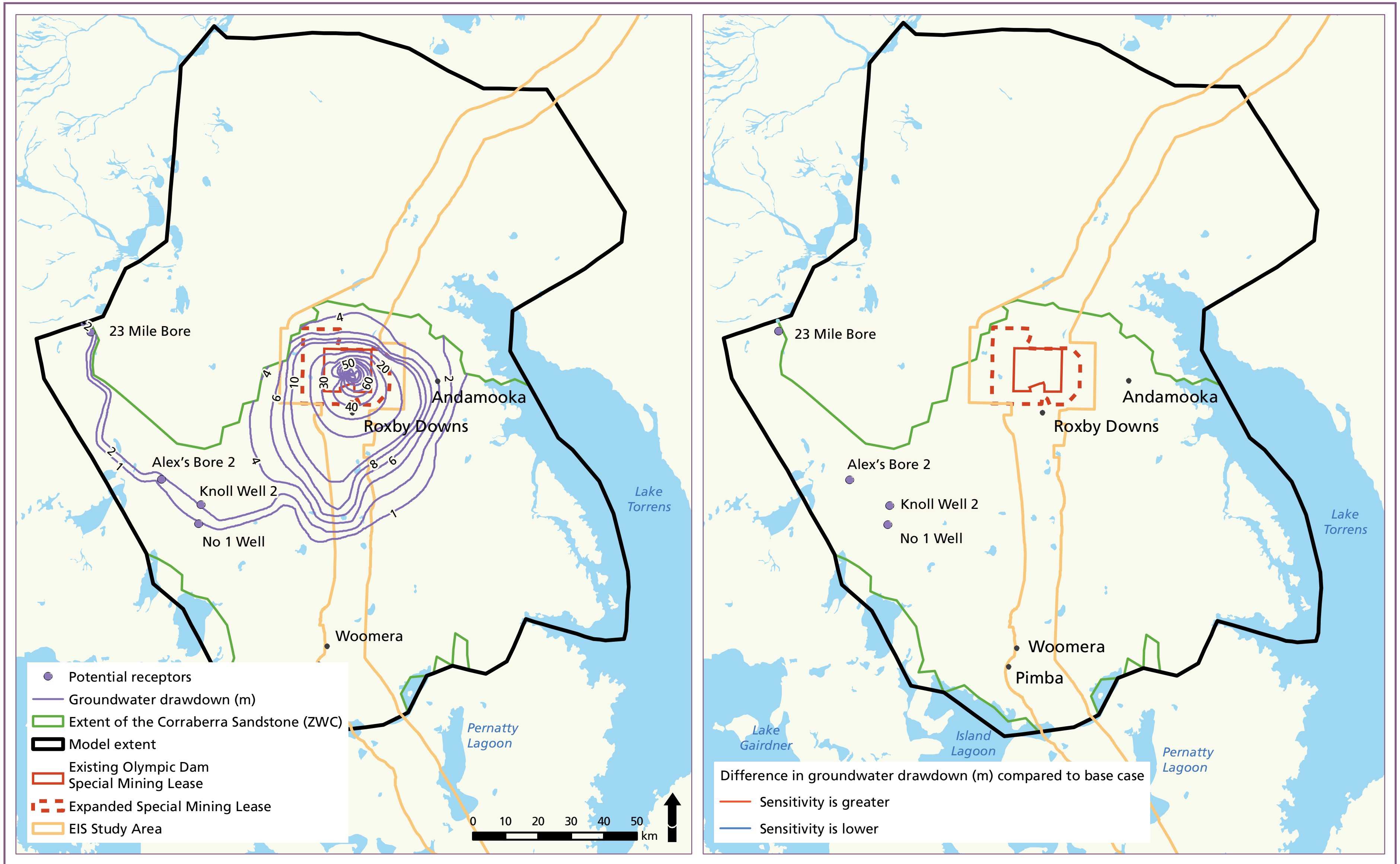


Figure 12.22 Corraberra Sandstone (ZWC) predictions from 'Declining inflow from Arckaringa Basin' sensitivity (run X)

Consideration of the influence of the proposed mining operation on users of the Arckaringa Basin groundwater resource is subject to significant uncertainty relating to the hydraulic connection between the Stuart Shelf and Arckaringa Basin aquifers. Appendix F1 of the Supplementary EIS provides a description of the conceptual connectivity between the Stuart Shelf and surrounding basins. However, simulated drawdown at a location about 1 km inside the western boundary of the model (adjacent to the inflow boundary) provides an indication of the magnitude of response in the Stuart Shelf aquifers that bound the Arckaringa Basin. Predictions of drawdown at this location provided by the updated groundwater model show that the range is likely to be between less than 1 m and 5 m, 500 years post-closure. The only prediction of drawdown greater than this (9 m) is provided by the low ZAL storage scenario. This is not considered to represent a significant change to groundwater users many kilometres west in the Arckaringa Basin proper.

Incorporation of monitored changes in groundwater levels at Prominent Hill and the potential consequences of the effects of the pit lake on groundwater flow from the Arckaringa Basin on groundwater users outside the modelled zone

The Draft EIS makes no mention of monitoring groundwater levels at Prominent Hill. However, results from the Prominent Hill Mine Regional Groundwater Model (Aquaterra 2007) were used to constrain the western model boundary. In the original groundwater model this was achieved in two ways:

- the calibrated 2007 Prominent Hill model provided an estimate of inflow (2,142 m^3/d) into the western boundary of the Draft EIS model
- as the western boundary of the Draft EIS model is situated tens of kilometres within the eastern portion of the Prominent Hill model, the calibrated groundwater contours from that model were used to set the reference level of the constant heads used along the boundary in the Draft EIS model. The heads along the western boundary were therefore set at 60 mAHD.

In the updated groundwater model, the inflow has been based on results from the recalibrated Prominent Hill Mine Regional Groundwater Model (Aquaterra 2009) and was set at 740 m^3/d. This is significantly lower than the value used in the Draft EIS model (3,060 m^3/d) and the previous Prominent Hill model (2,142 m^3/d; Aquaterra 2007) and is therefore considered to be conservative. Figures 12.10 and 12.11 show the newly simulated groundwater drawdown in the Tent Hill and Andamooka Limestone aquifers at the end of the construction period (2017), at the end of the 40-year mine life (2050), 100 years post-closure (2150) and 500 years post-closure (2550).

Review of the revised drawdown contours shows that there are no third party groundwater users influenced by the expanded operation up to the year 2150. This is the same result as reported in the Draft EIS.

However, the updated simulations of groundwater drawdown contours for 500 years post-closure, at 2550, show a potential effect on two third party groundwater users in the region (Parakylia station and Parakylia South station). A total of nine wells may be affected in Parakylia station, with potential drawdown in the Tent Hill aquifer of less than 1 m at two wells (see Figure 12.10b) and a potential drawdown in the Andamooka Limestone aquifer of less than 4 m in seven wells (see Figure 12.11b). Three wells may be affected on the Parakylia South station, with potential drawdown in the Tent Hill aquifer of less than 2 m (see Figure 12.10b) and no drawdown effects to wells that are currently in use in the Andamooka Limestone aquifer. The potential consequences of the effects of the updated modelling on third party groundwater users are further discussed in Section 12.5.7 of the Supplementary EIS.

Particle tracking and the implications on local plume movement

As was noted in Appendix K6 of the Draft EIS, particle tracking in the original groundwater model (to steady state conditions) was undertaken using the predictive base-case model and sensitivity tested to increased RSF seepage. In both of these cases, particles released into the groundwater within the footprint of the TSF and the RSF are captured by the open pit. This finding, along with empirical geochemical data (see Appendix F5 of the Supplementary EIS), negated the need to undertake particle tracking on the remaining model sensitivity runs as the RSF seepage sensitivity was considered to be the worst-case scenario in terms of potential for flow away from the TSF or RSF.

For the updated groundwater model the prediction and sensitivity runs have been repeated and expanded. This was necessary because the model calibration was revisited and because the predicted seepage rate from the TSF was refined.

The analysis shows that for all of the sensitivity runs (parameter changes and seepage rates), particles released beneath and in the vicinity of the TSF and RSF footprints would still be captured by the open pit. The sensitivity run includes an RSF seepage of 5% annual rainfall (consistent with the 5% used in the Draft EIS), considered to be at the upper limit of long-term possible values (see Appendix F7 of the Supplementary EIS for details).

Discussion of the implications of seepage modelling if allowing for an inactive TSF cell

The seepage schedule used in the groundwater model is simplified by not including inactive cells, however, because of this there is a slightly greater flux used in the model predictions and therefore it is considered to be a conservative modelling approach. Furthermore, sensitivity analysis has been carried out on TSF seepage rates as discussed above and detailed in Appendix F4 of the Supplementary EIS and the implications were insignificant, with seepage reporting to the open pit post-closure.

Provision of modelling results at finer time-steps and with smaller drawdown contours

Figures 12.14 and 12.15 of Section 12.6 of the Draft EIS provided results for the base-case scenario at three time-steps (2017, 2050 and 2550) in the Andamooka Limestone (ZAL) and the Corraberra Sandstone (ZWC). Contoured predicted drawdown was not provided for the sensitivity analyses. Hydrographs showing base-case and sensitivity results for the entire prediction model run (540 years) were provided at potential environmental and third party receptors and a number of other sites in the Stuart Shelf in Appendix K6 of the Draft EIS. These hydrographs therefore present an uninterrupted record of the predictions during this time period, and with the inclusion of location RT9 (north of the Stuart Shelf), provided an acceptable spatial distribution.

To provide modelled contours for the two main aquifers at finer time-steps (e.g. yearly intervals for the first 40 years, five-year intervals for the next 100 years, then 20 years for the next 400 years) would require 134 figures to be produced for each model prediction run (67 for the ZAL and 67 for the ZWC), and as there were 12 sensitivity runs in total, result in 1,608 figures. This would not be appropriate or practical and is unlikely to add clarity to the interpretation and assessment of the modelling predictions.

As with the Draft EIS model, contoured predicted drawdown for all predictive runs undertaken with the updated model is provided at 2017, 2050 and 2550 along with hydrographs that provide an uninterrupted record of the predictions during this time period at the locations listed above (see Figures 4.4 to 4.6, Figures 5.1 to 5.8 and Figures 6.1 to 6.24 of Appendix F4 of the Supplementary EIS).

Extension of model domain to include the Great Artesian Basin aquifers

As was described in Chapter 12 and Appendix K6 of the Draft EIS, the southern margin of the Great Artesian Basin (GAB) aquifer system (artesian extent) was used to delineate the northern boundary of the numerical flow model. Appendix K1 of the Draft EIS described the conceptualisation of the groundwater system in this area and this description has been expanded in Section 12.1 and Appendix F1 of the Supplementary EIS. In particular, the northern and north-eastern boundaries of the model are identified as discharge zones for groundwater in the most northerly portion of the Stuart Shelf. This part of the Stuart Shelf is separated from the main flow system by a groundwater divide. There is no connection between the artesian GAB aquifers and the main Stuart Shelf aquifers (Andamooka Limestone and Corraberra Sandstone).

This northern model margin discharge was simulated in the original groundwater model using several ‘seepage boundaries’ which were defined in this region to represent flow from springs and diffuse groundwater leakage at the northern margin of the Stuart Shelf. Four constant heads were used in this region to provide a mechanism for water to flow into the numerical model from the GAB aquifers if the heads dropped below 22 mAHD. The elevation of 22 mAHD was based on the ground elevation of the southern-most extent of the GAB margin. The results of the predictive modelling showed no discernible changes in the outflow from these boundary conditions and no significant drawdown in this region even after 500 years post-closure.

As no connection between the GAB and Stuart Shelf is thought to exist, the Stuart Shelf model has not been extended north to incorporate the GAB aquifers.

The updated groundwater model has provided no contradictory results in terms of the predicted drawdown at the northern extent of the model. At 500 years post-closure in the predictive run and in all sensitivities, drawdown at this model boundary does not exceed 1 m (see Figure 12.23). It is suggested therefore that an extension of the model northwards is not required to conclude that groundwater head changes at the GAB springs resulting from open pit operations are extremely unlikely.

Provision of verifications and calibrations for all aquifers using the recalibrated model, including provision of monitored pump test time series data

Use of long-term pumping test time series data

A long-term and high-volume pumping test of the ZWC was commenced in September 2008. The test was required to develop a better understanding of the site hydrogeology, particularly in the behaviour of the ZWC and the response of the lower conductivity units above (ZWA) and below (ZWT) for the purpose of pit water control. These units have been identified as requiring significant depressurisation prior to the development of the open pit.

This ‘trial depressurisation’ involved the drilling of, and abstraction from, seven test production wells in the vicinity of the proposed open pit (see Figure 12.24). All of the wells were located within the current SML boundaries and targeted the ZWC. Abstraction associated with the trial depressurisation was between 1,000 and 3,500 m^3/d (12 and 40 L/s).

For the entire period detailed monitoring was carried out at the pumping wells, monitoring bores and vibrating wire piezometers (VWPs). The positions of these are shown in Figure 12.24. Time variant abstraction from pumping bores and the time series observations are shown in Attachment C of Appendix F4 of the Supplementary EIS.

Figure 12.23 Predicted change in Andamooka Limestone (ZAL) groundwater elevation at 2550

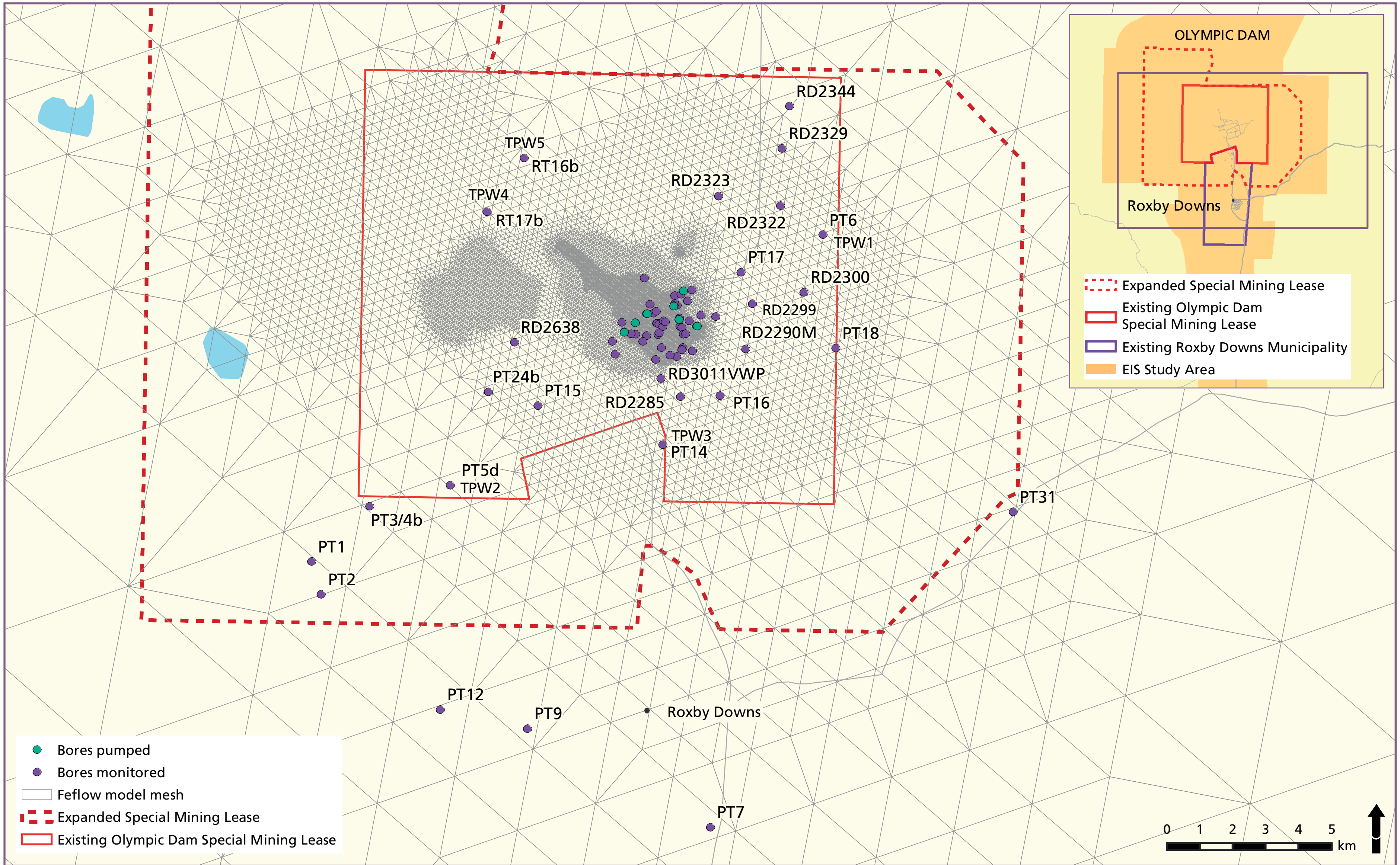


Figure 12.24 Boreholes associated with the trial depressurisation

Model calibration
Calibration of the updated model was undertaken using a greatly expanded dataset of time variant groundwater observations.

The inflow assigned to the western boundary (representing inflow from the Arckaringa Basin) was reduced significantly in the updated groundwater model. This inflow was changed from 3,060 m^3/d to 740 m^3/d, and fixed so that even as the groundwater gradient towards the open pit increased through time the flow across the boundary could not increase. This was done to be consistent with the recalibrated Prominent Hill Mine Regional Groundwater Model (Aquaterra 2009) and to eliminate any potential increases in model inflow due to the changes in hydraulic gradient. The only other inflow to the model (and conceptual model) is rainfall recharge, which is 3,243 m^3/d in both the original and updated groundwater models. Therefore, in terms of inflow to the Stuart Shelf groundwater system, this modification reduced inflow from over 6,000 m^3/d to about 4,000 m^3/d.

The other major change to the model during the update that was significant in terms of the understanding of regional groundwater processes was the increase in the extent of the saline interface. This change was included to be consistent with the additional data captured since the Draft EIS (see Appendix F1 of the Supplementary EIS for details). A change in the hydraulic properties of the saline interface was made to achieve a regional steady state calibration similar to that in the Draft EIS model. Very little difference in predictions can be attributed to the changes, however, as the results from the original and updated groundwater models are similar.

The calibration results are described below.

As was noted in Chapter 12 and Appendix K6 of the Draft EIS, calibration of the Stuart Shelf steady state numerical model is constrained by a number of factors. The most significant of these are:

- uncertainty in the observation data (their absolute values, whether they represent a true steady state condition and whether they are representative of the unit that they are reportedly screened within)
- the large size of the model domain (26,000 km^2) and hydro-lithological complexity
- the complex nature of the aquifer and aquitard rocks
- the complex nature of the groundwater flow mechanisms (fractured and karstic)
- uncertainty associated with estimates of system stresses (rainfall recharge, inflow from other basins and outflow)
- the existence of variable-density groundwater.

Given the above, the calibration methodology adopted for the development of this model was based on an approach where simplistic, homogeneous conditions would be adopted when complexity could not be substantiated with measured data.

The model has been updated and this has included some changes to the model finite element mesh, boundary conditions and an expansion of the calibration dataset. The calibration has also been updated. However, given the discussion above, the priority of this update was not to improve the calibration statistics of the model. Calibration statistics from the updated groundwater model are provided in Tables 12.5 to 12.7 for the steady state and time variant (absolute value and magnitude of change) models.

Storage co-efficient values
Adopted hydraulic parameters used in the calibrated model are detailed in Appendix F4 of the Supplementary EIS, including presentation of the areal distribution of storage coefficient values and hydraulic conductivity values (see Table 12.4 of the Supplementary EIS.

Extent of model domain and contouring
As was noted in Chapter 12 and Appendix K6 of the Draft EIS, the model extent does not necessarily correspond to the full extent of any one Stuart Shelf aquifer, because the extent of the most significant hydrogeological units (the Andamooka Limestone, the Corraberra Sandstone and the Arcoona Quartzite) are not the same. Therefore the groundwater head contours presented in the Draft EIS have been cropped to within the spatial extent of the aquifers which they represent.

The locations of all boreholes with associated steady state and time variant groundwater observations are provided in Appendix F4 of the Supplementary EIS. Simulated and observed groundwater contours in July 2008 are presented in Figures 12.21 and 12.25 of the Supplementary EIS. In these figures, and those in the Draft EIS, the groundwater contours have been limited to within the physical extent of the aquifer to which they relate.

Resolution of predicted drawdown contours
As was noted in Chapter 12 and Appendix K6 of the Draft EIS, drawdown of magnitude measured in metres represents the limit of model prediction and accuracy. This limit is determined by several factors, the most significant of which in terms of the Stuart Shelf model are:

- the large size of the model and the spatial extent over which groundwater stresses are simulated and predictions required
- the complexity of the system (variable density, fractured rock, heterogeneous, anisotropic)
- the uncertainty in significant model inputs (inflow from the Arckaringa Basin, discharge mechanisms, and hydraulic parameters)

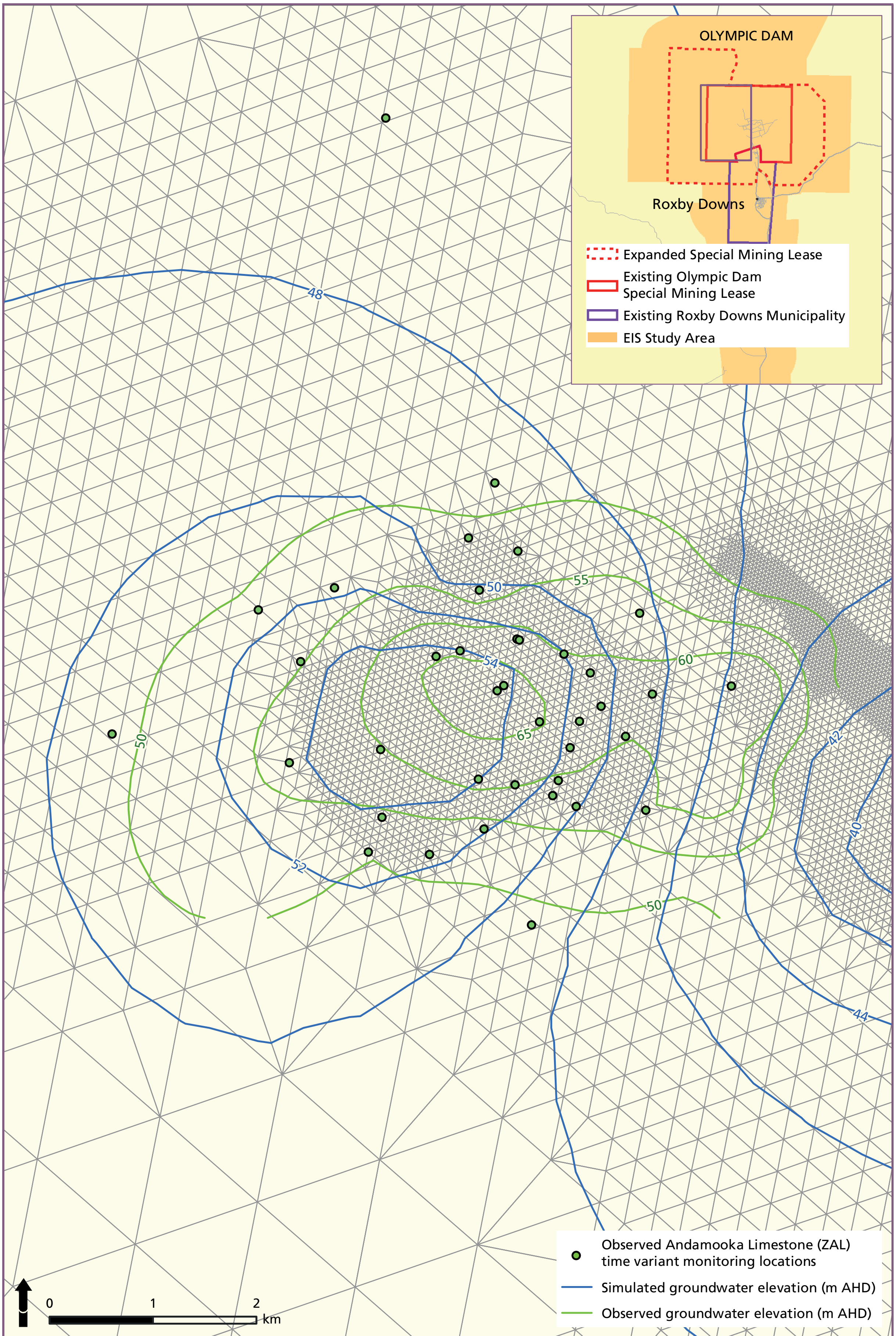


Figure 12.25 Observed and simulated groundwater elevations in the Andamooka Limestone (ZAL) in 2008

- time variant observation data density. The area in the Stuart Shelf numerical model that can be calibrated to a time variant response amounts to less than 1% of the total model area
- the timeframe over which predictions are required.

Prediction of drawdown of magnitudes less than 1 m is therefore considered beyond the realistic capability of the numerical model. Furthermore, manually extrapolating the predictive results to provide more refined contours would add additional uncertainty.

Solute particle tracking, fate and transport

As discussed previously and noted in Section 12.6 and Appendix K6 of the Draft EIS, particle tracking (to steady state conditions) was undertaken with the predictive base-case model and with the increased RSF seepage sensitivity. In both of these cases particles released in the footprint of the TSF and the RSF are captured by the open pit. This observation was considered to negate the need to undertake particle tracking on the remaining model sensitivity runs as the RSF seepage sensitivity was considered the worst-case scenario in terms of potential for flow away from the TSF or RSF.

The prediction and sensitivity runs have been repeated and modified in the updated groundwater model. This was necessary because the model calibration was revisited and because the predicted seepage rate from the TSF was refined.

The conclusions from this expanded set of sensitivities are the same as those from the Draft EIS modelling. That is, none of the parameter combinations combine to produce a situation where particles released under or in the vicinity of the TSF and RSF migrate away from the open pit. This includes the 'climate change' scenarios. Steady state particle tracking results from all the updated groundwater model sensitivities, as discussed previously in Section 12.2.1, are detailed in Appendix F4 of the Supplementary EIS.

Hydraulic conductivity units

Clarification was sought on the units for hydraulic conductivity used on Figures 13 and 14 of Appendix K6 of the Draft EIS relative to that presented in Table 7.1 of the same appendix. The units used are m/s $x10^{-4}$ which is the unit automatically adopted by the numerical groundwater flow modelling software FEFLOW (i.e. a value of 0.5 in standard FEFLOW units is actually 5×10^{-5} m/s). The values quoted for the Andamooka Limestone (ZAL) and the Corraberra Sandstone (ZWC) in Table 7.1 of Appendix K6 of the Draft EIS have been left in this unit and were not converted into the stated m/s unit, unlike the other values in this column of the table that are in m/s. All values in Table 7.1 quoted in m/d (adjacent column) have been converted correctly from the FEFLOW units and are therefore representative of the values used in the model. The significantly lower values shown on Figures 13 and 14 in the layers that correspond to the ZAL and ZWC are used in areas where these units are not actually present and the values are therefore representative of the hydraulic conductivity of neighbouring lithological units. As noted in Appendix K6 of the Draft EIS:

> 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.

The relationship between the hydrogeological layer extent and the model domain is discussed further in Appendix F4 of the Supplementary EIS.

Extension of model scenarios to reach steady state

Five hundred years post-closure was considered a reasonable limit of the Draft EIS model predictive capability, especially in view of:

- the length of time variant data available for calibration (24 years in the ZWC, 15 years in the ZAL)
- the fact that over 99% of the model domain has no time variant observed data and no measured (or otherwise) groundwater stress associated with it
- the size of the model (26,000 km^2)
- the uncertainties associated with the regional physical configuration of the model (e.g. layering)
- the uncertainties associated with the model input parameters (e.g. hydraulic parameters, recharge)
- the uncertainties associated with how some model inputs might change over time (e.g. recharge and inflow from the Arckaringa Basin)
- the uncertainty in the predictive inputs (pit size, pit lake level and abstraction requirements)
- the potential influence of natural or anthropogenic climate change over the protracted timescale.

The model has not reached equilibrium at 500 years and it is very unlikely to have done so by 1,000 years. The uncertainties described above have been considered against the alternative to run the model past 500 years post-closure or to steady state. The results from any longer predictive runs would be subject to the underlying uncertainties in the model and presenting the results would suggest a degree of confidence in those results that is unrealistically high.

The updated groundwater model report, including model set-up, calibration, predictions and sensitivity analysis (including TSF and RSF scenarios), is documented in Appendix F4 of the Supplementary EIS.

Although the predicted groundwater drawdown cannot be reliably represented beyond 500 years post-closure with the numerical model, it is possible to present some discussion around the likely conceptual development of drawdown.

Ultimately, the regional groundwater level would stabilise (i.e. approach a steady state). It is unknown when steady state would be approached, but based on Stuart Shelf recharge estimates it is expected to be well in excess of 1,000 years.

Steady state conditions would typically occur when the equilibrium between pit inflows and rainfall recharge (within the area of influence) is established and/or a constant head source can be intersected. In the very long term, these constant head flows would likely come from the bounding Arckaringa Basin and from flows originating in the eastern Flinders Ranges.

These bounding groundwater systems are believed to have the capacity to contribute a significant flow without modifying the groundwater flow conditions in the systems that they support, primarily because:

- The volume of water lost through evaporative discharge on Lake Torrens has been estimated by Schmid (1985) to be 50 mm/year. Assuming evaporative discharge is almost equal to recharge from the east within a portion of northern Lake Torrens (500 km^2), over 65 ML/d could be available to contribute to a constant head source to the west (Stuart Shelf). However, it is recognised that other hydraulic and climatic factors that could reduce this estimate need to be considered.
- Hydraulic heads in the Arckaringa Basin sediments that overlie the margins of the Stuart Shelf are around 12–20 m above groundwater levels in the Stuart Shelf aquifer system (see Section 12.1.1 and Figure 12.8 of the Supplementary EIS). This head difference would drive additional groundwater flow.

Mass water balance, including Lake Torrens

The steady state mass balance for the updated groundwater model is illustrated in Figure 12.26 of the Supplementary EIS. This mass balance shows that:

- recharge provides the largest inflow (3,243 m^3/d)
- the greatest discharge of water from the model (over 75% of total inflow) occurs at the northern portion of Lake Torrens (3,070 m^3/d)
- discharge from the central portion of Lake Torrens is much less (516 m^3/d)
- discharge from the model along the northern boundary is small (45 m^3/d).

The discrepancy between the calibrated steady state model inflow and outflows is less than 0.001%.

Due to pit lake development, long-term discharge from the Stuart Shelf groundwater system to the northern portion of Lake Torrens would likely reduce to around 2,000 m^3/d, 500 years post-closure.

However, while the numerical groundwater model has the capability to generate a mass water balance, it was not the intention of the model to provide estimates of flows into Lake Torrens; this was not one of the objectives of the modelling and there are no measurements of flow with which to calibrate this feature of the model. The local and regional discharge at Lake Torrens has been simulated with 'drain' conditions that are set at a reference level, in this instance ground surface derived from a digital elevation model (DEM). If the groundwater elevation is above this reference level water will flow out of the model; if elevations are below, no inflow or outflow occurs from these 'drains'.

The groundwater discharge mechanism at Lake Torrens, as discussed in Appendix F3 of the Supplementary EIS, will be far more complex than the numerical representation described above. The current conceptual understanding is that most regional discharge occurs as evaporation from near-surface zones of low elevation on the lake fringe rather than by surface flows onto the lake bed. The mechanisms controlling regional groundwater discharge are not well understood and therefore the link between drawdown (as supplied by the groundwater model) and the resultant change in discharge from the model and impact on the Lake Torrens water balance is subject to significant uncertainties. These include:

- there is no opportunity to calibrate the Lake Torrens water balance with any monitored environmental flow
- the model assumes the discharge at Lake Torrens is coincident with natural surface, while the natural condition is likely to vary considerably from this case
- the model elevations are interpolated from a regional DEM and extrapolated to a minimum mesh size of 2,000 m in the area of Lake Torrens
- there is geological and hydrogeological simplification in the model representative of the available data in the area
- assuming that evapo-transpiration is the major mechanism for regional discharge from the Stuart Shelf to Lake Torrens, the key relationship between evaporation rates, depth below ground surface and extinction depth is unknown.

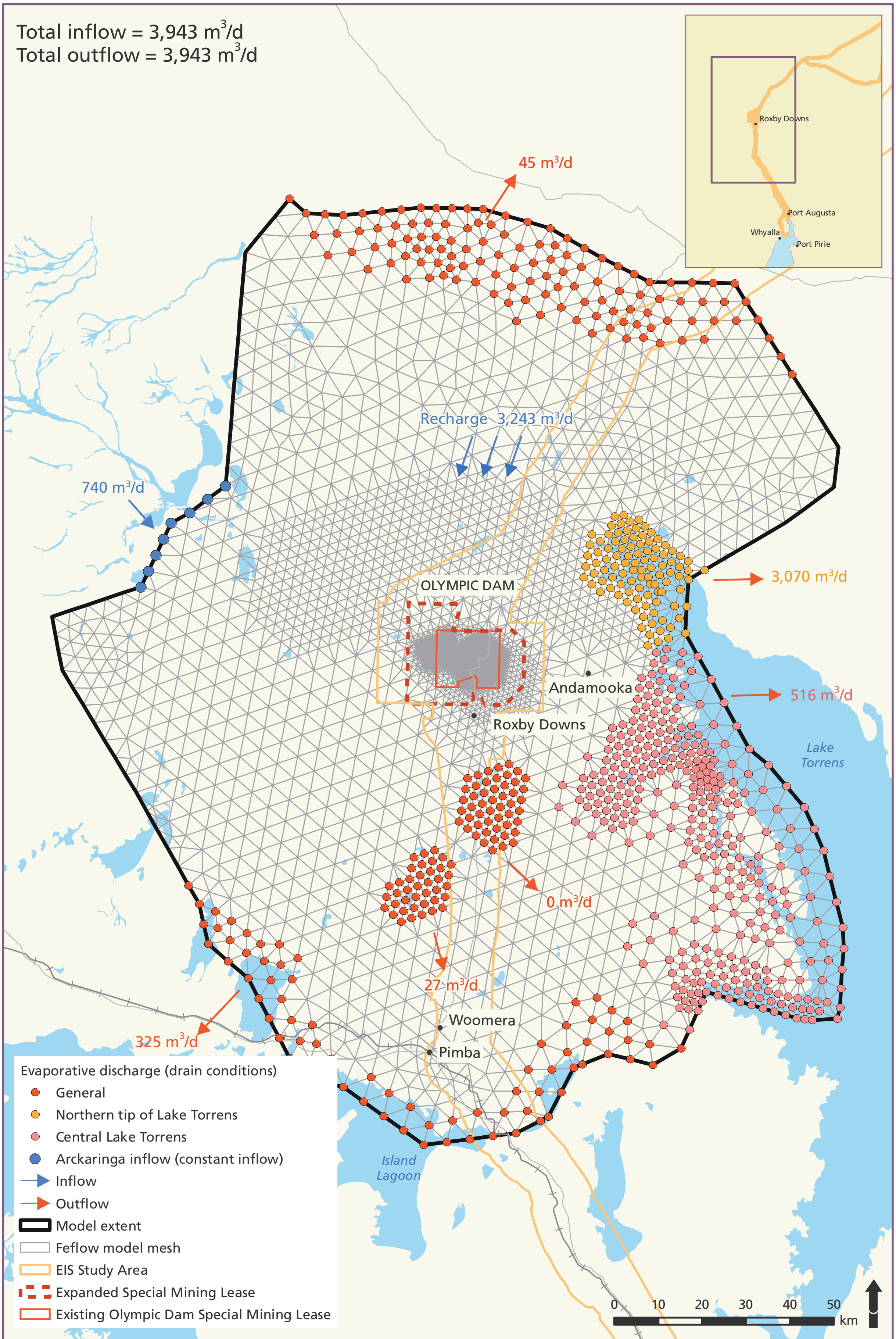


Figure 12.26 Numerical model mass water balance

The model does not account for the volume of groundwater in storage beneath Lake Torrens, nor recharge from the east. The groundwater model does not represent the entire Lake Torrens catchment and associated water balance, and in effect only simulates the western and northern catchment areas. The remainder of the Lake Torrens catchment to the east and south is not represented in the model and this would be considered crucial in determining the total water balance of the lake. Furthermore, the model only simulates groundwater flow and does not consider surface inflow or run-off during rainfall events. This surface water component would be essential when dealing with a water balance assessment of the lake.

The uncertainties addressed above will have a significant effect on the accuracy of the modelled response of discharge to groundwater head fluctuation, and for this reason caution should be applied when considering the influence of the predictions on the Lake Torrens water balance.

12.2.2 SEEPAGE

Issue:

Clarification and substantiation was sought on predicted seepage movements from the proposed tailings storage facility (TSF) as presented in the numerical groundwater model. Specific issues raised included:

- provision of sensitivity analysis of seepage rates in the flow model simulations
- clarification and implications of local anisotropy on groundwater mounding in the Andamooka Limestone aquifer.

Submissions: 1 and 2

Response:

Sensitivity analysis of seepage rates

The updated groundwater model is discussed in Section 12.2.1 and provided as Appendix F4 of the Supplementary EIS. The updated groundwater model was used to test the sensitivity of predictions to the rate of seepage from the TSF. A higher seepage rate from the TSF was modelled to assess the potential for solute (particle tracking) to flow away from the open pit post-closure and to assess the groundwater mounding sensitivities. In this sensitivity scenario the higher TSF seepage is defined by the 48% tailings solids schedule rather than the 53% tailings solids schedule used in the base-case model. The TSF seepage sensitivity used a seepage rate considered to be the worst case during mine operations. This was coupled with a post-closure seepage rate of 1% of rainfall (1.5 mm/y), appropriate for a TSF with no engineered cover. The TSF seepage base-case model used a seepage rate of 0.1 mm/y. Comparison of the seepage rates is shown in Figure 12.27 of the Supplementary EIS. A description of the engineering design of the TSF was provided in Section 5.5.6 and Appendix F1 of the Draft EIS.

Particle tracking using the results of this sensitivity analysis showed that even at these very high seepage rates, water emanating from beneath and in the vicinity of the TSF would be captured by the open pit.

The predicted magnitude of groundwater mounding beneath the TSF cells in the base-case scenario is between 6 and 8 m in 2017 and between 2 and 4 m in 2050. Beyond this time, due to the expanding influence of groundwater inflow to the pit, drawdown is predicted beneath the TSF (i.e. no mounding). In the sensitivity analysis, the higher seepage rate results in a predicted mounding of about 35 m in 2017, which remains unchanged through to 2050. As with the base case, by the end of the simulation, drawdown is predicted beneath the TSF cells, rather than mounding.

Effects of local anisotropy on groundwater mounding in the Andamooka Limestone aquifer

Figure 12.28 of the Supplementary EIS presents a selection of hydrographs from bores screened in the ZAL that are considered representative of the range of observed time variant groundwater responses. The full dataset is presented and discussed in Appendix F4 of the Supplementary EIS, which also includes a detailed description of the 'type' responses referred to on Figure 12.28. Observed and simulated groundwater contours for the ZAL in July 2008 are presented in Figure 12.25 of the Supplementary EIS. As noted above, the time variant ZAL dataset shows significant variability, which is likely to be controlled by two main factors:

- karstic and fracture dominated flow in the ZAL, resulting in significant heterogeneity and anisotropy that produces large spatial variability of hydraulic parameters at a local scale
- non-uniform leakage (spatially and time variant) from the TSF and previously existing unlined evaporation ponds.

The potential also exists in the monitoring network for construction integrity issues in individual monitoring bores. For the purposes of the modelling calibration this has not been considered as part of the study, however, it is recognised that a number of bores may not be measuring a true groundwater head. This needs to be considered when analysing individual modelled versus observed hydrographs.

In terms of the absolute groundwater heads, in the majority of cases the model simulates lower elevations than observed. This discrepancy is 11 m, and is present from the date of the first observations, usually 1994 (i.e. the discrepancy doesn't develop

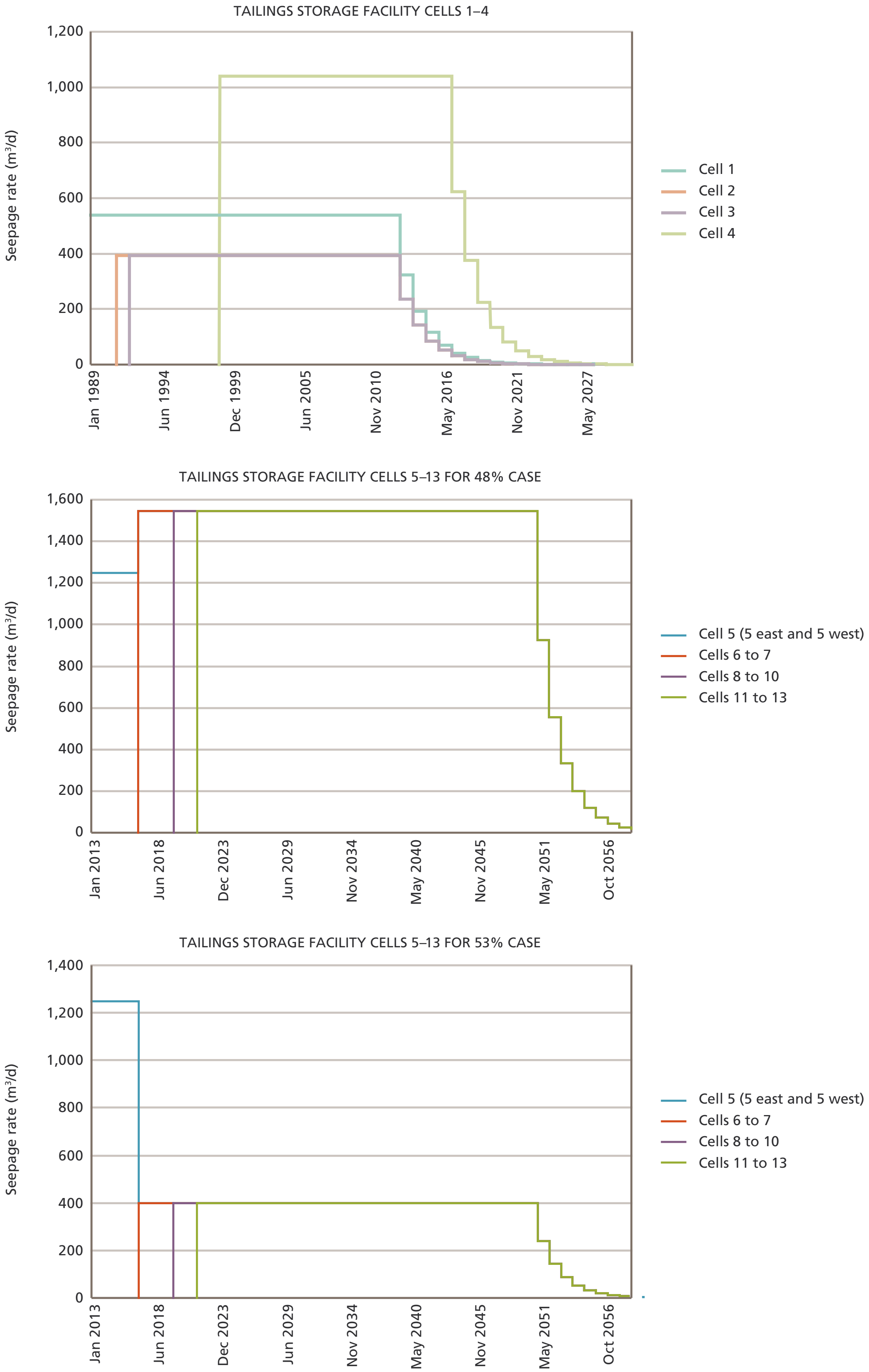


Figure 12.27 Tailings storage facility seepage estimates used in the modelling

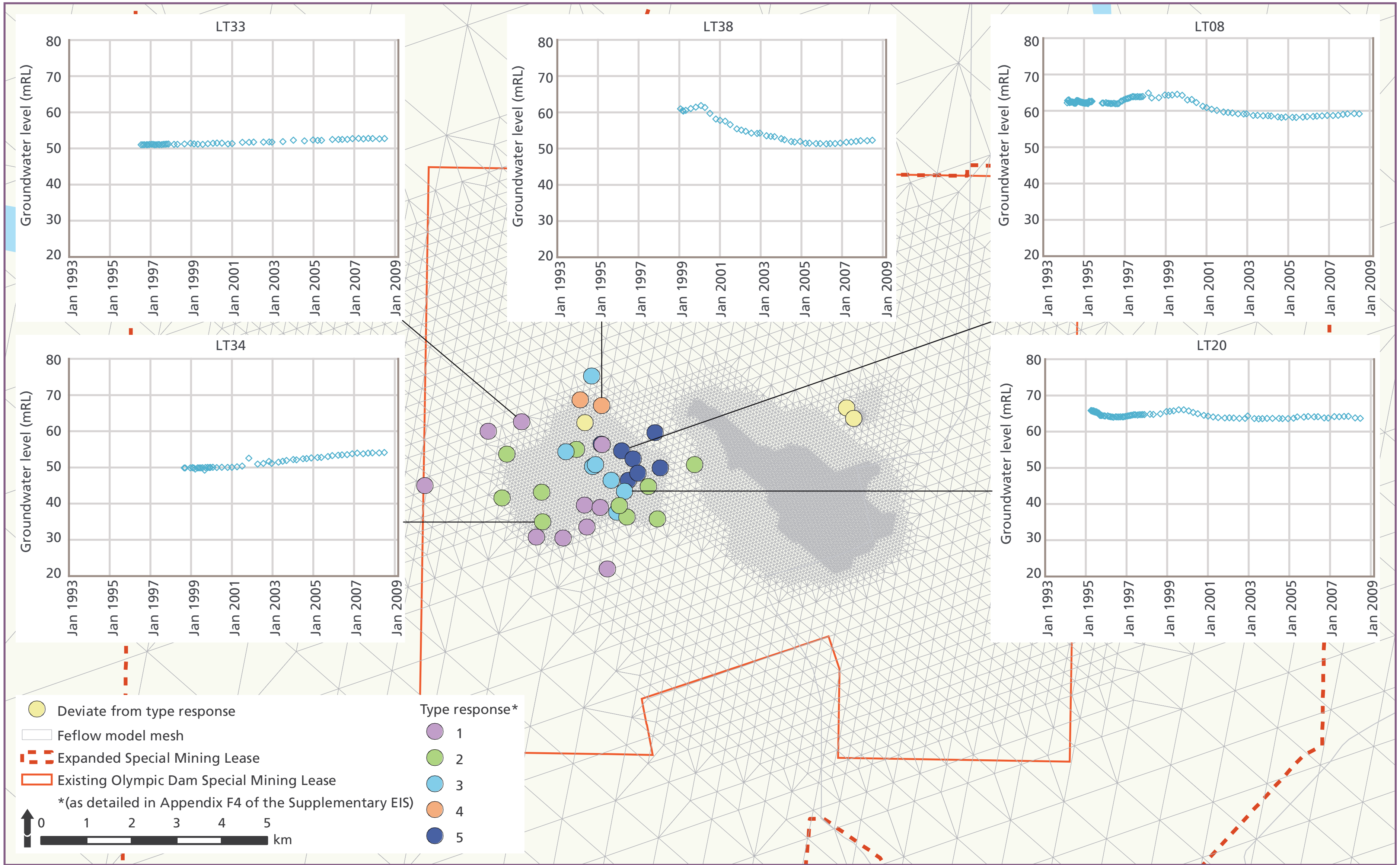


Figure 12.28 Representative Andamooka Limestone (ZAL) groundwater hydrographs

with time). These initial elevations are controlled by the steady state model calibration, which, in the area of the SML, in the ZAL provides elevations that match the observed to within 1.5 m. The steady state groundwater elevations in this area are between 47.8 and 48.5 mAHD. This fact highlights again the compromise that must be made when calibrating a model to both steady state and time variant data. At the time of the majority of the first observations in 1994, the existing TSF had been in operation for around six years. Groundwater levels in many of the observation bores had, by that time, been influenced by seepage from the TSF, the former wash water evaporation pond and the former mine water evaporation pond. The initial observation at LT17, for example, was about 68 mAHD in 1994, which is 20 m higher than the steady state observations in the area.

Complexity was not introduced to the model where it was not warranted or supported by data and where it would only serve to improve the statistical and visual fit between observed and simulated groundwater elevations. The time variant calibration was given highest priority, however, within this, calibration to the observations local to the mine was given a lower priority than calibration to the observations around the perimeter of the mine. This was intended to ensure that the regional predictions provided by the calibrated model were based on the most appropriate parameter values. Heterogeneity in the local Olympic Dam area was considered in the sensitivity analysis by increasing and decreasing the hydraulic conductivity of key units.

The groundwater model is regional in scale and the calibration and predictive capacity of the model was focused toward this where possible. The model is an acceptable tool for the prediction of regional impacts. While the model includes local scale seepage and abstraction, it is not the intent of the model to perfectly simulate and calibrate against these stresses. Local responses to seepage and abstraction are ultimately influenced by local factors such as geology and the spatial distribution of seepage which cannot practically be included in a regional scale model.

Although not simulated with numerical modelling, it is recognised that around the RSF and TSF, minor dispersion may occur locally due to preferential pathways and permeability contrasts in the shallow sediment and karst features. This is unlikely to result in an expression of seepage at the surface due to the net vertical downward unsaturated flow gradients being sufficient to support the TSF seepage flux. Any lateral dispersion of solutes is likely to be of limited extent.

Groundwater monitoring (level and quality) in the vicinity of the existing TSF is an analogue for the proposed system and provides empirical evidence that lateral dispersion of solutes in the unsaturated soil profile and shallow groundwater system does not occur beyond the immediate vicinity of the TSF. Seepage from the TSF is expected to be greater than the likely seepage from the RSF and seepage along preferential pathways is likely to fall in the zone of influence from the hydraulic sink created as part of the closed mine pit. It is impractical to quantify the variability of the shallow soil profile to identify the location of these permeability contrasts for the purpose of an EIS.

The geology between the base of the RSF and the top of the aquifer comprises unconsolidated sands, clayey and sandy clay calcareous sediments, and weathered to moderately weathered dolomites and limestone to depths of around 50 to 70 m. Although increased infiltration could support perched conditions leading to some minor lateral flow and dispersion, unsaturated flow conditions would dominate, resulting in an overall net vertical flux and eventual infiltration to the groundwater system beneath the base of the RSF. Any perched conditions that did develop beneath the RSF would be unlikely to introduce seepage to the surface due to:

- the flat topographic gradients around the RSF
- a net vertical flux
- a discontinuation of perched layers.

Perched groundwater conditions have not been identified during hydrogeological or geotechnical drilling, nor during routine groundwater monitoring in the vicinity of the existing TSF or the proposed RSF.

12.2.3 GROUNDWATER DRAWDOWN

Issue:

The potential impacts from groundwater drawdown on local aquifers, and on flora and fauna were questioned.

Submissions: 2, 27, 136 and 189

Response:

Local aquifers

Considerable attention was paid to this issue in the assessment and presentation of the groundwater chapter of the Draft EIS (refer in particular to Sections 12.6.1, 12.6.3 and 12.6.4; Figures 12.14 and 12.15; and Appendices K2 and K6).

There are two aquifers beneath Olympic Dam: the Tent Hill aquifer and the Andamooka Limestone aquifer. The Tent Hill aquifer is comprised of both the Corraberra Sandstone and the overlying Arcoona Quartzite. As outlined in Section 12.3.2 of the Draft EIS, the water table in the Tent Hill aquifer typically occurs 160–200 m below ground level, while the Andamooka Limestone aquifer typically occurs about 50 m below ground in the area of the mine.

Section 12.7 of the Draft EIS outlined that groundwater drawdown in the lower Tent Hill aquifer would initially occur due to the pumping of satellite water supply wellfields and would gradually be overridden by the effects of groundwater flow to the open pit. The final zone of influence (500 years post-closure) was expected to be around 20 km north and up to 45 km south of Olympic Dam. Groundwater drawdown in the Andamooka Limestone of up to 10 m below pre-mining levels was expected beneath the Special Mining Lease (SML) with a zone of influence that would extend up to 5 km north of the SML and up to 20 km south-east. Figures 12.14 and 12.15 of the Draft EIS, reproduced here as Figures 12.29 and 12.30, presented the outcomes of this drawdown modelling.

Subsequent to the publication of the Draft EIS, additional groundwater modelling has been undertaken to take account of additional information, which is discussed in Section 12.2.1 and Appendix F4 of the Supplementary EIS. This modelling aimed to refine the understanding of the extent of groundwater drawdown.

Based on the updated modelling, the final zone of influence (500 years post-closure) in the Tent Hill aquifer is expected to be around 65 km west and 40 km south, with the majority of drawdown occurring within 20 km of the expanded SML, as presented in Figure 12.10b. The modelled drawdown at 500 years post-closure in the Andamooka Limestone aquifer is expected to be around 55 km north and 25 km south in the Andamooka Limestone aquifer, with the majority of drawdown occurring within 15 km of the expanded SML, as presented in Figure 12.11b.

Flora and fauna

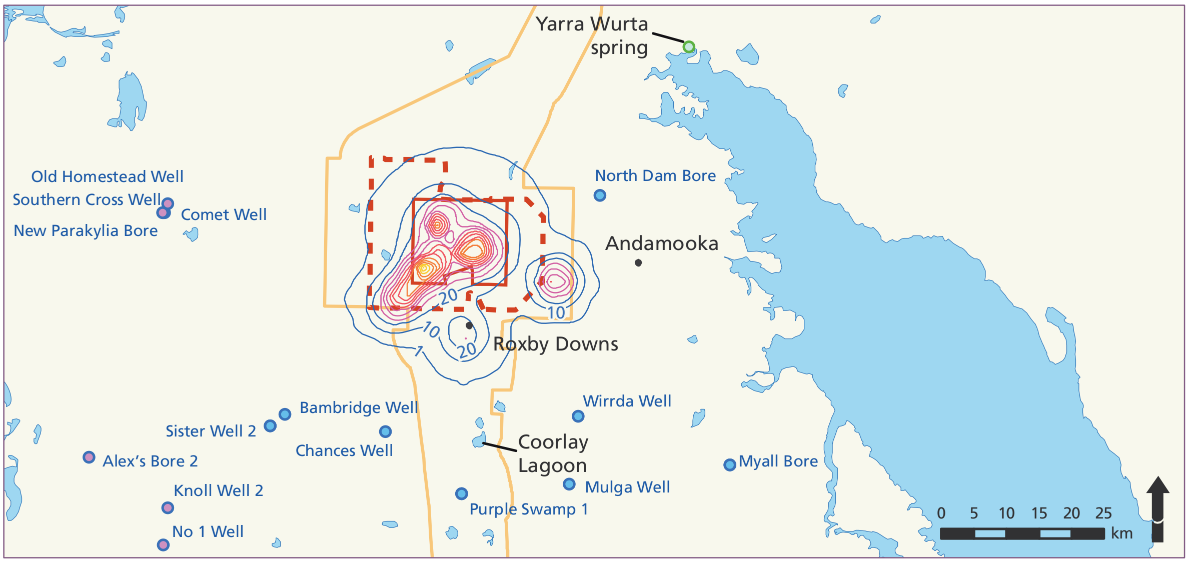
Section 12.7 of the Draft EIS concluded that regional groundwater drawdown would not affect flora and fauna. This conclusion remains unchanged with the updated modelling, and the main two reasons for this were detailed in Section 15.5.8 of the Draft EIS, being that:

- the groundwater of the Andamooka Limestone aquifer is hypersaline and therefore would not be usable by trees and shrubs in the region
- the groundwater is also at least 50 m below the surface, which is significantly beyond the depth to which tree roots are reported to penetrate.

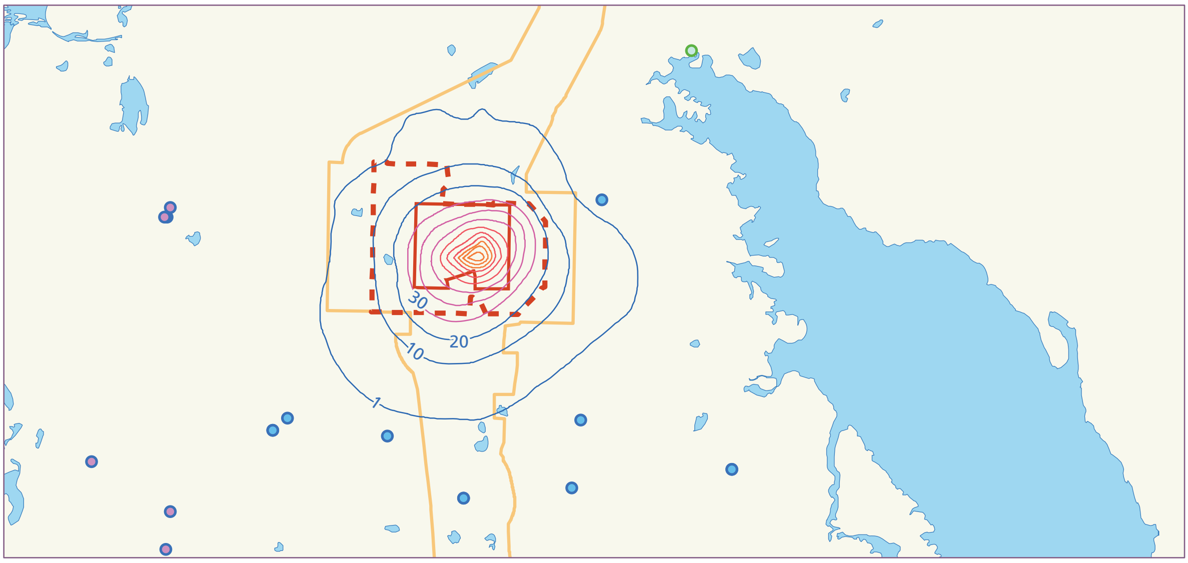
It was questioned whether the local Acacia woodlands, specifically the Mulga *Acacia aneura* and the Western Myall *Acacia papyrocarpa*, would tap into the shallowest aquifer as a water source. *Acacia aneura* has a shallow and branching root system (Hill and Hill 2003) that reaches a maximum depth of 135 cm below ground level (Whibley and Symon 1992).

The Western Myall is found mainly in shallow uniform calcareous soils (Groves 1994). The Mulga and the Western Myall are known to avoid saline water sources and are likely to rely on their extensive surface lateral root systems which would access pore water in the top metres of the soil profile (N Reid [CSIRO] 2010, pers. comm., 15 June). Therefore, the root systems of the local Acacia woodlands would not reach the shallowest groundwater at about 50 m below ground.

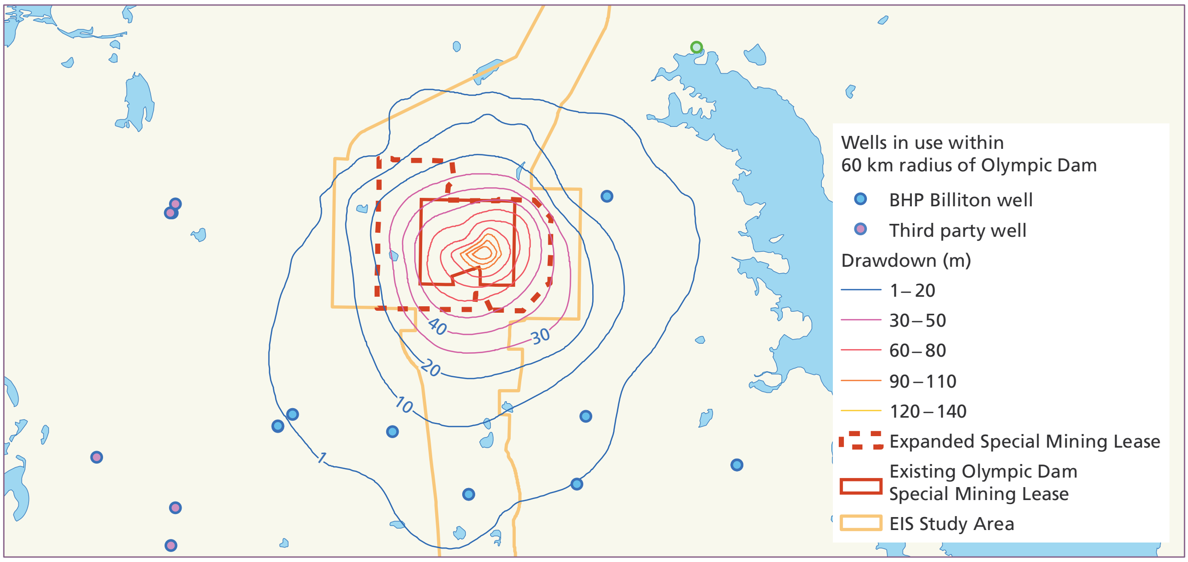
One submission questioned whether *Eriocaulon carsonii* (a Great Artesian Basin endemic plant) would be affected by reduced flows or potential reinjection in and around Hermit Hill and Wellfield A. From the detailed assessment of groundwater drawdown undertaken for the Draft EIS, Section 12.7 concluded that drawdown due to the open pit and saline water supply would not affect the northern boundary of Stuart Shelf and therefore would not affect the artesian aquifers of the GAB and the corresponding springs. The extent of predicted drawdown to the north towards the GAB is constrained by the groundwater divide and low-permeability Proterozoic rocks of the Torrens Hinge Zone (see Sections 12.1.1 and 12.2.1, Appendices F1 and F4 of the Supplementary EIS). The proposed expansion does not seek any additional extraction of water from the GAB that is not already approved by the Australian and South Australian governments.



Year 2017



Year 2050



Year 2550

Figure 12.29 Predicted drawdown in the Tent Hill (ZWC) aquifer for the Draft EIS

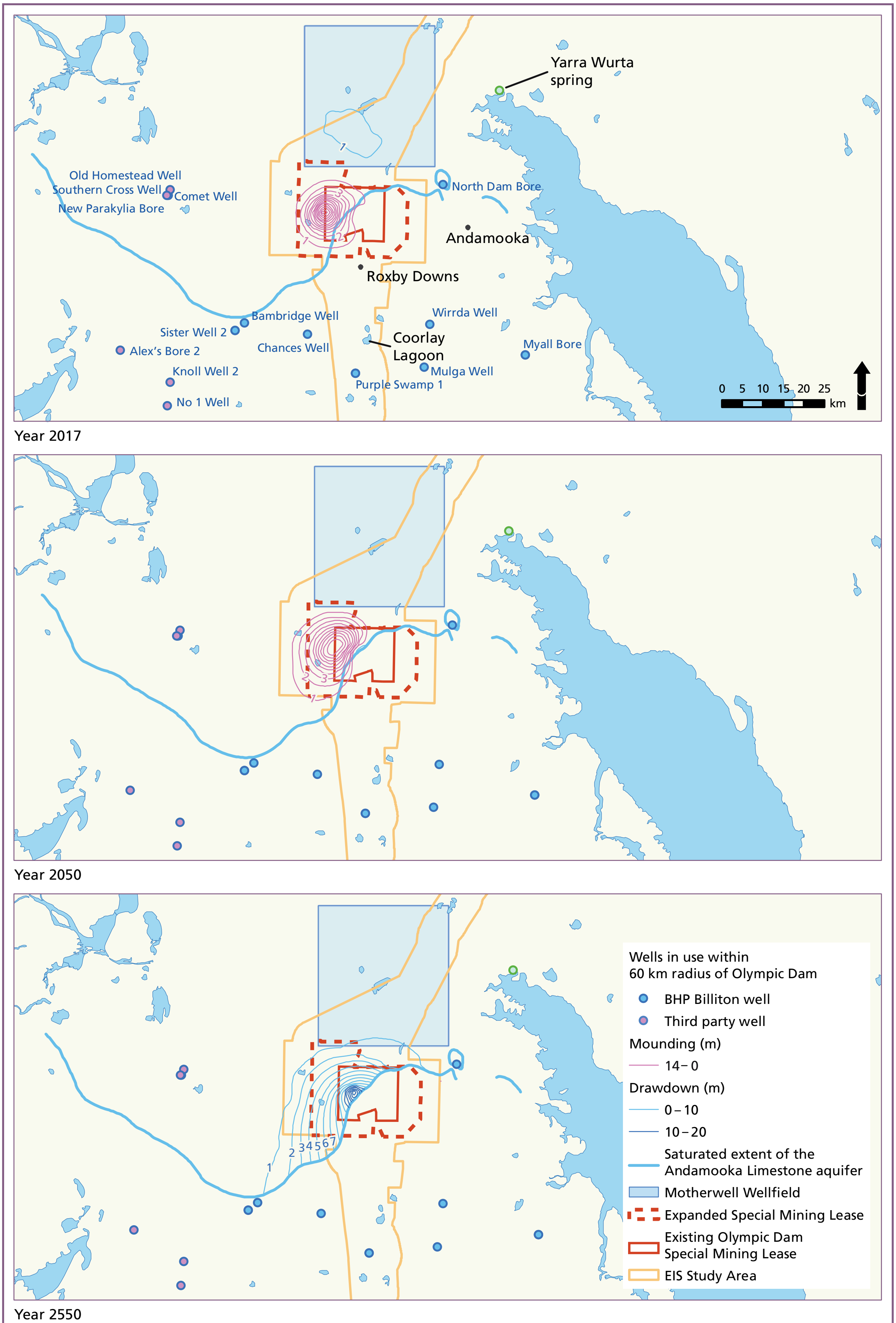


Figure 12.30 Predicted drawdown and mounding in the Andamooka Limestone (ZAL) aquifer for the Draft EIS

12.3 TAILINGS STORAGE FACILITY

12.3.1 GEOCHEMICAL MODELLING

Issue:

Justification and clarification was sought on the geochemical and predictive modelling of potential seepage from the tailings storage facility (TSF): in particular, substantiation that the existing TSF represents the proposed TSF, composition of leachate, and the effectiveness of limestone to neutralise it. It was also requested that the modelling details for the assessment be provided to government.

Submissions: 1, 2 and 13

Response:

A supplementary investigation of the tailings geochemistry, water quality of the percolate from the TSF and the interaction between the percolate and soils and rock underlying the existing and proposed TSF areas was undertaken by SRK. The investigation is presented as Appendix F5 of the Supplementary EIS. That assessment was undertaken to support the conceptual model that was presented in the Draft EIS and to address submissions received on the Draft EIS.

The investigation included a field sampling program to obtain representative samples of the tailings deposited in the TSF to date and establishing piezometers to allow porewater and groundwater monitoring. A laboratory testing program was undertaken to characterise samples and extracted porewater, and to examine water-rock interactions. Finally, predictive geochemical modelling was undertaken to assess future behaviour of the system.

The findings from the assessment indicated that the current tailings are low in sulphide mineral content. The total sulphur contents of the bulk of the tailings range up to 2.39% (1.31% average), the sulphate up to 1.98% (0.98% average) and the sulphide sulphur range only up to 0.64% (0.34% average). Mineralogical assessment confirmed these outcomes and chalcopyrite was detected in only one sample. The corresponding acid generation potential (AP) values range up to about 19.7 kgH_2SO_4/t, with an average of 10.6 kgH_2SO_4/t and a median value of 10.3 kgH_2SO_4/t. These estimates are based on the assumption that all of the sulphide would react, and that pyrite is the only sulphide mineral present. Therefore the actual potential to generate acid would be lower than indicated.

The processing of the ore involves an oxidative acid leach and results in acidic water being discharged with the tailings. The supplemental investigations indicated that process water and the porewater in the tailings has an acidity of up to 70 g/L as $CaCO_3$ equivalent. The acidity present in the porewater of the tailings therefore exceeds the potential acidity that may be generated from sulphide mineralisation and has to be considered in the overall acid base balance calculations.

The same conclusions are valid for the tailings that would be produced in the future as they are expected to remain unchanged from the current tailings. The reasons for this are as follows:

- processing of the ore for copper and uranium recovery would remain unchanged (thus the process water properties would fluctuate within the same range as currently observed)
- ore from the open pit operation would be less selective than underground mining and therefore the proportion of non-mineralised material that would be present in the ore is likely to increase, which means that the future tailings are likely to be less mineralised than the current tailings.

Consequently, the existing TSF represents an excellent analogue for the larger TSF that would be developed in time, and the observed interactions between percolate from the existing TSF and the underlying strata can be used to infer the future interaction that may occur. The supplemental investigation (see Appendix F5 of the Supplementary EIS) evaluated first the acid neutralisation and then the controls on solute mobility.

An overall acidity balance was completed to assess the total load of acid that could accumulate in the tailings and therefore could be released in the future. The total acidity would comprise the acidity contained in the process water and the acidity that may be generated from the residual sulphide minerals present in the tailings.

The process water balance as was described in Appendix F1 of the Draft EIS indicated that the total process water inflow to the TSF on average would be about 149,900 m^3/d, of which about 8,300 m^3/d would be decanted from the system. The net inflow into the TSF is therefore about 136,600 m^3/d. Although some of this water would evaporate, the associated acidity would accumulate within the TSF. Characterisation of the process water indicates an acidity concentration of about 70 g/L as $CaCO_3$ equivalent (or about 68.7 g/L as H_2SO_4). At this concentration, over the life of the TSF, the total acidity that would accumulate in the tailings when deposited to a maximum height of 65 m is estimated to be about 3,880 kg H_2SO_4/m^2, assuming all of the acidity is mobile.

The residual sulphide minerals may contribute an additional 900 kgH_2SO_4/m^2 of acidity for an overall TSF height of 65 m (note that the test results indicated a lower acid generation potential for the tailings solids than had been assumed in the Draft EIS). The combined average acidity loading from the TSF is therefore estimated to be about 4,780 kgH_2SO_4/m^2.

Field observations together with the supplemental investigation showed that acidity in the percolate from the TSF would be neutralised by the carbonate minerals present in the underlying sediments. The assessment also confirmed that the Andamooka Limestone would contribute to the neutralisation process.

The depth to which the acid front may advance below the TSF before the acidity from the porewater and the tailings solids would be neutralised will depend on the neutralising capacity of the sediments. The measured acid neutralising capacities (ANC) for the sediments ranges from negligible to a maximum of 959 kgH_2SO_4/t. The median ANC for the sediments is about 50 kgH_2SO_4/t. This means that complete neutralisation may occur within as little as about 3 to 4 m below the TSF, but would be about 50 m (at the median ANC value). The sediment depth, however, varies from a few metres to in excess of 15 m. This means that the acid front in some areas could eventually penetrate through the soils/sediments and reach the Andamooka Limestone formation.

The Andamooka Limestone formation comprises predominantly dolomite. The supplemental testing verified that the Andamooka Limestone provides readily available neutralisation capacity and the ANC values range from about 120 to about 930 kgH_2SO_4/t, with an average of about 480 kgH_2SO_4/t. In order to assess the availability of the neutralising capacity present in the Andamooka Limestone materials, the acid base characteristic curve (ABCC) was determined. The ABCC results show significant pH buffering capacity down to a pH of 6 (typical of dolomite), with an available neutralisation capacity of about 530 to 550 kgH_2SO_4/t (while buffering to a pH in excess of 6).

This means that, discounting any neutralisation that may occur in the sediments, sufficient available neutralisation capacity is available within the first 3 m of the first contact with the Andamooka Limestone. The average thickness of the Andamooka Limestone formation is about 60 m across the entire area of the existing and proposed TSF areas.

Field observations and test results further indicated that neutralisation of the percolate leads to the formation or precipitation of secondary mineral phases. These phases would effectively capture applicable solutes and limit their concentrations in the percolate to that in equilibrium with the phases. Precipitation reactions coincide with the change from acid to neutral pH conditions. Sorption of solutes was also identified as a significant attenuation mechanism. Sorption reactions tend to coincide with neutral pH conditions. Although sorption delays or retards the migration of dissolved elements, it does not ultimately prevent 'breakthrough' (assuming the supply of the element from the source remains constant). However, considering that i) the acidity load in the TSF is finite, and, ii) there is sufficient neutralisation capacity in the upper few metres of the Andamooka Limestone to neutralise all of the acidity, breakthrough of attenuated solutes beyond the neutralisation zone is unlikely to occur.

The supplemental testing results show that significant attenuation of in particular Co, Cu, Pb, U, Th and Zn takes place in the sediments underlying the TSF due to the above mechanisms.

Geochemical modelling (PHREEQC) was undertaken to further examine measured porewater and experimental solution chemistries and verify potential solubility controls. The results for aluminium indicated most neutralised solution concentrations to be controlled by oxyhydroxide phases (boehmite or diaspore). In the case of iron, solubility is likely controlled by a combination of jarosite in advance of neutralisation and by ferrihydrite after neutralisation (i.e. in the near-neutral to alkaline pH range). Uranium solubility is shown to be likely to be controlled by soddyite or uranyl hydroxides (schoepite). Other minerals and mineral groups were found to be either close to equilibrium, or supersaturated, included gypsum ($CaSO_4{:}2H_2O$), barite ($BaSO_4$), celestite ($SrSO_4$) molybdates, arsenates, chromates and uranates. Native copper (Cu) and cuprite (Cu_2O) metal-bearing carbonates and hydrated carbonates – malachite ($Cu_2CO_3(OH)_2$), rhodocrosite ($MnCO_3$) – may also be potential solubility controlling phases.

The potential water quality that may develop in the aquifer was estimated from the test results obtained for contact and column tests that yielded pH values in excess of 6. The results are summarised in Table 12.8 (note that the concentration units for cadmium (Cd) reported in the Draft EIS for the mound and the regional water quality monitoring results were incorrectly reported as mg/L – it should have been reported as µg/L). The maximum concentrations reported in the table tended to be associated with the low end of the pH scale (i.e. 6.0).

The water quality in the mound would be expected to transition from the minimum concentrations through to the average concentrations and may reach the maximum (considered an upper bound). After the peak concentrations are reached the water quality would be expected to transition back to the average and then the low end of the range as the acidity loadings from the TSF were depleted. Therefore, in general most solute concentrations would not be expected to change much beyond those currently observed in the groundwater mound beneath the TSF (i.e. remain in the range observed in the groundwater mound). Although the maximum concentration for uranium as indicated in Table 12.10 is about 11 mg/L, test results may not represent equilibrium conditions and a predicted equilibrium concentration of about 5 mg/L at a pH of about 6 would be considered more likely to eventuate. More typically, concentrations of 0.7 mg/L or less at a pH of about 6.5 would be expected (as indicated by speciation modelling).

Table 12.8 Summary of estimated aquifer concentrations (post-neutralisation)

Parameter	Units	Concentration range		
		Minimum	Mean	Maximum
pH		6.1	6.9	8
Eh	mV	81	323	495
EC	mS/cm	3	15.9	41.7
Cl	mg/L	83	3,155	12,500
F	mg/L	1.7	7.7	10.9
SO_4^{2-}	mg/L	1,920	4,726	12,200
Nitrate as N	mg/L	1.2	7.3	10.4
Bicarbonate alkalinity as $CaCO_3$	mg/L	100	1,160	2,100
Na	mg/L	297	2,786	9,330
K	mg/L	3	192	780
Mg	mg/L	26	423	1,010
Ca	mg/L	490	592	807
Ag	mg/L	<0.01	<0.01	<0.01
Al	mg/L	<0.01	2.48	12
As	mg/L	<0.01	<0.01	0.004
B	mg/L	1.4	9.8	33
Ba	mg/L	0.006	0.014	0.026
Be	mg/L	<0.01	<0.01	<0.01
Bi	mg/L	<0.01	<0.01	<0.01
Cd	mg/L	<0.002	<0.002	0.0044
Ce	mg/L	<0.001	0.057	0.281
Co	mg/L	<0.001	7.3	39.4
Cr	mg/L	<0.01	0.02	0.11
Cu	mg/L	<0.01	0.61	2.69
Fe	mg/L	0.11	1,994	9,170
Hg	mg/L	<0.0001	<0.0001	<0.0001
Li	mg/L	0.009	0.834	3.78
Mn	mg/L	<0.001	20	106
Mo	mg/L	<0.01	0.020	0.074
Ni	mg/L	<0.001	0.514	2.81
Pb	mg/L	<0.01	<0.01	0.013
Re	mg/L	<0.001	0.002	0.017
Sb	mg/L	<0.01	<0.01	0.0034
Se	mg/L	<0.01	0.03	0.12
Si	mg/L	0.20	6.36	35
Sn	mg/L	<0.01	<0.01	<0.01
Sr	mg/L	2.27	7.76	24
Th	mg/L	<0.01	<0.01	<0.01
Ti	mg/L	<0.1	<0.1	<0.1
Tl	mg/L	<0.005	<0.005	0.023
U	mg/L	0.002	2.2	11
V	mg/L	<0.1	<0.1	<0.1
W	mg/L	<0.01	<0.01	<0.01
Y	mg/L	<0.001	0.026	0.137
Zn	mg/L	<0.005	0.94	4.79

Note: Maximum values tended to be associated with a single contact test result at a pH of 6.

With regard to provision of the model, these models are particularly complex and therefore BHP Billiton and the specialist consultants working on their behalf extend an invitation to the government to view the model in operation and discuss any issues or concerns.

12.3.2 SEEPAGE

Issue:

Clarification was sought on several aspects of the design of the tailings storage facility (TSF) which impact on potential seepage from the TSF, namely:

- definition of seepage rate from the existing TSF and the potential for lateral movement into surrounding swales and variability in vertical migration
- effectiveness of the TSF construction when sediments vary in thickness from zero to 30 m
- clarification of seepage rate, seepage volume, evaporation rate and basis for determination of infiltration rate
- determination of the location of the phreatic surface
- clarification of climate change incorporation
- definition of how seepage is controlled and managed to prevent further groundwater contamination
- comparison of TSF engineering to other mines, including modelling a fully lined TSF, providing an estimate of benefit in improved environmental protection, then a comparison to its costs.

Submissions: 1, 2, 8, 10, 11, 12, 13, 27, 35, 37, 40, 44, 92, 112, 141, 147, 161, 185, 206, 208, 216, 233, 247, 254, 255, 265, 278, 287, 290, 306, 309, 315, 335, 351, 363, 369, 379, 389 and 391

Response:

The response to these issues is provided in Section 5.3 of the Supplementary EIS as they are related to the design features of the TSF that influence potential seepage.

Issue:

Clarification was sought on several aspects of potential seepage from the TSF, namely:

- clarification on how capping the TSF would reduce seepage
- reassessment of acidity balance
- substantiation of self-neutralisation capabilities
- clarification on an attenuation zone.

Submissions: 1 and 2

Response:

The seepage rate from the TSF would be dictated by the phase of the operation of the TSF or, more specifically, the TSF cell. During the active operational period, water would continuously be deposited with the tailings and the tailings would be saturated. This would lead to high hydraulic heads and porewater displacement rates would be dictated by the saturated permeability of the tailings and the hydraulic head. In comparison to other phases, the rate of seepage would be high. Seepage modelling showed that the rate of seepage across the footprint of an active cell would range from about 146 mm/y (or 4 m^3/ha/d) during the first 18 months to two years of operation to about 36 mm/y (or about 1 m^3/ha/d) in the later part of the operation.

Once active deposition ceased, no additional water would be added to the facility other than natural rainfall. Any ponded water would either evaporate or infiltrate to the tailings. Recharge by natural rainfall would be expected to be very small due to the high evaporation rates and the low permeability of the tailings. The tailings porewater would drain down naturally and the tailings moisture content would transition from saturated to a field moisture content that may be as low as 10% or less depending on the properties of the tailings. This means that the seepage rate would transition from a relatively high rate (of about 36 mm/y) to a low rate that would equal the net recharge rate from rainfall. Placement of the waste rock cover after closure would then dictate the rate of infiltration, which would then determine the rate of percolation. Infiltration modelling for the RSF (see Appendix F7 of the

Supplementary EIS) indicated that the rate of recharge through the waste rock cover may range from 1–4% of mean annual rainfall, or about 2 mm/y to about 7 mm/y.

As the reassessment of the acidity balance forms part of the supplemental geochemical assessment, it is discussed above in Section 12.3.1 and in Appendix F5 of the Supplementary EIS. As a further clarification it is noted that, as discussed above, the deposited tailings themselves do not have any neutralisation capacity; rather, the neutralisation capacity is provided by the underlying soils and sediments and the large Andamooka Limestone formation that contain the carbonate minerals that neutralise the percolate. Over time the acidic porewater contained in the tailings at the time of deposition would drain down, and be displaced by infiltrating rainwater. During that time oxidation of the residual sulphide minerals also would progress until depleted. In the very long term the acidity generated from the sulphide minerals also would be displaced and once all sources of acidity had been depleted the tailings would naturally return to neutral pH conditions.

The presence of the Andamooka Limestone formation is of primary importance to the neutralisation of the percolate from the TSF. As discussed in Chapter 12 of the Draft EIS, the Andamooka Limestone formation covers a continuous area of about 14,000 km^2, extending from 50 km south and 80 km north-west of Olympic Dam – well beyond the area of the proposed TSF. In the immediate vicinity of the proposed TSF, the Andamooka Limestone formation is approximately 50 to 70 m thick. In addition, the underlying soils and soils sampled from within the footprint of TSF Cell 5 (approved for the existing operation) indicate that sediment conditions are very similar to those observed below the existing TSF cells (Cells 1 to 4). Therefore, the geological conditions are not expected to vary within the footprint of the proposed TSF.

Further clarification was requested relating to the following statement contained in Appendix F1 of the Draft EIS:

> After closure (100 to 500 years), the perched TSF mound and the groundwater mound begin to recede as a result of the shutting down of the seepage by the closure capping. Indications are that the recession of the tailings mound would be quite rapid (Draft EIS, Appendix K6). During this period, contained seepage water is neutralised further, thereby reducing the size of the 'attenuation' zone.

The third sentence of the statement is not correct. While the mound receded the seepage from the TSF would still percolate through the sediments and then into the Andamooka Limestone. The neutralisation zone would remain the same (i.e. below the acid front, wherever that may be at the time). The progress of the acid front would, however, be slowed significantly and the width of the front would be narrower due to the lower flow rates, as discussed previously in this section.

Issue:

Clarification was sought about the seepage beneath the tailings storage facility (TSF), specifically:

- how long would TSF seepage occur
- what impacts would the seepage have on the surrounding environment, including groundwater levels beneath the TSF, groundwater quality, and subsequent impact to humans and wildlife
- how long would the surrounding environment be affected.

Submissions: 27, 85, 92, 98, 112, 136, 146, 287, 290, 343 and 361

Response:

Considerable attention was afforded this issue in the assessment and presentation of the groundwater chapter of the Draft EIS (refer in particular to Sections 12.6, 12.7 and Appendix K4). The geochemical investigation is further supported by supplemental works provided in Appendix F5 of the Supplementary EIS.

Process tailings from the existing and expanded metallurgical plants would be disposed of in a new TSF. Although improvements to the design and construction of the TSF would reduce the rate of seepage per unit area, seepage would occur over a greater area due to the increased scale of the facility, and the total seepage rate would be higher than for the existing TSF. Seepage from the TSF is expected to be higher in the first two years following cell commissioning, after which tailings would consolidate and form a low permeability base. Then at post-closure the TSF cells would be decommissioned and capped. As no more tailings would be added to the cells the tailings would drain down over time and would reach steady state. The percolation rate from the base of the TSF would decrease over time until drain down was complete and long-term steady state percolation rates would become equal to the net recharge from rainfall. While percolation rates would continue indefinitely, the solute concentrations in the percolates would decrease over time as the soluble components were depleted from the tailings. Solute concentrations in the percolate may start to decrease in about 800 years, but may persist for as long as 10,000 years (see Appendix F5 of the Supplementary EIS), depending on the rate of infiltration through the final cover, and the actual proportion of secondary minerals that may be available for dissolution. Section 5.3 of the Supplementary EIS provides further technical detail regarding timeframes and volumes of seepage from the TSF.

As reported in Section 12.6.1 of the Draft EIS, seepage from the TSF would cause a groundwater mound in the Andamooka Limestone aquifer to form beneath the facility during mine operation. The mound is expected to rise to a maximum of 14 m above existing water levels (around 35 m below ground) during the first 10 years of mining and then gradually subside as seepage rates decrease. Post-closure, the influence of the open pit as a regional drawdown sink would start to dominate and the mound under the TSF would dissipate or drain away.

The updated numerical groundwater model detailed in Appendix F4, and described in Section 12.2 above, predicts mounding beneath the TSF to be between 6 and 8 m. This is within the maximum range predicted in the Draft EIS.

Section 12.6.2 and Appendix K4 of the Draft EIS discussed the changes to groundwater quality and the fate of contaminants in detail. Groundwater chemistry under the existing TSF was investigated as a comparison with the seepage from the proposed TSF into the same local environment. The investigation showed that the groundwater chemistry under the existing TSF, after seeping for around 25 years, is stable and is characterised by a slight local increase in uranium. Geochemical investigations, as provided in Appendix K4 of the Draft EIS and further supported in Appendix F5 of the Supplementary EIS, have shown that the calcareous clays and Andamooka Limestone beneath the TSF have been demonstrated to, and are expected to continue to, attenuate most metals in the seepage and neutralise the acidic percolate seeping from the TSF. As concluded in Appendix F5, after around 25 years of operation the acid front is neutralised in depths of less than 1 m, on average, of the soils and sediments that immediately underlie the TSF.

As was detailed in Section 12.6.2 and Appendix K6 of the Draft EIS, the maximum distance that solutes could move away from the facilities is 500 to 1,500 m from the TSF, which would occur between 100 and 500 years post-closure, before the effect of the drawdown from the open pit dominated and regional groundwater flowed towards the pit. Simulation of seepage movement in groundwater shows that, in the longer term, drawdown caused by the open pit would effectively capture contaminants that entered the groundwater system from the TSF.

The groundwater mound or seepage from the TSF would not adversely affect humans or wildlife for the following reasons:

- the nearest sensitive receptor (pastoral well) is around 55 km up hydraulic gradient and therefore too far away to be impacted
- the nearest groundwater-dependent ecosystem is at Lake Torrens, around 45 km from Olympic Dam and therefore too far away to be impacted
- the groundwater beneath Olympic Dam is highly saline and has naturally high concentrations of metals, which make it unsuitable for domestic (human) or stock use
- the groundwater quality would not adversely affect native flora and fauna because the groundwater would be well below the ground surface and well below the depths of tree roots.

Section 12.6.2 of the Supplementary EIS summarises that based on current modelling, seepage from the TSF is not expected to pose an environmental risk. Nevertheless, BHP Billiton Group standards require that the designs of water containment and tailings storage facilities aim to minimise seepage. Control measures have been considered in the design of the TSF. The existing groundwater monitoring program would be extended to monitor effects on groundwater quality from seepage and would be compared against predicted solute movement. The data would be assessed regularly and incorporated into the BHP Billiton Environmental Management Program (EM Program).

12.4 ROCK STORAGE FACILITY

12.4.1 GEOCHEMICAL MODELLING

Issue:

Justification and clarification was sought on the geochemical modelling and potential seepage from the rock storage facility (RSF). In particular:

- justification of the assessment of seepage impacts on the basis of geochemical testing on 19 samples
- justification of the proposed thickness of the basal limestone layer/sand dune material
- clarification on how the RSF design and modelling confirm that seepage is minimised
- explanation of the potential for acid generation based on the placement of inert material
- clarification on the implications of acid generation from the low-grade ore stockpile
- clarification on clay alteration description
- provision of ENSR/AECOM RSF geochemistry report.

Submissions: 1, 2, 13, 27 and 173

Response:

The characterisation program for the assessment of the geochemistry of the waste rock generally is undertaken in stages, with the first step typically directed at determining the abundance of sulphur, more specifically the sulphide mineral content of the waste materials, and generally a large number of samples are analysed. An assessment of acid generation potential only is conservative because it neglects the potential benefits of acid neutralisation by the acid neutralisation capacity (ANC) of the rock. This initial assessment provides an indication of the overall risk of acid generation, which then forms the basis for completing more detailed assessments such as leach extractions and kinetic testing as considered appropriate following the risk analysis. Another important consideration in defining the risk is an assessment of the risk of acid migration from the site, the potential impacts on receptors and the effectiveness of the controls that would be put in place.

Because the Olympic Dam mine has been operational for around 25 years, there exists a large database of resource drilling and analysis. As stated in the Draft EIS, about 2.2 million samples exist in this database that were analysed for at least sulphur. Therefore, it is possible to assess the overall risk of acid generation from these results. Although not all of the samples represent waste, the data can be used to assess the mineralisation and how it varies across the deposit. Removing the samples that represent ore and low-grade ore, in excess of 68,000 analyses were available for characterising the basement rock. The results indicated that the maximum potential acid generation (MPA) for the basement rocks in general is low, with a mass weighted average MPA of about 11 kgH_2SO_4/t, as summarised in Table 12.9.

Table 12.9 Summary of sulphide, acid generation potential and acid neutralisation potential

Mine rock lithology	Mass (Mt)	Proportion of RSF (wt%)	# of S assays	Average S(T)	MPA (H_2SO_4/t)	# of ANC assays	ANC (H_2SO_4/t)
EVB – Brecciated/ fragmented igneous dyke (unclassified)	45	0.40%	5	0.06	1.8	–	–
EVD – Igneous dyke	14	0.12%	–	–		–	–
GRN – Granite	62	0.55%	30,000	0.13	4.0	–	–
GRNB – Granite >90%, Hematite <10%	1,410	12.54%	11,921	0.22	6.7	–	–
GRNH – Granite 70–90%, Hematite 10–30%	393	3.49%	5,926	0.31	9.5	–	–
GRNL – Granite 40–70%, Hematite 30–60%	100	0.89%	5,389	0.45	13.8	–	–
HEM – Granite <10%, Hematite >90%	58	0.52%	1,345	0.51	15.6	–	–
HEMH – Granite 10–40%, Hematite 60–90%	103	0.92%	2,992	0.66	20.2	–	–
HEMQ – Hematite >90% + quartz	859	7.64%	10,920	0.73	22.3	–	–
HEMV – Hematite >volcanic components	152	1.35%	3	0.02	0.6	–	–
KHEMQ – Laminated hematite-quartz sandstone/siltstone	280	2.49%	53	0.37	11.3	–	–
ZAL – Andamooka Limestone	1,070	9.52%	95	0.12	3.7	95	481
ZRS – Cainozoic Sands and clays	427	3.80%	–	0.12[a]	3.7	–	-[b]
ZWAR – Arcoona Quartzite – Red	2,910	25.88%	391	0.04	1.2	391	13
ZWAW – Arcoona Quartzite – White	675	6.00%	81	0.05	1.5	81	20
ZWC – Corraberra Sandstone	289	2.57%	77	0.05	1.5	77	24
ZWP – Pebble Conglomerate	21	0.19%	13	0.26	8.0	13	90
ZWT – Tregolana Shale	1,500	13.34%	469	0.08	2.4	469	38
ZWT trans – Tregolana Shale transitional	877	7.80%	–	0.08[c]	2.4	–	38[c]
TOTAL	**11,245**	**100.00%**	69,680	–	–	1126	–
Mass weighted average – all materials	–	–	–	0.17	5.2[d]	–	59.6[e]
Mass weighted average – basement sequence	–	–	–	0.38	11.6[d]	–	–
Mass weighted average – cover sequence	–	–	–	0.07	2.1[d]	–	85.6

Notes: (a) The total sulphur content of the ZRS – Cainozoic Sands and clays is assumed to be similar to that of the Andamooka Limestone.
(b) The ANC of the sands and clays underlying the TSF area is variable (see Appendix F5 of the SEIS), ranging from about 2 kg H_2SO_4/t for sand to 139 kg H_2SO_4/t for calcareous clays – conservatively the ANC is assumed to be negligible.
(c) The sulphur content and ANC values for the "ZWT trans – Tregolana Shale transitional" lithological unit is assumed to be similar to those of the "ZWT – Tregolana Shale" unit.
(d) Average AP = mass weighted average S(T) * 30.6 H_2SO_4/t.
(e) Lower bound or minimum ANC since any potential contribution by the basement rocks has conservatively been disregarded.

The highest average maximum acid generation potential is indicated for the HEMQ (hematite >90% + quartz) at about 22.3 kgH_2SO_4/t.

Not counting the acid neutralisation capacity (ANC) of these rocks, clearly the overall potential for acid generation is low. The mass weighted average sulphur content of all the rock that would be placed in the RSF is only 0.17%. Since, generally, waste rock with a sulphide content of 0.20% or less is considered non-acid forming (irrespective of the ANC) the overall risk of acid generation is very low. In the light of these observations alone the need for additional testing would be considered to be minimal.

As was discussed in Section 5.4.6 of the Draft EIS, the RSF would be constructed with a base layer of about 10 m of overburden rock to provide a stable foundation. This layer of rock would contain an average acid neutralising capacity of about 85.6 kgH_2SO_4/t. At its maximum height the RSF would be 150 m tall. The maximum height of basement sequence rocks above this layer of overburden rock would therefore be 140 m. At an average sulphur content of 0.38%, or a maximum acid generation potential of about 12 kgH_2SO_4/t, (the total acid loading that can occur from this rock, assuming that i) all of the sulphur is present as sulphide (pyrite), ii) all the sulphide minerals would be oxidised and iii) all of the acidity released would be transported downwards) the average acid yield from the basement sequence rocks would be about 3,000 kgH_2SO_4/m^2. The 10 m of overburden rock underlying the RSF, at an average acid neutralising capacity of about 85.6 kgH_2SO_4/t, would neutralise about 1,520 kgH_2SO_4/m^2. Therefore the average potential acid release that may occur from the RSF would be in the order of 1,480 kgH_2SO_4/m^2. This net potential for acid release is less than half that estimated for the TSF of about 3,880 kgH_2SO_4/m^2 (see Section 12.3.1 of the Supplementary EIS). Similar to the TSF, the RSF is underlain by calcareous sediments up to 15 m thick, which is underlain by the Andamooka Limestone up to 60 m thick. As discussed for the TSF, the sediments and the Andamooka Limestone formation provide a large excess of neutralisation capacity so that even if acid was to be released from the RSF, it would be neutralised almost completely in the sediments and the balance in the Andamooka Limestone.

Finally, as discussed in the Draft EIS and supported by recent modelling (see Appendix F7 of the Supplementary EIS), the RSF would be located near the open pit and any percolate that was released from the RSF would be captured in the drawdown cone that would form around the open pit. Consequently, the percolate from the RSF would flow to the pit. Since the open pit would be a net sink for groundwater, any solutes released from the RSF would be captured and contained in the pit.

The risk of percolate released from the RSF to migrate away from the site is therefore considered to be very low.

Nevertheless, samples that generally represent each of the lithological units were subjected to detailed static and kinetic testing. While the kinetic tests conducted on the overburden samples were terminated early (mainly because they were clearly acid-consuming and unlikely to become acidic), the kinetic tests conducted on the basement lithologies were continued for 174 weeks. The properties of the samples tested are summarised in Table 12.10.

Of the samples tested, static testing indicated that four of these would clearly be net acid generating (tests OD_1, OD_3, OD_10 and OD_17) on the basis of the calculated net acid generation potential and because their ANC/MPA ratios are less than one. However, as reported in Appendix F6 of the Supplementary EIS, within the 174-week period none of the samples became acid, indicating that there is at least some ANC present in the basement rocks and that either the sulphide minerals are not very reactive or available for reaction. This indicates that the potential for acid generation in the basement rocks is overestimated by the sulphide analysis. A possible reason for this is that the sulphate sulphur analysis may not accurately reflect the actual sulphate content in the materials. This commonly occurs when alunite, barite and other insoluble sulphate minerals are present. While the sulphide estimate presented in the table has been corrected for the barite content of the sample, there may be other sulphate minerals that have not been accounted for.

Table 12.10 Summary of basement sequence kinetic tests sample properties

Test/Sample	ANC	Total S	Sulfide S	MPA	NAPP	NAG pH	NAG (pH 4.5)	NAG (Ph 7)
		%	%					
OD_1/148187 (HEMH)	1.3	1.2	1.14	34.9	33.6	6.1	<0.1	0.3
OD_2/148207 (GNRL)	2.1	0.17	0.04	1.2	–0.9	7	<0.1	<0.1
OD_3/148194 (HEM)	1.1	0.72	0.64	19.6	18.5	6.2	<0.1	0.3
OD_10/HEMQ	1.8	0.59	0.53	16.2	14.4	8.7	<0.1	<0.1
OD_11/HEMH	9.1	0.04	0.03	0.9	–8.2	7.2	<0.1	<0.1
OD_12/GRNH	4.5	0.38	0.28	8.6	4.1	5.5	<0.1	3.4
OD_13/GRNB	5.4	0.35	0.2	6.1	0.7	7.5	<0.1	<0.1
OD_14/GRNL	2.4	0.16	0.15	4.6	2.2	6.7	<0.1	0.1
OD_15/KASH	65.1	0.01	0	0	–65.1	9	<0.1	<0.1
OD_16/KASH laminated	7.8	0.04	0	0	–7.8	7.2	<0.1	<0.1
OD_17/VHEM	4.9	0.86	0.8	24.5	19.6	9.2	<0.1	<0.1
OD_18/KHEMQ–VASH	8.9	0.52	0.43	13.2	4.3	6.3	<0.1	<0.1
OD_19/CONGLO	81.7	1.03	0.95	29.1	–52.6	8.5	<0.1	<0.1

It is also noted that the NAG test results are in agreement with the kinetic test results in that none of the samples were shown to be potentially acid-forming, which further supports the conclusion that other insoluble sulphate mineral phases are present that are not being accounted for and hence the acid generation potential is being overestimated from the total sulphur analysis, even after it is corrected for the barite content.

In summary, although few in number, the samples used in the kinetic tests generally represented the range of sulphide content that would be expected to be encountered in the waste rock, and generally were low in ANC (with the four samples with the highest NAPP containing almost negligible ANC). Nevertheless, since none of the samples became acidic in the kinetic tests, the results indicate that:

- the sulphide content is likely overestimated or that the sulphide minerals are not readily available for reaction
- there is ANC available in the basement rocks that would neutralise some or all of the acidity that may be generated.

The results from the kinetic and NAG tests also indicate that potential for acid generation in the RSF would be lower than indicated by the more than 68,000 samples analysed for total sulphur.

In the event that acidity is generated in the RSF, the foundation layer would provide sufficient neutralising capacity to neutralise about 50% of the potential acidity loading. Furthermore, as discussed for the TSF, the underlying soils and sediments, together with the Andamooka Limestone formation, would provide more than enough neutralisation capacity to neutralise any acidity. The risk of acidity release therefore is very small. The available geochemical information is therefore considered adequate.

While the Draft EIS did not directly report any geochemical data for the low-grade ore that would be stockpiled at site, as for the waste rock, the properties for the low-grade ore can be drawn directly from the site exploration database. A summary of the analytical results for basement rocks that would be classified as low-grade ore is provided in Table 12.11, based on approximately 37,000 samples submitted for sulphur analysis.

As shown, the range of acid generation potential is only marginally higher than that indicated for the corresponding waste rock units. On average, the conclusion with respect to the risk for acid generation and acid release described above for the RSF also applies to the low-grade ore stockpile, in the event it remained in place and was not processed by the end of the life-of-mine.

Table 12.11 Summary of low-grade ore analyses

Parameter	Units	Statistic	Lithological unit						
			GRN	GRNB	GRNH	GRNL	HEMH	HEM	HEMQ
Au	ppm	Mean	0.1	0.19	0.37	0.51	0.5	0.35	0.52
		Count	16,921	20,067	5,014	3,201	1,399	1,462	763
Cu	%	Mean	0.33	0.34	0.35	0.35	0.34	0.34	0.3
		Count	16,937	20,138	5,032	3,204	1,399	1,463	770
U_3O_8	ppm	Mean	130	167	202	215	250	305	248
		Count	16,937	20,023	5,032	3,204	1,399	1,463	762
Ag	ppm	Mean	0.65	0.81	0.84	1.25	1.58	1.69	2.75
		Count	16,332	14,539	4,846	3,039	1,366	1,451	449
Ba	%	Mean	0.33	0.39	0.67	1.46	1.85	1.35	2.21
		Count	16,873	15,293	4,893	3,085	1,376	1,457	447
S	%	Mean	0.29	0.51	0.77	1.00	1.29	1.17	0.84
		Count	15,999	11,473	4,178	2,644	1,181	1,272	224
CO_2	%	Mean	0.94	0.91	1.36	1.56	1.51	0.91	0.78
		Count	16,610	14,289	4,810	3,001	1,350	1,452	420
Fe	%	Mean	5.31	9.33	18.53	31.53	44.08	55.36	39.46
		Count	16,885	12,260	4,541	2,698	1,104	1,253	68
Al	%	Mean	6.94	6.44	5.24	3.6	2.16	1.37	2.62
		Count	16,099	10,525	4,029	2,499	1,029	1,150	66
Si	%	Mean	31.55	29.58	24.47	17.12	10.22	4.9	10.74
		Count	16,099	10,533	4,029	2,499	1,029	1,150	66
K	%	Mean	4.52	3.76	2.56	1.44	0.71	0.41	0
		Count	15,003	7,800	3,320	1,932	826	1,030	0
Ca	%	Mean	0.55	0.55	0.65	0.85	1	0.71	0
		Count	15,003	7,827	3,320	1,932	826	1,030	0
Mg	%	Mean	0.19	0.23	0.22	0.19	0.17	0.1	0
		Count	13,774	7,543	3,180	1,828	802	998	0
Mn	%	Mean	0.07	0.08	0.11	0.14	0.14	0.06	0.01
		Count	13,776	7,523	3,180	1,832	814	1,008	1
P	%	Mean	0.04	0.06	0.1	0.13	0.16	0.17	0
		Count	13,775	7,531	3,182	1,828	802	998	0
Ti	%	Mean	0.22	0.21	0.17	0.12	0.07	0.04	0
		Count	13,773	7,530	3,183	1,830	802	998	0
Co	ppm	Mean	148.59	99.4	118.35	148.64	188.55	194.94	419.27
		Count	14,598	8,737	3,725	2,042	877	1,102	13
Pb	ppm	Mean	254.21	176.04	107.58	104.56	86.48	95.33	72.28
		Count	14,596	8,736	3,725	2,041	877	1,102	13
Zn	ppm	Mean	83.02	80.83	94.86	78.38	73.71	67.98	69.51
		Count	14,596	8,748	3,732	2,041	877	1,102	14
La	%	Mean	0.05	0.07	0.1	0.15	0.17	0.12	0.21
		Count	16,681	15,192	4,883	3,081	1,371	1,456	445
Ce	%	Mean	0.08	0.11	0.15	0.21	0.24	0.18	0.31
		Count	16,681	15,194	4,882	3,079	1,369	1,456	444
Sulphide S*	%	Average	0.21	0.42	0.61	0.66	0.86	0.85	0.32
MPA	kgH_2SO_4/t	Average	6	13	19	20	26	26	10

Note: * Corrected for barite.

The statement that 'the clay minerals (illite and smectite) tend to weather to kaolinite' from Appendix K5 of the Draft EIS was questioned. This process was reported incorrectly. Rather, illite may weather to smectite, whereas montmerillonite tends to weather to kaolinite. Of significance, however, is not the transformation of the clays; rather that the clays are present in the soils and that they provide a high sorption capacity for the attenuation of metals.

In relation to the provision of the ENSR/AECOM report, the report was superseded by the geochemical assessment of the proposed RSF that was included as Appendix K5 to the Draft EIS. Subsequent to that assessment, further justification and clarification of the issues raised in the submissions relating to the geochemical assessment of the RSF are discussed in Section 12.4 of the Supplementary EIS.

12.4.2 ROCK STORAGE FACILITY WATER BALANCE

Issue:

Further explanation was sought on the basis for the determination of the rock storage facility (RSF) infiltration rates, together with a request for further modelling to confirm the predicted infiltration rates.

Submissions: 2 and 13

Response:

Modelling of surface infiltration to, and percolation from, the RSF has been completed to supplement the Draft EIS and is included as Appendix F7 of the Supplementary EIS. While the terms 'infiltration' and 'percolation' are used interchangeably in some literature, 'infiltration' of water through the soil surface is distinguished herein from the 'percolation' of water downwards through the soil profile. That distinction is very important in arid regions, where water that has penetrated the soil surface can subsequently be removed by a number of processes, so that 'percolation' can be much less than 'infiltration'. The term 'net percolation' is used to refer to the water that continues to move into the soil and ultimately reports to groundwater.

The infiltration modelling was completed on the basis of the local climate around Olympic Dam, as described in Chapter 8 of the Draft EIS. The lithological units that would be encountered as the open pit deepened would all be represented in the RSF, and would form the surface of the RSF in various proportions throughout the operational period of the RSF. These include:

- unconsolidated dune sands and clay pans that form the current soil surface
- several units of overburden rock types including Andamooka Limestone (ZAL), red Arcoona Quartzite (ZWAR), white Arcoona Quartzite (ZWAW), Tregolana Shale (ZWT), and Corraberra Sandstone (ZWC)
- basement rock types including granites (GRNB), with smaller amount of basement hematite (HEMQ) and hematitic granite (HEM).

At the end of operations the basement materials would be encapsulated with materials from the cover sequence, so that after closure the RSF surface would consist only of overburden sedimentary rocks.

Infiltration and net percolation would be most strongly influenced by the grain-size distribution of the surface materials. The RSF construction process would influence the physical properties of the material. Dumping the materials in 25 m lifts would sort them, with coarser boulders rolling further downhill and finer particles remaining near the lift surface. Abrasion and compaction by traffic would cause a further breakdown of the surficial material to finer grain sizes. The redistribution of fine particles by localised erosion can further affect surface material properties. The physical properties of the RSF surface would also be determined in part by the weathering behaviour of the exposed sedimentary rocks.

In an arid climate, many processes may affect precipitation that falls in a given area. For example, when light rain falls on a hot surface, some fraction of the precipitation evaporates almost immediately and this process continues until the surface cools. Another fraction of the initial precipitation is taken up in wetting the soil surfaces. The next fraction of the precipitation is 'pulled' into soil pores by capillary effects, or capillary suction. Very dry soils can take several per cent moisture by weight into capillary storage before any flow is possible. If the rainfall continues with sufficient intensity, water will begin to fill the larger soil pores and infiltrate the soil surface. Recent work has shown that, depending on the rainfall intensity and soil structure, the flow type can range from unsaturated flow through the soil matrix to channelised flow through open 'macropores' (e.g. Nichol 2002). If rainfall continues at a rate that exceeds the initial infiltration capacity of the soil, small puddles or surface ponding may develop. Depending on the surface slope and texture, the puddles may need to deepen before they are sufficiently continuous to flow laterally as surface overflow. If they reach the surrounding environment before being trapped or infiltrating, they become run-off.

The water that infiltrates the surface is subject to adhesion and capillary effects that act to hold water in the soil; the effect is greater when the soil is drier. Therefore, the initial infiltration from a precipitation event is captured within the soil, and downward percolation only becomes significant once the soil gets wetter. These effects are also strongly dependent on the soil grain size and fabric. Finer-grained soils tend to retain more water. In theory, the size distribution of a soil can be used to predict its soil water characteristic curve (SWCC). The ability of a soil to allow flow also varies with the water content. Wetter soils tend to have more interconnected water channels and therefore exhibit a greater hydraulic conductivity.

Some of the water that is retained by the soil will evaporate. Evaporation from soil surface is normally considered as a three-phase process. In Phase 1 evaporation, water retained on the soil surface or in near-surface pores evaporates directly at rates that approach the maximum potential rate. The Phase 2 evaporation begins once the surface water is gone. It requires water to be transported upwards to the surface from deeper in the soil profile. Matric suction provides the driving force. The Phase 2 evaporation slows over time, as the water needs to be drawn from increasing depths. Nonetheless, Phase 2 evaporation is very significant in arid regions, and is generally the main reason why net percolation is significantly less than infiltration. In Phase 3 evaporation, the water moves through the soil surface as a vapour only. It is generally only noticeable once the Phase 2 process has removed the mobile liquid water from the upper soil. Phase 3 evaporation can be significant in arid regions where there are long, dry periods between rain events. Water vapour would also be transported by thermal convection. At the scale of the Olympic Dam RSF and the relatively low moisture contents under consideration, thermal convection could be a significant mechanism of water removal. When vegetation is present, evapo-transpiration can also be significant. The sparse vegetation of the area suggests that evapo-transpiration would not be significant on the Olympic Dam RSF.

In general, water that flows deeper into the rock at a rate sufficient to saturate the material is thought to percolate through coarse channels, while unsaturated flows are thought to move downwards at a much slower rate through the finer-grained matrix. In an arid environment like Olympic Dam, the latter pattern is likely to be dominant.

Although there may not be sufficient water to generate lateral flows within the Olympic Dam RSF, the buried lift surfaces could be influential; any water that did percolate through rapid flow channels would have a high likelihood of being intercepted and attenuated by the buried lift surfaces.

If percolating water reaches the original ground surface, it can be further attenuated and directed laterally. For example, seeps are commonly observed along the toe of rock piles in wetter climates. The clay pan layers in the natural soil at Olympic Dam could theoretically have a similar effect on water percolating through the RSF. However, the flat gradients and the long distances to the middle of the RSF make it likely that any toe seeps would be highly localised, and play little role in the overall RSF water balance.

The soil water modelling, as presented as Appendix F7 of the Supplementary EIS, was performed using Hydrus-1D software Version 4.14 (Simunek et al. 2009). Hydrus-1D numerically solves Richard's equation for variably saturated water flow, subject to a range of user input material properties and boundary conditions. The model was developed as a cooperative effort of the U.S. Salinity Laboratory and the University of California at Riverside. It is one of the most widely used models for simulating unsaturated water flow in soils.

Four sets of material properties (Materials 1 to 4) were selected from literature and used to represent materials ranging from a clean gravel to a silty sand to represent the material types that would be encountered in the RSF. The material descriptions are as follows:

- Material 1 – Sandy gravel
- Material 2 – Gravel-sand-silt mixture
- Material 3 – Poorly graded gravel with sand
- Material 4 – Sandy silt.

In all cases the property sets were chosen to represent the gravel and finer sizes of the mine rock. Cobble and boulder-size materials are also common in mine rock piles, especially at depth, but do not contribute to the unsaturated water flow properties of the surface layer.

Since it is not possible to accurately predict how the rock excavation, hauling, deposition, compaction, abrasion and natural weathering would affect particle sizes of the RSF surface, a direct correspondence between the sedimentary rock units that would form the RSF surface and the material types used in the Hydrus-1D modelling cannot be drawn. However, it is likely that at least half of the rock units comprising the surface of the RSF at closure would be finer than Material 1 since:

- Tregolana Shale is expected to cover 25% of the RSF surface. It is also expected to constitute half of the mixed shale-sandstone unit that would cover another 14% of the RSF surface. The Tregolana Shale, if it weathered similarly to drill core samples, would include a significant percentage of fines.

- Corraberra Sandstone would comprise the remainder of the mixed shale-sandstone unit, and a unit of its own covering another 8% of the RSF surface. Material 2 represents sandstone taken from a mine rock pile in Canada, which showed a fines contents between 4% and 14%.
- The red and white quartzite units would cover 27% and 10%, respectively of the RSF surface. Quartzite can be quite resistant to weathering, but the geological descriptions indicate that they contain 5–15% shales.
- The remaining 16% of the RSF surface is expected to be covered with limestone rock.

Table 12.12 summarises the results as totals, over a 10-year simulation period, and as percentages. The 'net infiltration' values shown in Table 12.14 are the net water fluxes monitored at the soil surface (i.e. total infiltration minus evaporation). These values can go slightly negative over short periods, indicating a net removal of water from the material. However, the long-term percentages correspond closely to 'net percolation'.

Table 12.12 Summary of Hydrus-1D modelling results

	Material 1	Material 2	Material 3	Material 4
Description	**Sandy gravel**	**Gravel-sand-silt mixture**	**Poorly graded gravel with sand**	**Sandy silt**
10-year totals (mm)				
Precipitation	1,470	1,470	1,470	1,470
Evaporation	1,362	1,443	1,444	1,043
Run-off	0	0	0	414
Net infiltration	108	27	26	13
Percentage of total precipitation				
Evaporation	92.65%	98.16%	98.23%	70.95%
Run-off	0.00%	0.00%	0.00%	28.16%
Net infiltration	7.35%	1.84%	1.77%	0.89%

Sensitivity runs were also completed to assess the effect of large rainfall events. The results in Table 12.13 compare the net infiltration and run-off percentages from the base case runs with six-hour rainfall to the analogous results from the runs with all daily rainfall assumed to fall in only two hours (i.e. at much higher intensity). As shown, higher-intensity rainfall leads to greater amounts of infiltration and run-off.

Table 12.13 Summary of Hydrus-1D sensitivity analyses for rainfall intensity

	Material 1	Material 2	Material 3	Material 4
Description	**Sandy gravel**	**Gravel-sand-silt mixture**	**Poorly graded gravel with sand**	**Sandy silt**
Base case (six-hour rainfalls)				
Net infiltration	7.3%	1.8%	1.8%	0.9%
Run-off	0.0%	0.0%	0.0%	28%
High-intensity rainfall (two-hour rainfalls)				
Net infiltration	11%	3.2%	2.7%	0.4%
Run-off	0%	0%	0%	43%
100-year storm in Year 3				
Net infiltration	12%	5.1%	4.5%	0.4%
Run-off	1.4%	0.0%	0.0%	45%

The effect of adding a 100-year storm to Year 3 of the rainfall record was tested by a second set of sensitivity runs. The model predicted significant infiltration as an immediate result of the 100-year storm, but much of the infiltrating water was predicted to be stored and subsequently evaporated. As the last rows of Table 11.13 show, the 10-year model results showed only slight increases in overall infiltration.

For all of the runs reported above, the model allowed no ponding of water above the soil surface. In other words, any water that did not immediately infiltrate the surface was assumed to run-off. Even under that assumption, the model predicted no run-off for most of the material types.

However, the base-case Hydrus-1D runs did predict significant run-off for Material 4. Therefore, a set of sensitivity analyses was run, allowing up to 25 mm of water to accumulate on Material 4 prior to running off. The results are shown in Table 12.14 and indicate that the no ponding assumption has a significant effect on predicted run-off rates, but much less effect on net infiltration. The reason is that the water is stored in the fine-grained material and subsequently evaporated.

Table 12.14 Summary of Hydrus-1D sensitivity analyses for surface ponding

Material 4 sandy silt	Base-case rainfall intensity		High-intensity rainfall	
(all runs)	No ponding	With ponding	No ponding	With ponding
Net infiltration	0.9%	3.8%	0.4%	4.5%
Run-off	28%	3.7%	43%	5.5%

In summary, as a best current estimate, half of the RSF surface material would be expected to behave similarly to Material 2 or 3, and the other half similarly to Material 1. The resulting overall average percolation rate would be about 4.6% of precipitation. Taking into account water vapour removal, the net percolation would be in the order of 1–4% of mean annual precipitation.
The Hydrus-1D simulations and sensitivity analyses also showed that there are several opportunities to control infiltration and run-off, in the event that the material properties or rainfall intensities fall outside the range modelled. Should it be shown to be necessary in operation, the material size distribution of the RSF surface could be modified by placement of finer-grained materials to cover sections of the surface most at risk, or additional trafficking and/or purposeful compaction of coarse materials to reduce grain sizes and increase the water retention capacity of the surface layer.

Detailed discussion on the infiltration modelling to the proposed RSF, including permeability of rock materials (representing both deposited and in the basal layer), permeability of dune and other foundation materials is included in Appendix F7 of the Supplementary EIS. As discussed, the infiltration modelling indicated that the percolation rate from the RSF would be about 1–4% of mean annual precipitation, or up to 6 mm per year. At this rate of recharge and considering the high permeability of the waste rock, a phreatic surface is not likely to form within the RSF. Similarly, this rate of percolation would not result in a phreatic surface in the underlying dune sands and therefore is not of consequence to the geotechnical assessment of the foundation.

The dune sands are very permeable and, at the low rate of percolation from the RSF, the percolate would tend to drain downward through the dune sands. The only means by which the dune sands could provide a conduit for lateral movement of percolate is if they overlay an impermeable clay layer. However, even then most of the percolate would tend to infiltrate due to the very low rate of percolation.

12.5 MANAGEMENT AND MONITORING

12.5.1 IMPACT ASSESSMENT AND MANAGEMENT

Issue:

The potential impacts to groundwater associated with mining and processing in the vicinity of Olympic Dam were questioned. Specific issues raised were:

- the suggestion that the project could affect the environmental profile of the Outback, including groundwater around Olympic Dam
- whether there would be an exemption or variation to the South Australian Government's groundwater quality criteria
- to identify and justify an attenuation zone encompassing the TSF and RSF with identification of potential changes in groundwater chemistry.

Submissions: 2, 27, 62, 85 and 173

Response:

One submission expressed concern that the expansion could impact on the environmental profile of the Outback based on indicators highlighted in the State of the Outback Report (OACDT 2005) in terms of groundwater impact. The indicator chosen for this report in regard to water is groundwater-dependent ecosystems in relation to extraction of Great Artesian Basin (GAB) water. The proposed expansion does not seek any additional extraction of water from the GAB that is not already approved by the government. Sections 12.3.6 and 12.6.4 of the Draft EIS and Section 12.5.8 below address the potential interaction and impacts of the proposed expansion with the GAB and associated groundwater-dependent ecosystems.

Section 12.6.2, Table 12.4 and Appendix K of the Draft EIS detailed the potential changes to the groundwater quality beneath Olympic Dam as a result of the proposed expansion. Section 12.6.2 also explained that the current groundwater beneath Olympic Dam is highly saline and has naturally high concentrations of metals, which make it unsuitable for domestic or stock use. The South Australian Environment Protection (Water Quality) Policy 2003, however, specifies that groundwater-affecting activities should not alter groundwater chemistry even when natural groundwater quality exceeds criteria prescribed by the policy. Furthermore, if changes to groundwater chemistry are likely, the person undertaking those activities is to either obtain an exemption from the obligation to comply with the water quality criteria (which also requires the establishment of an attenuation zone), or seek to have the criteria amended to reflect the naturally occurring groundwater quality.

As seepage from the TSF and RSF would change the concentrations of elements in the vicinity of these facilities (refer Section 12.6.2 of the Draft EIS), BHP Billiton proposes to either apply for an exemption or seek a variation to the quality criteria of the local groundwater system, thus complying with the requirements of the Environment Protection Policy.

If an exemption was sought and BHP Billiton established an attenuation zone, it is anticipated that the boundary of the zone would coincide with the expanded Special Mining Lease (SML) boundary in most areas. The exception is the area immediately south and west of Arid Recovery, where there is less than a 1 km buffer between the TSF and the edge of the SML.

If an attenuation zone extended further than this boundary it would not affect any third party users. Elevated concentrations of metals in groundwater would not adversely affect native flora and fauna because the groundwater would be well below the surface and the depth of tree roots.

12.5.2 SEEPAGE

Issue:

Monitoring programs, contingency plans and remediation strategies addressing seepage from the TSF and RSF during the operation of the mine and post-closure were requested, including:

- an appropriate monitoring program to detect the movement of leachate beyond the boundary of the SML
- risk management strategies to reduce TSF seepage
- mitigation and remediation strategies to prevent lateral seepage from the TSF and RSF.

Submissions: 1, 2 and 265

Response:

Attenuation zone and water quality criteria

As outlined in section 12.6.2 of the Draft EIS, BHP Billiton proposes to either apply for an exemption (which also requires the establishment of an attenuation zone) or seek a variation to the groundwater quality criteria of the local groundwater system. BHP Billiton could readily comply with the requirements of the WQ EPP under each scenario.

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

Groundwater seepage

The existing groundwater monitoring program for Olympic Dam is submitted annually to government. The monitoring activities are undertaken to quantify any change in the extent or significance of impacts of the operation on groundwater, in particular:

- the groundwater levels below the TSF
- potential changes in groundwater chemistry below the TSF, including analysis for pH, TDS, calcium, chloride, sulphate, metals and radionuclides
- comparison to ANZECC criteria
- potential impacts of seepage from the TSF
- assessment of the performance of the control measures employed to limit the impacts.

As detailed in Chapter 12 (refer Section 12.6.2 of the Draft EIS), the existing Groundwater Monitoring Program would be extended for the expanded project to monitor effects on groundwater quality from seepage and would be compared against predicted groundwater movement. The data would be assessed regularly and incorporated into the BHP Billiton Environmental Management Program (EM Program). As outlined in Environmental Management Program ID 4.2 and ID 4.3 of Appendix U1.2 of the Draft EIS, the existing operating manual for the TSF would be reviewed to incorporate expansion requirements. Also, an operating manual for the RSF would be developed to include controls and contingencies.

Groundwater monitoring (level and quality) in the vicinity of the existing TSF provides empirical evidence that lateral dispersion of solutes within the unsaturated soil profile and shallow groundwater system has not extended beyond the immediate vicinity of the TSF. Lateral movement of seepage within groundwater from the TSF is constrained to within a few hundred metres of the expanded TSF. No groundwater mound is expected to form beneath the RSF. Seepage from the TSF is much greater than that of the RSF and seepage along preferential pathways is likely to fall within the zone of influence from the groundwater sink created as part of the open pit post-closure.

If rates of seepage transport away from the TSF or RSF were higher than predicted, risks would be reviewed and contingency plans and remedial actions would be investigated. However, experience from operation of the existing TSF suggests this is highly unlikely, as the groundwater mound has remained within the immediate vicinity of the TSF during more then 20 years of operation, equivalent to about half the operational life of cells within the expanded TSF.

Should continual monitoring and assessments during the operational phase indicate that the impact may occur (i.e. attenuation less than demonstrated and infiltration sufficient to change regional groundwater gradients) then a number of mitigation options are available to protect the receptor. These mitigation measures are dominantly passive in nature and would not require post-closure maintenance. A robust option for prevention of solute transport off-site could include the installation of interception wells and passive drains to increase interconnectivity and induce vertical leakage from the Andamooka Limestone to the more permeable sections of Arcoona Quartzite aquifer (Corraberra Sandstone). Induced vertical leakage would limit potential for off-site seepage migration within the Andamooka Limestone and result in greatly increased capture of seepage to the pit.

Surface expression of lateral seepage

Groundwater has no natural surface expression in the vicinity of the Olympic Dam Mine and would therefore not contribute to lateral movement of seepage leading to surface expression of seepage at the base of the TSF or RSF.

As detailed in Sections 5.5.6, 11.4.2 and 11.5.1 of the Draft EIS, the proposed TSF cells and RSF have been designed to inhibit surface expression of seepage at their base by including the following controls:

- construction of temporary divider walls to enable rapid covering of the TSF floor during the cell start-up process
- infrastructure to remove decant liquor from the edges of the temporary area to the lined central decant area to evaporate during the cell start-up process
- construction of toe drains and internal curtain drains around the perimeter of the TSF
- under-drainage of the TSF promoting consolidation of tailings and direction of seepage flow towards the central drainage area rather than towards the cell perimeter
- construction of a layer of benign material at the base of the RSF, due to its ability to be highly acid neutralising and naturally attenuating.

Infiltration modelling for the RSF and LGS was undertaken to assess the overall water balance for the RSF and the LGS (see Appendix F7 of the Supplementary EIS). The rate of percolation from the RSF is predicted to be in the order of about 1–4% of mean annual precipitation, or about 2–7 mm/year. This would result in a flux of water through the underlying sediments of about 1 x 10^{-10} to 4 x 10^{-10} m/s. The hydraulic conductivity of clean sand is typically in the range of 10^{-2} to 10^{-5} m/s; clearly any flux from the RSF would pass downward through the sands with no lateral flow likely. The hydraulic conductivity of clays is typically less than 10^{-8} m/s. Since the water flux would be in the order of less than the hydraulic conductivity of the clays, the risk of lateral flow across the clays and clay pans would be minimal. Also as noted in the TSF assessment, the clay layers in the sediments are discontinuous so that should lateral flow occur it would flow only as far as the clay layer extends and the probability of seepage daylighting from the base of the RSF is small. In contrast, the water flux from the base of tailings during operation is estimated to range from 146 mm/d to about 32 mm/d, which is equivalent to a flux of about 10^{-8} m/s on the high end of the range. Consequently there is a possibility at the TSF for percolate to flow laterally along the surface of clay layers, and it has the potential to daylight as seepage in localised areas as has been observed at the existing TSF. This has been mitigated via the design improvements detailed above.

The seepage rates predicted from the modelling presents a change to the values presented in the Draft EIS of 1% and a sensitivity of 5% of mean annual precipitation.

With this assessment outcome, lateral seepage controls in place and with regular monitoring it is considered unlikely that surface expression of seepage would occur from the TSF or RSF.

The rate of seepage from the RSF would be much less than from the TSF, is likely to be non-acidic and is likely to have lower concentrations of metals. Consequently, the impact from seepage would be considerably less than for the TSF. If the occurrence of lateral seepage from the base TSF or RSF was higher than predicted, risks would be reviewed and contingency plans and remedial actions investigated. The concepts discussed above would be refined during the detailed design phase of the project and documented in the management plans for the mine site.

12.5.3 REGIONAL GROUNDWATER FLOW

Issue:

It was requested that a monitoring program and contingency plan that addressed the possible worst-case scenario for the western inflow zone be provided to the South Australian Government.

Submission: 2

Response:

The predicted range of groundwater responses to abstraction from the proposed Motherwell wellfield and the mine is discussed in a response above and detailed in Appendix F4 of the Supplementary EIS. Groundwater monitoring at designated monitoring points would commence prior to and during pumping to monitor the drawdown in the regional aquifer and to support, review and update the numerical modelling if required. The specific observation wells to facilitate monitoring of groundwater response around the western inflow zone and the surrounding area would be selected once a groundwater monitoring plan had been developed.

At this time it is considered premature to develop a monitoring plan with established triggers, contingency plans and reduced pumping conditions, as the production wellfield and operating configuration has yet to be established, nor has the Prominent Hill model been validated against monitoring results. However, once the configuration has been developed during the detailed design phase of the project, BHP Billiton will provide the South Australian Government with a monitoring program, including contingency measures, for the proposed abstraction of groundwater from the Motherwell wellfield.

12.5.4 DEWATERING AND SALINE WATER SUPPLY BALANCE

Issue:

A management plan and contingency plan that addressed the excess water from the dewatering process, including the potential contingency of managed aquifer recharge, were requested.

Submission: 2

Response:

As described in Section 5.4.3 and Table 5.35 in Section 5.7.7 of the Draft EIS, extraction of groundwater to depressurise the open pit walls would continue for the life of the open pit mine at a rate of abstraction of about 5 ML/d, but dewatering would be at its greatest during construction (up to about 15 ML/d) up to Year 6. Water abstracted from the open pit depressurisation would be used for dust suppression and construction activities.

An indicative water demand during construction, as outlined in Table 5.24 in Section 5.7.1 of the Draft EIS, would be up to 25 ML/d sourced from mine depressurisation (about 20% or about 5 ML/d) and saline aquifer extraction (about 80% or about 20 ML/d). A water demand during operation for dust suppression and engineering needs of an average of 25 ML/d is shown in Table 5.26 of Section 5.7.2 of the Draft EIS. This water would be sourced from the coastal desalination plant, with local saline groundwater and water from open pit depressurisation available as alternative sources.

Table 12.15 summarises the supply and demand from the open pit dewatering; the precise water demand requirements will be established during detailed design of the project.

Table 12.15 Supply and demand from open pit dewatering

Phase	Supply from dewatering	Total demand	Demand from dewatering	Draft EIS reference
Construction	15 ML/d (up to Year 6)	25 ML/d	5 ML/d	Section 5.4.3 and Table 5.35 in Section 5.7.7
Operation	5 ML/d	25 ML/d	Contingency only	Table 5.24 in Section 5.7.1 Table 5.26 in Section 5.7.2

Management options for potential excess water from open pit depressurisation during construction would be investigated during the design phase of the project and implemented into the environmental management program. Contingency options could include consideration of reduction in demand from saline wellfield abstraction or managed aquifer recharge. A monitoring program using piezometer monitoring wells would be established to review the depressurisation system and optimise its performance.

Refer to Section 11.4.3 of the Supplementary EIS for detail about the quality and fate of water produced by the dewatering undertaken around the perimeter of the open pit.

12.5.5 TERRESTRIAL ECOLOGY

Issue:

The South Australian Government requested a contingency plan that addressed the potential impact of groundwater drawdown on native plant species.

Submission: 2

Response:

As discussed in Section 12.2.3 of the Supplementary EIS, the regional groundwater drawdown would not affect flora, and the two main reasons for this were detailed in Section 15.5.8 of the Draft EIS, being that:

- the groundwater of the Andamooka Limestone aquifer is hypersaline at 20,000 mg/L to 60,000 mg/L and up to 200,000 mg/L close to Lake Torrens (seawater salinity is about 36,000 mg/L), therefore would not be usable by trees and shrubs in the region
- the groundwater in the shallowest local aquifer is about 50 m below the ground surface, which is significantly beyond the depth to which tree roots are reported to penetrate, including the local Acacia woodlands.

The Mulga *Acacia aneura* has a shallow and branching root system (Hill and Hill 2003) that reaches a maximum depth of 135 cm below ground level (Whibley and Symon 1992). The Western Myall *Acacia papyrocarpa* is found mainly in shallow uniform calcareous soils (Groves 1994). Therefore, the root systems of the local Acacia woodlands would not reach the shallowest groundwater at about 50 m below ground.

As included in Draft EM Program ID 1.4 of Appendix U of the Draft EIS, groundwater levels would be monitored during mine operation to check that drawdown has no unexpected affect on the local environment. Although it is considered very unlikely for drawdown to impact on local Acacia woodlands, if monitoring showed that drawdown was having an unexpected affect on local flora, contingency options would be considered.

12.5.6 GROUNDWATER-DEPENDENT ECOSYSTEMS

Issue:

Further information and consultation was sought on the proposed monitoring of groundwater-dependent ecosystems at Yarra Wurta spring, including:

- monitoring of open pit drawdown levels to ensure they do not exceed predicted levels
- monitoring of Motherwell Wellfield groundwater level drawdown, with trigger levels, to reduce pumping, including independent evaluation
- monitoring of groundwater-dependent vegetation and Lake Eyre Hardyhead populations within Yarra Wurta spring, with the inclusion of observation wells
- contingency plans in case impacts do occur.

Submissions: 2 and 85

Response:

The predicted range of groundwater responses to abstraction from Motherwell and the open pit is detailed in Appendix F4 of the Supplementary EIS. Appendix U of the Draft EIS included the Draft Environmental Management Program (EMP) ID 1.4 for aquifer level drawdown. The groundwater modelling undertaken for the proposed expansion shows that dewatering and depressurisation of the open pit and extraction of groundwater for water supply would result in an overall loss of groundwater from the system and drawdown in the Andamooka Limestone and Tent Hill aquifers. One objective of EMP ID 1.4 is that there will be no significant adverse impacts to groundwater-dependent ecosystems as a result of drawdown associated with BHP Billiton's expansion activities. Evaluation of this objective would be met by monitoring to ensure that there was no significant decline in groundwater flow rate to Yarra Wurta spring.

As detailed in the draft EMP ID 1.4 (Appendix U of the Draft EIS) the existing operation has a groundwater monitoring program in place, which would be reviewed to incorporate expansion requirements for regulatory review and approval prior to implementation. The program would include provision for:

- monitoring the groundwater levels in wells in the Olympic Dam region to confirm and validate the groundwater model predicted levels
- ongoing monitoring of groundwater levels and spring flow at Yarra Wurta springs
- establishing a program using piezometer monitoring bores to review the depressurisation system.

Sufficient data points exist within the Andamooka Limestone and Tent Hill aquifer to provide controls on lateral and vertical groundwater monitoring. The specific observation wells to facilitate monitoring of groundwater drawdown within Motherwell wellfield and the surrounding area would be selected once a groundwater monitoring plan had been developed. The monitoring plan would be developed to support a groundwater licence.

The draft EMP ID 1.4 (Appendix U of the Draft EIS) also details that the existing Fauna Monitoring Program would be reviewed to ensure groundwater communities/ecology (such as the Yarra Wurta springs) relevant to monitoring the expanded operation was incorporated.

BHP Billiton has extensive experience with the monitoring of spring flow, and biological monitoring of groundwater-dependent ecosystems (GDEs), as a result of monitoring of springs in the Great Artesian Basin (GAB) over the past 25 years. Existing monitoring programs for springs conducted by Olympic Dam, and assessed annually, include monitoring of spring flows as well as monitoring of flora and fauna populations.

At this time it is considered premature to develop a monitoring plan with established triggers, contingency plans and reduced pumping conditions as the production wellfield and operating configuration have yet to be established. The modelling does, however, consider a representative pumping scenario of Motherwell production wells.

As discussed in Section 12.1.3, 12.1.4 and 12.2.1 of the Supplementary EIS, any impact of the operation at Yarra Wurta springs is considered to be unlikely, although there is a theoretical possibility under a worst-case scenario that the springs may be affected 500 years after mine closure. The risk assessment for this conservative worst-case scenario returned a ‘high’ risk, representing a ‘possible’ likelihood and a ‘moderate’ consequence. As discussed in Section 1.6.2 and illustrated in Figure 1.11 of the Draft EIS, a 'high' risk is considered to be a tolerable risk, however 'high' risks are considered to be key project risks and require active control through specific management measures. In this instance, groundwater levels within wells would be monitored near the open pit and at regular intervals from the open pit to determine the extent and timing of drawdown compared with that of the modelled predictions. The monitoring program would be reported through the Environmental Management Program, as discussed in Section 26.3 of the Draft EIS and further in Chapter 29 of the Supplementary EIS.

12.5.7 THIRD PARTY GROUNDWATER USERS

Issue:

Clarification was sought on:

- the number of groundwater users in the region
- the extent to which groundwater users are likely to experience impacts (quality or quantity) on their groundwater resources
- BHP Billiton commitments to future monitoring of groundwater supplies.

Submissions: 2 and 146

Response:

Each of these issues is addressed separately below.

The number of groundwater users in the region

The third party groundwater survey was undertaken by Soil and Groundwater Pty Ltd in 2006 as part of the Draft EIS (refer Appendix K2 of the Draft EIS).

The survey identified the location, construction details, water quality and water levels of all available pastoral wells located on the Stuart Shelf and parts of the broader Gawler Craton – the geological province of relevance to Olympic Dam. The survey aimed to confirm which wells were in use at the time of the investigation. Since the survey, some wells may have been taken out of service and new wells may have been installed. The investigated wells and relevant pastoral stations are shown on Figure 12.31.

Figure 12.31 Investigated wells for the third-party groundwater survey in 2006

As discussed in Section 12.3.5 of the Draft EIS, despite the generally high salinity of groundwater in the Stuart Shelf, 14 groundwater wells within 60 km of Olympic Dam were in operation at the time of the 2006 survey. Of these, seven are located on pastoral leases held by BHP Billiton, four are located on Parakylia station and three are located on Parakylia South station. There are 19 groundwater wells in use in the extended area assessed for the Supplementary EIS, as shown on Figure 12.10a. Of these, seven are located on pastoral leases held by BHP Billiton, nine are located on Parakylia station and three are located on Parakylia South station.

The existing Olympic Dam operation also uses local groundwater. Therefore there are currently three users of groundwater within the Olympic Dam region (i.e. BHP Billiton and two other pastoral lessees).

The extent to which groundwater users are likely to experience impacts (quality or quantity) on their groundwater resources

With regard to groundwater quality, Section 12.7 of the Draft EIS concluded that the majority of the metals in seepage from the TSF and RSF would be naturally attenuated by the underlying sediments. Also, the open pit would act as a regional groundwater sink, ultimately capturing all seepage from the TSF and RSF and therefore preventing contaminants from reaching any third party pastoral wells. These conclusions have been further investigated since the publication of the Draft EIS and have been confirmed (see Sections 12.3.1 and 12.2.2 of the Supplementary EIS for details).

Groundwater modelling undertaken as part of the Draft EIS and presented in Chapter 12 established that there would be no impact on the quantity or quality of groundwater supplies for third party groundwater users/pastoralists as a result of the proposed Olympic Dam expansion, including the operational period and up to 500 years post-closure.

With regard to groundwater drawdown (which may potentially affect the quantity of groundwater available for third party users), the assessment presented in the Draft EIS was based on a regional numerical groundwater model. This model was constructed to predict the changes in groundwater levels across the Stuart Shelf groundwater systems – the Tent Hill aquifer and the Andamooka Limestone aquifer – during construction, operation and post-closure (refer Section 12.6.1 and Appendix K6 of the Draft EIS for details). The assessment of potential impacts to groundwater users considered all wells within the area within which groundwater level drawdown was predicted to be in the range of centimetres, not metres.

The Draft EIS model simulations suggested that groundwater drawdown within the Tent Hill aquifer would develop slowly, and would extend between 20 and 45 km from Olympic Dam over a period of 500 years after closure (refer per Figure 12.14 of the Draft EIS, reproduced as Figure 12.29). In the shallower Andamooka Limestone aquifer, simulations suggested that drawdown would also develop slowly, and would also extend between 20 and 45 km from Olympic Dam over a period of 500 years after closure (refer per Figure 12.15 of the Draft EIS reproduced as Figure 12.30). No third party groundwater wells are located within 45 km of Olympic Dam, and as such no impact was predicted.

Subsequent to the publication of the Draft EIS, additional groundwater modelling has been undertaken to take account of additional information (described below). This modelling aimed to refine the understanding of the extent of groundwater drawdown. The details of this revised modelling are provided in Section 12.2 and Appendix F4 of the Supplementary EIS.

One of the key inputs to the model is the rate of groundwater inflow to the Stuart Shelf aquifers from the Arckaringa Basin to the west. For the Draft EIS, this rate of inflow was obtained from modelling undertaken for the Prominent Hill mine, and a value of 3,060 m^3/d was used. Subsequent to the publication of the Olympic Dam EIS, the Prominent Hill mine has produced a calibrated regional groundwater model that deduced a smaller inflow rate from the Arckaringa Basin to the Stuart Shelf of 740 m^3/d (Aquaterra 2009). When the change in inflow rate was applied to the Olympic Dam groundwater model, model simulations showed that the groundwater drawdown contours had extended relative to what had been reported in the Draft EIS.

Figures 12.10 and 12.11 show the newly simulated groundwater drawdown in the Tent Hill and Andamooka Limestone aquifers at the end of the construction period (2017), at the end of the 40-year mine life (2050), 100 years post-closure (2150) and 500 years post-closure (2550).

Review of the revised drawdown contours shows that there are no third party groundwater users influenced by the expanded operation up to the year 2150. This is the same result as reported in the Draft EIS.

However, the updated simulations of groundwater drawdown contours for 500 years post-closure, at 2550, show a potential effect on two third party groundwater users in the region (Parakylia station and Parakylia South station). A total of nine wells may be affected in Parakylia station, with potential drawdown in the Tent Hill aquifer of less than 1 m at two wells (see Figure 12.10b) and a potential drawdown in the Andamooka Limestone aquifer of less than 4 m in seven wells (see Figure 12.11b). Three wells may be affected on the Parakylia South station, with potential drawdown in the Tent Hill aquifer of less than 2 m (see Figure 12.10b) and no drawdown effects to wells that are currently in use in the Andamooka Limestone aquifer.

Given the timeframe before which this effect may be realised, and the potential for other influences to affect the groundwater system prior to 2550, this issue is addressed using the risk assessment framework presented in the Draft EIS (refer Section 26.2 and Appendix C for details):

- the risk rating for reduction in water quality at third party groundwater wells is 'low' (representing a 'rare' likelihood and a 'minor' consequence)
- the risk rating for drawdown at third party groundwater wells is also 'low' (representing an 'unlikely' likelihood and a 'minor' consequence).

As discussed in Section 1.6.2 and illustrated in Figure 1.11 of the Draft EIS, a 'low' rating is a tolerable risk and standard monitoring measures would be applied. In this instance, groundwater levels within wells would be monitored near the open pit and at regular intervals from the open pit to determine the extent and timing of drawdown compared with that of the modelled predictions. The monitoring program would be reported through the Environmental Management Program, as discussed in Section 26.3 of the Draft EIS.

It is also noted that interference drawdowns of a few metres between production wells is a common consequence of groundwater development. As a result, bores are typically installed to a depth that allows abstraction of groundwater from many metres within an aquifer, and a reduction of up to 4 m may not necessarily impact the use of a well.

BHP Billiton commitments to future monitoring of groundwater supplies

As noted above, risk events that return a low rating would be managed via the Environmental Management Program and therefore groundwater quantity and quality within a selection of operating wells in the Olympic Dam region would be monitored throughout the operation phase. As groundwater movement in the Stuart Shelf aquifers occurs very slowly, these wells would be located near and at progressively greater distances from the pit, so that the long-term evolution of the drawdown effects were monitored properly, to allow improved modelling of the long-term effects as well as demonstrating whether the drawdown was developing towards the wells in question.

As new information on the surrounding environment becomes available (e.g. monitoring results and any further changes to the estimates of the Arckaringa Basin groundwater discharge rate) it would be incorporated into the groundwater model to confirm the model's accuracy and the model would be refined and recalibrated as required. If monitoring results established that drawdown was likely to affect current third party users in the future, alternative water supply options would be investigated. These may include relocating or deepening existing groundwater wells, or providing an alternative water supply. Options would be considered in consultation with the third party user. Further detail regarding consultation with third party groundwater users can be found at Section 7.4 of the Supplementary EIS.

12.5.8 GREAT ARTESIAN BASIN

Issue:

The following information was requested to address the potential interaction and impacts of the proposed expansion with the Great Artesian Basin (GAB):

- an investigation to demonstrate no potential impacts, including calculated pressure reduction (drawdown) values
- a monitoring program to identify potential impacts
- contingency plans in case impacts do occur.

Submissions: 2, 146 and 287

Response:

The proposed expansion does not seek any additional extraction of water from the GAB that is not already approved by the Australian and South Australian governments.

With regard to potential impact from groundwater drawdown as a result of the open pit, the modelling undertaken for the Draft EIS demonstrated that the expansive artesian GAB aquifers are separated by evaporative discharge zones, geological and structural controls associated with the low-permeability rocks of the Adelaide Geosyncline and Torrens Hinge Zone. As stated in the Draft EIS (Section 12.3.3), and further detailed in Sections 12.1 and 12.2 above, this modelling is supported by hydrogeochemical and isotope data, which show that the composition of groundwater sampled from the high-flowing GAB aquifers is significantly different from that of relatively low-flowing groundwater from the Stuart Shelf (the groundwater system that would be influenced by the proposed expansion). As no connection between the GAB and Stuart Shelf is thought to exist it is not considered possible to calculate pressure reduction (drawdown) values for the GAB in relation to the proposed expansion.

Extraction of water from the GAB for the current operation is monitored via the Groundwater Monitoring Program, and BHP Billiton submits annual reporting based on the results of monitoring via the annual GAB Wellfields Report and the annual Environmental Management and Monitoring Report (EMMR) for the Olympic Dam operation to the South Australian Department of Primary Industry and Resources (PIRSA).

The GAB Wellfields Report provides an overview of the data that relates to the operation of the BHP Billiton Olympic Dam GAB water supply wellfields for the reporting year and provides an outline of monitoring as it relates to aquifer response in the wellfields (A and B), observation bores, and related zones, such as pastoral bores.

The EMMR provides an outline of the Olympic Dam site operations and activities in relation to conditions set on the EIS for the previous expansion of Olympic Dam (Kinhill 1997). Both the EMMR and GAB Wellfields Report will continue to assess the potential impacts of Olympic Dam operations on the GAB and will continue to be provided to the relevant regulatory parties. Additionally, there is an existing contingency plan maintained for addressing unexpected drawdown or spring flow decline near the Olympic Dam wellfields. This contingency plan would be followed for water taken within the existing licence approval.

The Groundwater Monitoring Program would also be reviewed to identify where modifications are required to incorporate requirements for the proposed expansion. Section 12.1 and Appendix F1 discuss the potential for impacts on the GAB. These investigations demonstrate that connection between the GAB and Stuart Shelf, and therefore potential for impacts, are extremely unlikely.