APPENDIX F1

Conceptual groundwater model

Olympic Dam expansion project – Supplementary Environmental Impact Statement groundwater studies

- Final
- 9 March 2011

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Terms and abbreviations

ALA or ZAL or €a:
Andamooka Limestone aquifer

AHD:
Australian Height Datum

ANZECC:
Australian and New Zealand Environment Conservation Council

ARMCANZ:
Agriculture and Resource Management Council of Australia and New Zealand

artesian Eromanga Basin:
that part of the Eromanga Basin where groundwater pressures are artesian

artesian Eromanga (GAB) aquifers:
the aquifers of the artesian Eromanga Basin

EIS:
Environmental Impact Statement

GAB:
Great Artesian Basin (in this document the term refers to the “artesian Eromanga Basin”

GDE:
groundwater dependent ecosystem

GFS:
groundwater flow system

NATA:
National Association of Testing Authorities

non-artesian Eromanga Basin:
that part of the Eromanga Basin where groundwater pressures are non-artesian, aquifers may be confined or unconfined

non-artesian Eromanga aquifers:
the aquifers of the non-artesian Eromanga Basin, i.e. groundwater pressures may be sub-artesian or the aquifers host the water table

OD:
Olympic Dam

RSF:
rock storage facility

SA EPA:
South Australian Environment Protection Authority

SEIS:
Supplementary Environmental Impact Statement

SML:
Special Mining Lease

SWL:
standing water level

TDS:
salinity, expressed as total dissolved solids

THA or ZWC:
Tent Hill aquifer (lower Arcoona Quartzite and Corraberra Sandstone)

THZ:
Torrens Hinge Zone

TSF:
tailings storage facility

TSS:
total suspended solids

Victorian EPA:
Victorian Environment Protection Authority

1. Introduction

1.1. Background

BHP Billiton Olympic Dam Corporation P/L (BHP Billiton) has engaged Sinclair Knight Merz Pty Ltd (SKM) to undertake additional groundwater-related studies to assist in preparation of the Supplementary Environmental Impact Statement (SEIS) for the proposed Olympic Dam Expansion Project. Figure 1.1 presents a locality plan for Olympic Dam.

Submissions received from the public and regulatory agencies requested further information to that provided in the Draft EIS for the proposed expansion. The submissions related to groundwater typically were in regard to the following issues:

- Conceptualisation of the Stuart Shelf groundwater system, and its potential for interaction with the *artesian* Eromanga (GAB) groundwater system.
- Risk assessment in regards to conceivable impacts of the proposed expansion on regional groundwater-related values.
- Representativeness of groundwater samples collected during the various groundwater investigation programs undertaken for the proposed expansion.
- Beneficial use status of regional groundwaters.
- The potential response of the Lake Torrens brines to the proposed expansion and the potential effects of the proposed expansion on the water balance of the lake.

This report provides information and interpretations in support of the SEIS, specifically to provide more detailed information to submission responses in Chapter 12 of that document. A list of terms and abbreviations presented after the Table of Contents section is provided for clarification of some terms and abbreviations used in this document.

1.2. EIS related studies

Various hydrogeological investigations and interpretations were carried out in support of the Draft EIS. This work continued in parallel with the EIS preparation and a good deal of information and interpretations were consequently not available for the EIS. However, results of the work programs are now available to assist with responses to comments made about the Draft EIS.

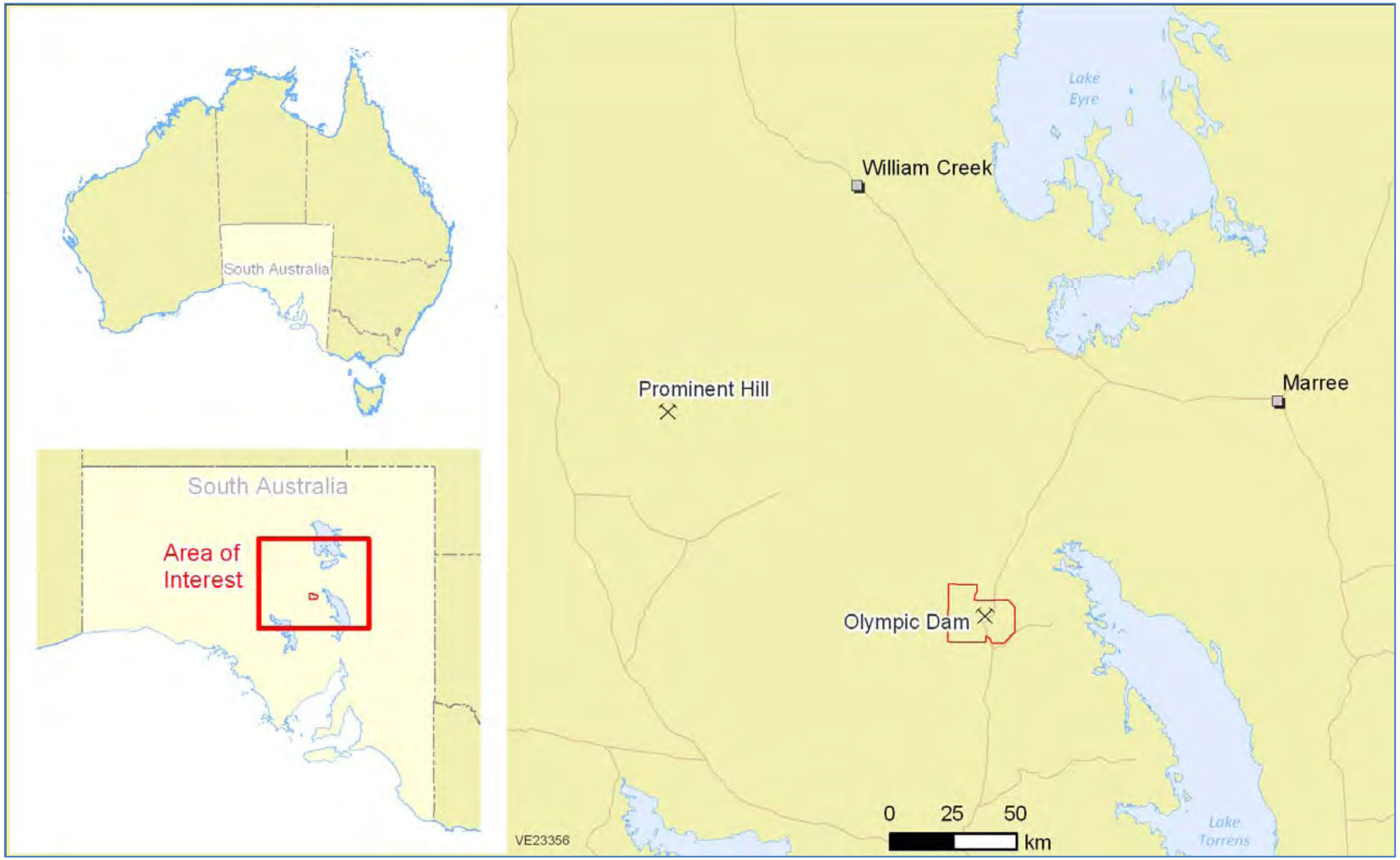


Figure 1.1 Locality plan

Details of the hydrogeological work programs (including composite well logs, airlift yield and salinity profiles, and water quality data) are presented in SKM (2010; Appendix F2 of the SEIS) and the following is a summary:

- Drilling, well construction and aquifer testing for EIS-related hydrogeological investigations in the Andamooka Limestone near Lake Torrens and further west toward the Arckaringa Basin (as Attachment A to SEIS Appendix F2).
- Drilling, well construction and aquifer testing for mine pit dewatering and depressurisation trial (as Attachment B to SEIS Appendix F2).
- A groundwater baseline sampling and analytical program (as Attachment C to SEIS Appendix F2).
- Drilling, well construction and aquifer testing for saline groundwater supply investigations of the Andamooka Limestone aquifer (as Attachment D to SEIS Appendix F2).

Other relevant, groundwater-related consultant reports available for preparation of groundwater responses to the SEIS include:

- refinement of the Stuart Shelf groundwater model originally developed for the Draft EIS (SWS, 2010: see Appendix F4 of the SEIS);
- rock storage facility (RSF) infiltration studies (SRK, 2010a: see Appendix F7 of the SEIS); and
- tailings storage facility (TSF) geochemistry studies (SRK, 2010b: see Appendix F5 of the SEIS).

1.3. Report structure

This report is structured as follows:

Section 1 Introduction
Presents introductory information concerning the need for the report.

Section 2 Conceptual hydrogeological model
Presents the current conceptualisation of the hydrogeology of the Stuart Shelf groundwater flow system in relation to other systems operating within the broader region.

Section 3 Hydraulic connectedness of regional aquifers
Presents the results of field testing of the hydraulic properties of Adelaide Geosyncline rocks, an assessment of hydrogeochemical data for regional groundwaters, and interpretation of the extent to which regional aquifers might interact with artesian Eromanga (GAB) aquifers.

Section 4 Beneficial use categories of regional aquifers

Presents an assessment of the potential uses to which regional groundwaters could be applied.

Section 5 Water sampling protocols

Presents information regarding the way in which groundwater sampling has been conducted at wells installed as part of the groundwater studies for the proposed expansion.

Section 6 Lake Torrens brine

Presents discussion of the interpreted interaction of brine developing from Lake Torrens with regional groundwater flow systems.

Section 7 Groundwater effects assessment

Presents an assessment of the effects the proposed expansion might have on groundwater assets within the region.

Section 8 Conclusions

Presents a summary of the key findings / outcomes of this report.

Section 9 References

A listing of reports, publications and mapping products referenced by this report.

Section 10 Acknowledgments

Acknowledgement of people external to SKM who have assisted in preparation of this report.

Attachments

Supporting data and analyses.

2. Conceptual hydrogeological model

2.1. Background

Olympic Dam (OD) is located on the Stuart Shelf, which is dominated by Cambrian and Proterozoic rocks. To the northwest of the Stuart Shelf lies the Permian Arckaringa Basin. The Arckaringa Basin groundwater system is in hydraulic continuity with the Stuart Shelf groundwater system, and together they comprise the Arckaringa-Stuart Shelf groundwater flow system (GFS).

A groundwater divide occurs toward the northern end of the Arckaringa-Stuart Shelf GFS, separating the primary aquifers of the Arckaringa-Stuart Shelf GFS (the Andamooka Limestone aquifer; ALA, and the Tent Hill aquifer; THA) from the *artesian* Eromanga (GAB) GFS, which supports the GAB Springs.

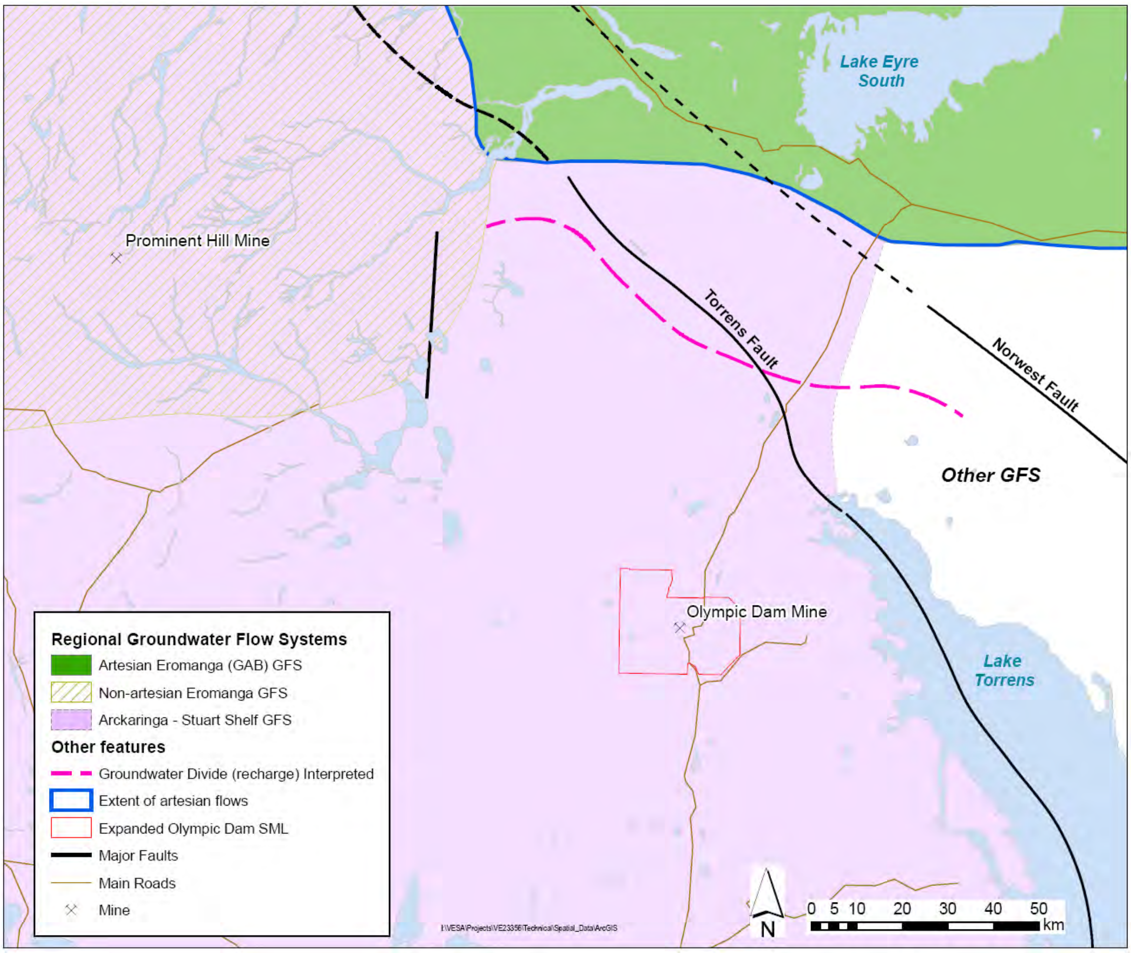
The Arckaringa-Stuart Shelf GFS comprises the THA and ALA as well as the "upstream" Boorthanna aquifer of the Arckaringa Basin. This GFS is recharged by incident rainfall (at rates much less than 1 mm/yr; Golder, 1998) and by throughflow from the western and northern Boorthanna aquifer. Water discharge from this GFS occurs predominantly by evaporation from:

- shallow water tables formed at the margins of the GFS, i.e. along the regional evaporative discharge zone that separates the *artesian* Eromanga (GAB) and Arckaringa-Stuart Shelf GFSs (to the north and northwest of OD), which is characterised by low lying topography (near sea level) and extensive salinised soils; and
- shallow water tables along the margins of Lake Torrens (some returns to the groundwater system occur as “reflux” brines).

Figure 2.1 presents a schematic showing the locations of the GFSs operating within the region, and Figure 2.2 presents an overview of the groundwater flow processes operating in the broader region. Further description of the GFSs that are active in the broader region is provided as Section 3.2.

2.2. Conceptual hydrogeological model

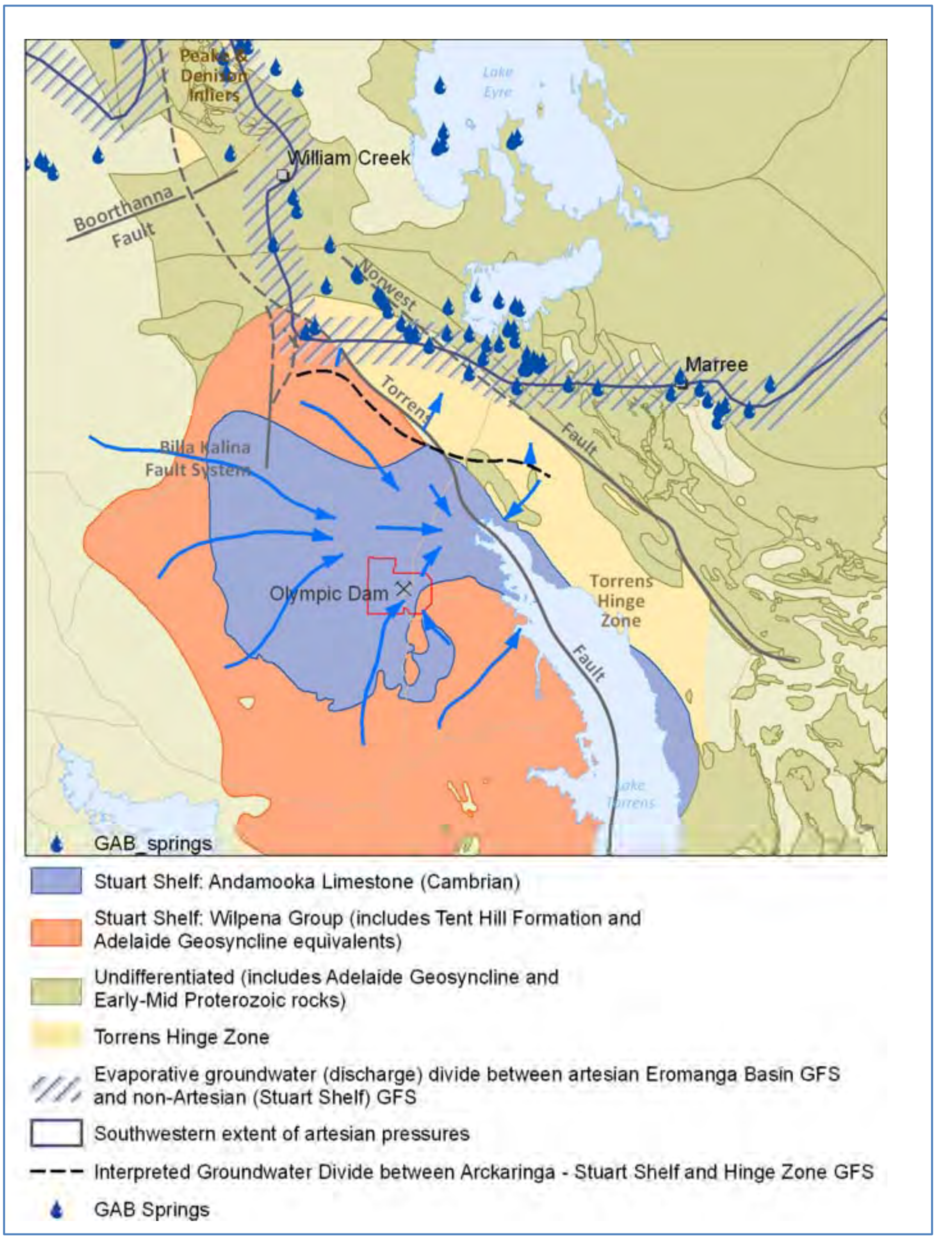
Groundwater flow on the Stuart Shelf is dominated by the ALA to the north of OD and the THA to the south. ALA permeability and yield largely relies on solution-enlarged fissures, while THA permeability is largely associated with brittle fracturing without any solution (karstic) effects.



- Figure 2.1 Regional groundwater flow systems

A significant increase in groundwater salinity occurs in the ALA to the north of OD at depths typically below 200 m, and at greater depths beneath the special mine lease (SML) in the THA. ALA groundwater salinity ranges from less than 50,000 mg/L to more than 200,000 mg/L closer to Lake Torrens. The very high groundwater salinities found near Lake Torrens are associated with brine that is discharging from Tertiary sedimentary aquifers beneath the Lake. Section 6 provides more detail.

Along with the extensive salinised groundwater discharge zone that separates the Arckaringa-Stuart Shelf GFS from the *artesian* Eromanga (GAB) GFS, the margins of Lake Torrens form the main groundwater discharge zone for the Arckaringa-Stuart Shelf GFS (Figure 2.2). The Lake is also a major ephemeral surface water body after sufficient rainfall occurs to generate run-off into the Lake, principally from the Flinders Ranges.



- **Figure 2.2 Interpreted groundwater flow processes within the Study Area**

The evaporative discharge of groundwater (mainly) and surface water (occasionally) from Lake Torrens has caused salinity stratification (and brine formation) near and beneath Lake Torrens. Regional groundwater discharging from the Arckaringa-Stuart Shelf GFS toward Lake Torrens is constrained by the presence of this brine, resulting in a density driven upward convergence of groundwater discharge from the ALA to the margins of the lake. The brine reduces the *effective* aquifer transmissivity of the ALA near the lake.

Costelloe et al. (2010) have undertaken studies aimed at estimating leakage rates around the southwestern margin of the *artesian* Eromanga (GAB) Basin. The results of their studies show that evaporative discharge of groundwater from areas where the water table is less than 1 m (termed the *saturated zone* by Costelloe et al.) range upwards of 100 mm/yr, and where the water table occurs between around 1 and 4 m (termed the *transition zone* by Costelloe et al.) evaporation losses could range between 10 and 100 mm/yr. These estimates of evaporative discharge from the *saturated* and *transition zones* are not insignificant, and can reasonably be expected to form an effective hydraulic (discharge) boundary between the *artesian* Eromanga (GAB) and Arckaringa-Stuart Shelf GFSs.

The existence of a groundwater divide between the Arckaringa-Stuart Shelf GFS and the *artesian* Eromanga (GAB) GFS, combined with intervening low permeability Adelaide Geosyncline rocks within which the divide is generally located (see Sections 3.3 and 3.4), indicates there is no connection between the primary aquifers of the Arckaringa- Stuart Shelf GFS (ALA and THA) and the *artesian* Eromanga (GAB) GFS. This conclusion is supported by hydrogeochemical data (see Section 3.5).

The schematic hydrogeological cross-section presented as Figure 2.3 describes the essential elements of the regional conceptual hydrogeological model, particularly in relation to the Arckaringa- Stuart Shelf and *artesian* Eromanga (GAB) GFSs to the north of OD.

Importantly, the schematic shows:

① A groundwater divide formed within low permeability Adelaide Geosyncline rocks (and Tent Hill equivalents) toward the north end of the Arckaringa-Stuart Shelf GFS, separating the ALA and THA from the *artesian* Eromanga (GAB) GFS.

② Evaporative loss of shallow groundwater at the margins of Arckaringa- Stuart Shelf and the *artesian* Eromanga (GAB) GFS is an important groundwater discharge process, causing salinisation of shallow and deep soil profiles and groundwater.

③ Density driven brine discharge from Lake Torrens to the ALA and, possibly, around the entire perimeter of the lake. Brine, extending out from Lake Torrens beneath the groundwater that moves towards Lake Torrens, causes the less saline regional groundwater to move up the brine interface to discharge to the margin of the lake.

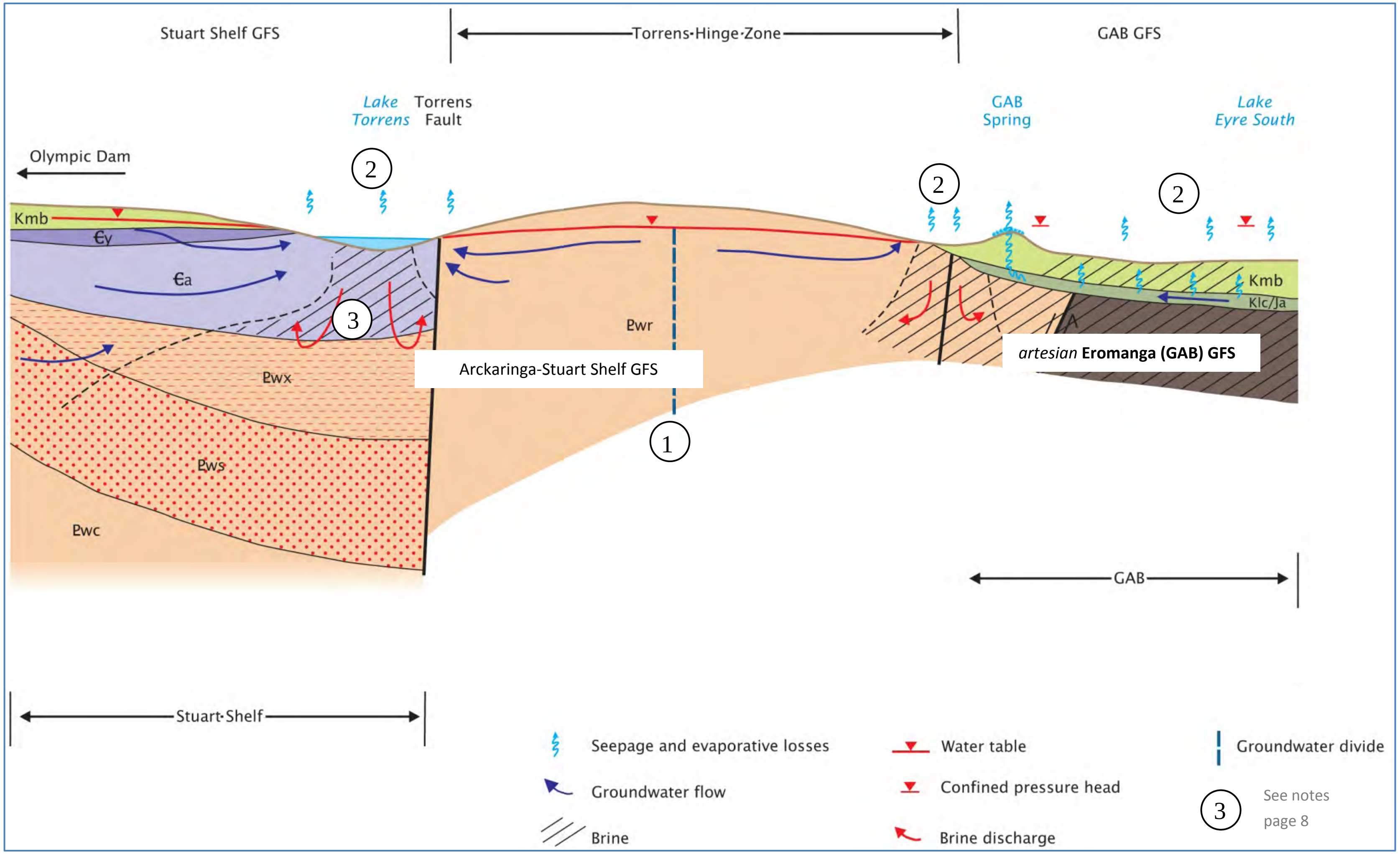


Figure 2.3 Schematic of the conceptual hydrogeological model of the Stuart Shelf and GAB groundwater flow systems

3. Hydraulic connectedness of regional aquifers

3.1. Groundwater monitoring locations

Groundwater monitoring locations used for the assessment of groundwater flow behaviour and hydraulic separateness of Stuart Shelf aquifers are presented in Figure 3.1. As shown, 55 wells have been completed in the Andamooka Limestone aquifer (ALA), 21 wells have been completed in the Tent Hill Aquifer (THA) and 78 shallow wells have been completed within regional water table aquifers in both the Stuart Shelf and Adelaide Geosyncline fractured rock aquifers and *non-artesian* Eromanga aquifers.

These new wells are in addition to wells existing prior to commencing environmental groundwater investigations for the proposed expansion.

3.2. Groundwater flow systems

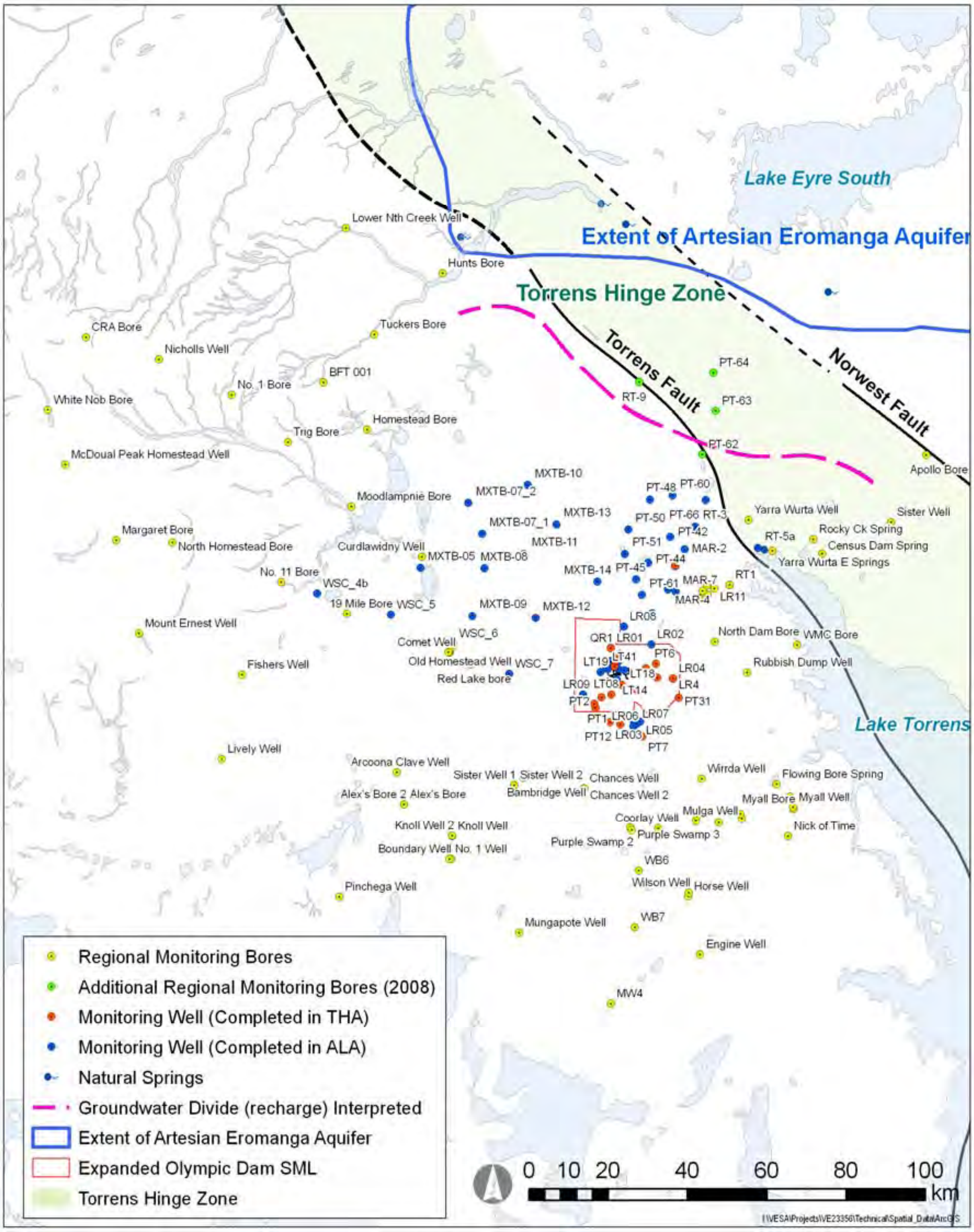
There are two dominant GFSs within the broader region of Olympic Dam. They are:

- the regional-scale Arckaringa-Stuart Shelf GFS, which incorporates the aquifers of the Stuart Shelf itself (the THA and ALA) as well as the aquifers of the neighbouring (upstream) Arckaringa Basin (the Boorthanna aquifer) to the west (Figure 2.1); and
- the regional-scale *artesian* Eromanga (GAB) GFS, comprising the aquifers of the Eromanga Basin where they are artesian north of Olympic Dam (Figure 2.1).

Details concerning each of these flow systems can be gained from references presented as Appendix K1 of the Draft EIS, as well as Douglas and Howe (2009) and Howe et al. (2008).

An overview of recharge-discharge mechanisms for the Arckaringa-Stuart Shelf GFS is provided in Section 2. Important concepts for setting the context of the potential for interaction between the *artesian* Eromanga (GAB) and Arckaringa-Stuart Shelf GFSs, though, are:

- The existence of a groundwater divide (Figure 3.1) separating the Stuart Shelf and *artesian* Eromanga (GAB) Basin groundwater systems to the north of Olympic Dam. Evidence for this divide includes water table elevation data collected from a number of monitoring wells located to the north of the SML (see Figure 3.1 for locations). Where there are no groundwater level data, a westerly extension of the divide has been inferred along a topographic divide and outcrop of low permeability Adelaide Geosyncline strata of the THZ.



- **Figure 3.1 Locations of wells used for regional groundwater flow analysis**

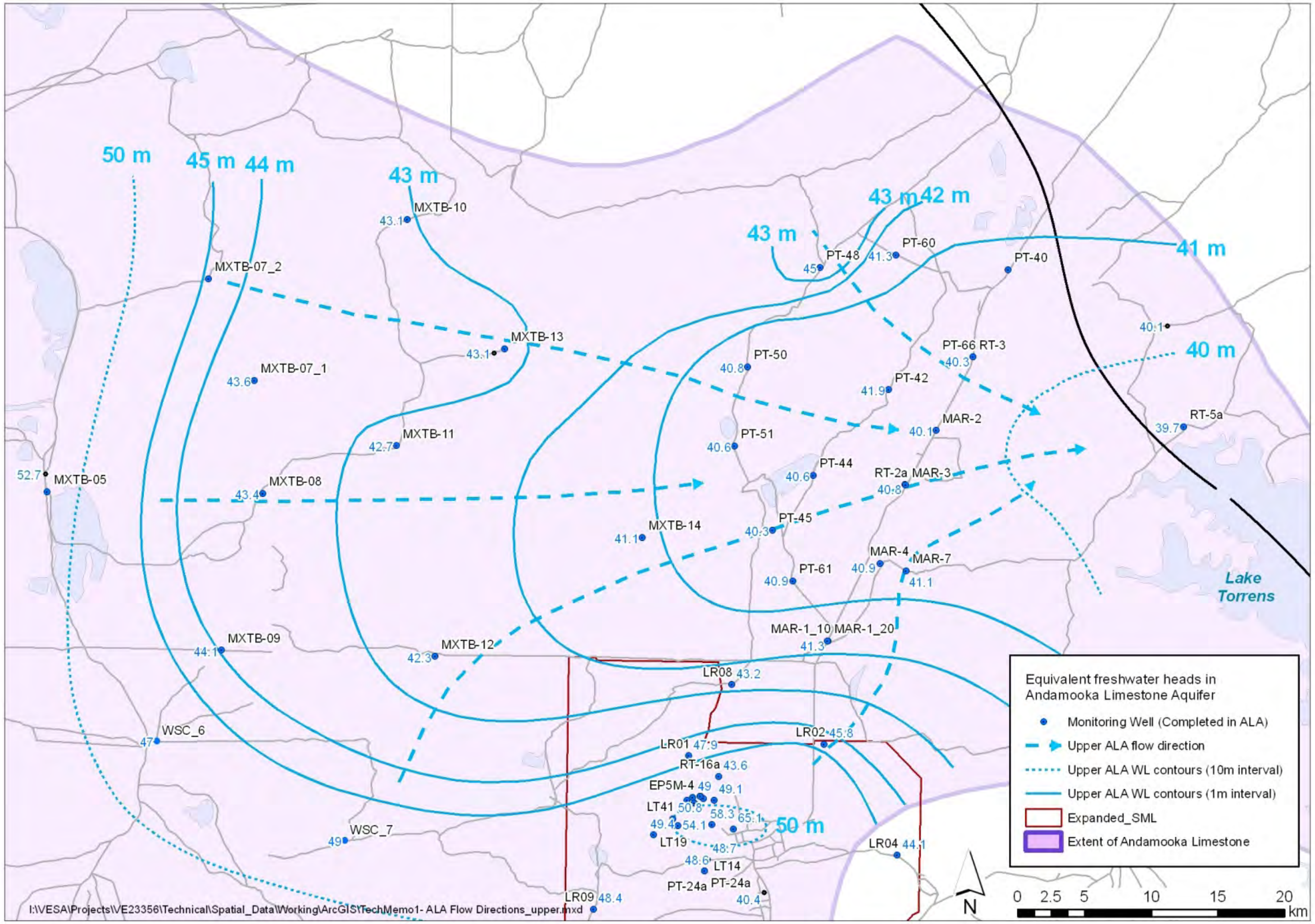


Figure 3.2
Interpreted groundwater elevation contours for the upper ALA

- The extensive area of salinised soils and groundwater along the broad contact (*saturated* to *transition*) zone where the two GFSs converge is evidence of a regional-scale groundwater evaporative discharge zone that separates them. Evaporation groundwater losses along this zone could range upwards of 100 mm (Costelloe, et al., 2010).

A third, less extensive GFS that overlies the Arckaringa-Stuart Shelf GFS, occurs to the west and northwest of OD, the non-*artesian* Eromanga (GAB) GFS. OZ Minerals (2009) presents a detailed description of the hydrogeology of the Arckaringa Basin and overlying (*non-artesian)* Eromanga Basin. In summary:

- Groundwater discharges as diffuse seepage and evaporation from the *non-artesian* Eromanga aquifers along the groundwater discharge zone separating the *artesian* Eromanga (GAB) aquifers from the *non-artesian* Eromanga aquifers (Figure 2.2).
- The *non-artesian* Eromanga GFS does not extend onto the Stuart Shelf. The underlying Arckaringa Basin (Boorthanna) aquifer is connected to the aquifers of the Stuart Shelf.

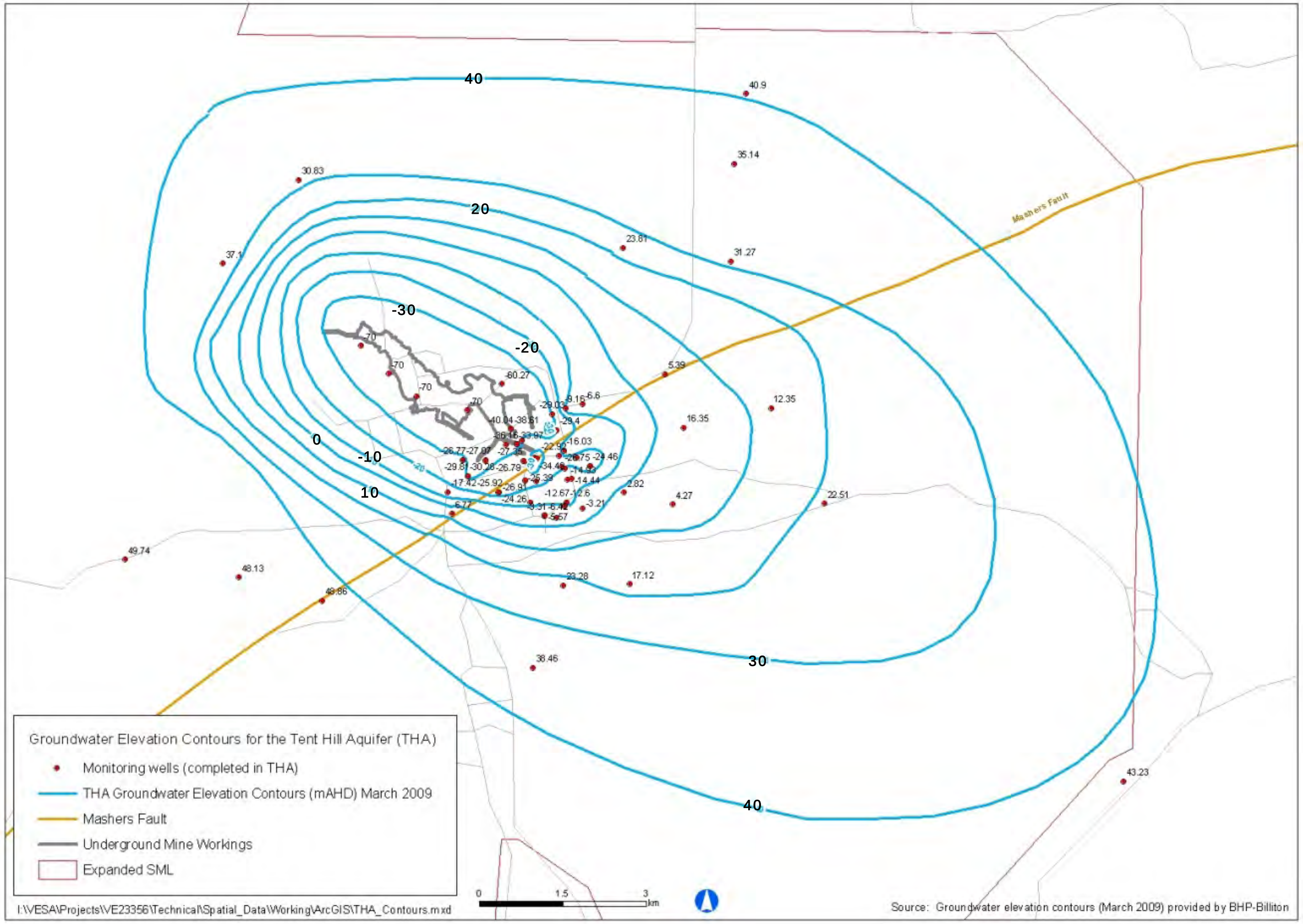
3.3. Groundwater flow

3.3.1. Regional water table aquifer

Standing water levels for all wells, where data exist (depths, elevations and density-corrected heads), are presented as Attachment A (Tables A.1 through A.4). Water level data have been used to generate groundwater elevation contours for each primary aquifer of the Stuart Shelf (ALA and THA) and these are presented as Figure 3.2 and Figure 3.3.

Figure 3.4 presents interpreted groundwater elevation contours for the regional water table aquifer of the Arckaringa-Stuart Shelf groundwater flow system (GFS), which extends across a number of hydrostratigraphic units, including the ALA, the THA and Arckaringa Basin. The *non-artesian* Eromanga aquifer forms a water table aquifer west of Olympic Dam, but does not extend on to the Stuart Shelf proper.

The data used to construct these regional contours have not been corrected for fresh water heads, as salinity data are not available for all locations used to generate the contours (a comparison of Figures 3.2 and 3.4 indicates the lack of salinity correction does not compromise the interpretation of groundwater flow direction across the Stuart Shelf).



Source: Groundwater elevation contours (March 2009) provided by BHP-Billiton

Figure 3.3
Interpreted groundwater elevation contours for the THA (March 2009; after Douglas et al., 2009)

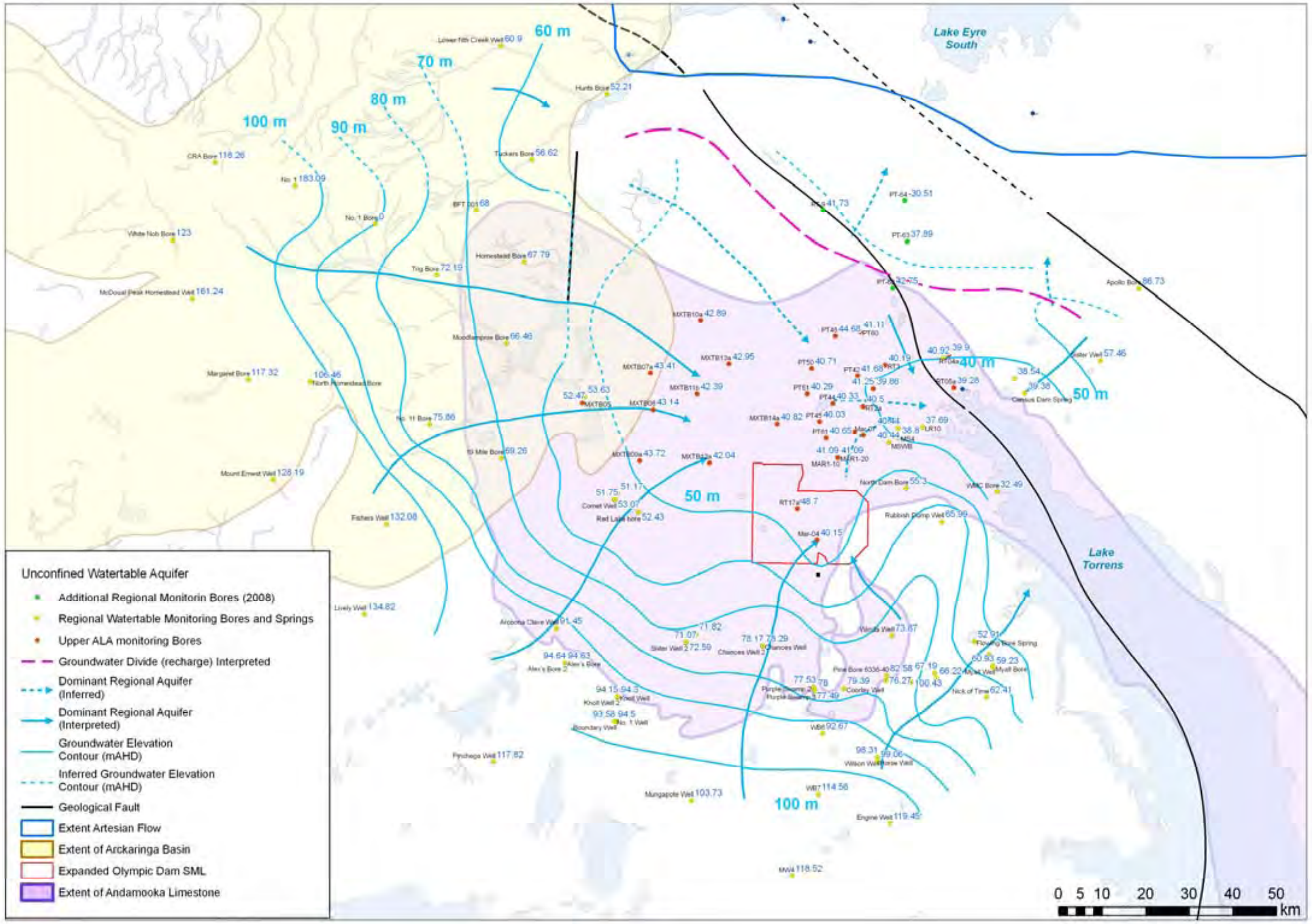


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Figure 3.4
Interpreted regional water table contours

Attachment A (Table A.6) presents estimated hydraulic conductivity values for the different hydrostratigraphic units of the Stuart Shelf (aquifers and aquitards), which is drawn from information presented in SKM (2010; Appendix F2 of the SEIS).

As shown on Figure 3.4, groundwater is interpreted to flow onto the Stuart Shelf, west from Arckaringa Basin aquifers, predominantly via the highly transmissive ALA. Consistent with the interpreted contours presented in Figure 3.4, water table aquifer discharge is toward the northern end of Lake Torrens, as well as toward low lying topography that occurs where the *artesian* Eromanga (GAB) GFS and Arckaringa-Stuart Shelf GFS converge along the southwestern extent of the *artesian* Eromanga (GAB) GFS.

A groundwater divide (Figure 3.1) separates the primary aquifers of the Arckaringa-Stuart Shelf GFS (ALA and THA) from the *artesian* Eromanga (GAB) GFS.

3.3.2. Andamooka Limestone Aquifer (ALA)

At the time of preparation of the Draft EIS, investigations of the ALA were being undertaken to the west and north of Lake Torrens. This section includes recent interpretations of data that were not available for inclusion in the Draft EIS.

Figure 3.2 displays the interpreted groundwater elevation contours for the upper ALA. These contours are based on water level measurements that have been corrected due to the variable density of regional groundwater within the Andamooka Limestone.

The general direction of groundwater flow in the less saline, upper ALA is from west to east in the study area, converging at the northern end of Lake Torrens. A slightly steeper gradient is evident between OD and Lake Torrens compared to the groundwater flow field that occurs to the north of OD, which is likely reflective of lower transmissivity due to reduced saturated thickness of the aquifer.

The lower ALA in the vicinity of the northern end of Lake Torrens is characterised by hyper-saline groundwater or brine (see Figure 3.5, eg. wells RT5b and LR10). A brine wedge extends westward away from the salt lake (Figure 3.6), which has been defined by Schmid (1985) as a groundwater playa. The regional (west to east) groundwater flow field within the upper ALA passes over the saline groundwater / brine interface. The interaction between the Lake Torrens brines and the ALA flow system is discussed further in Section 6.

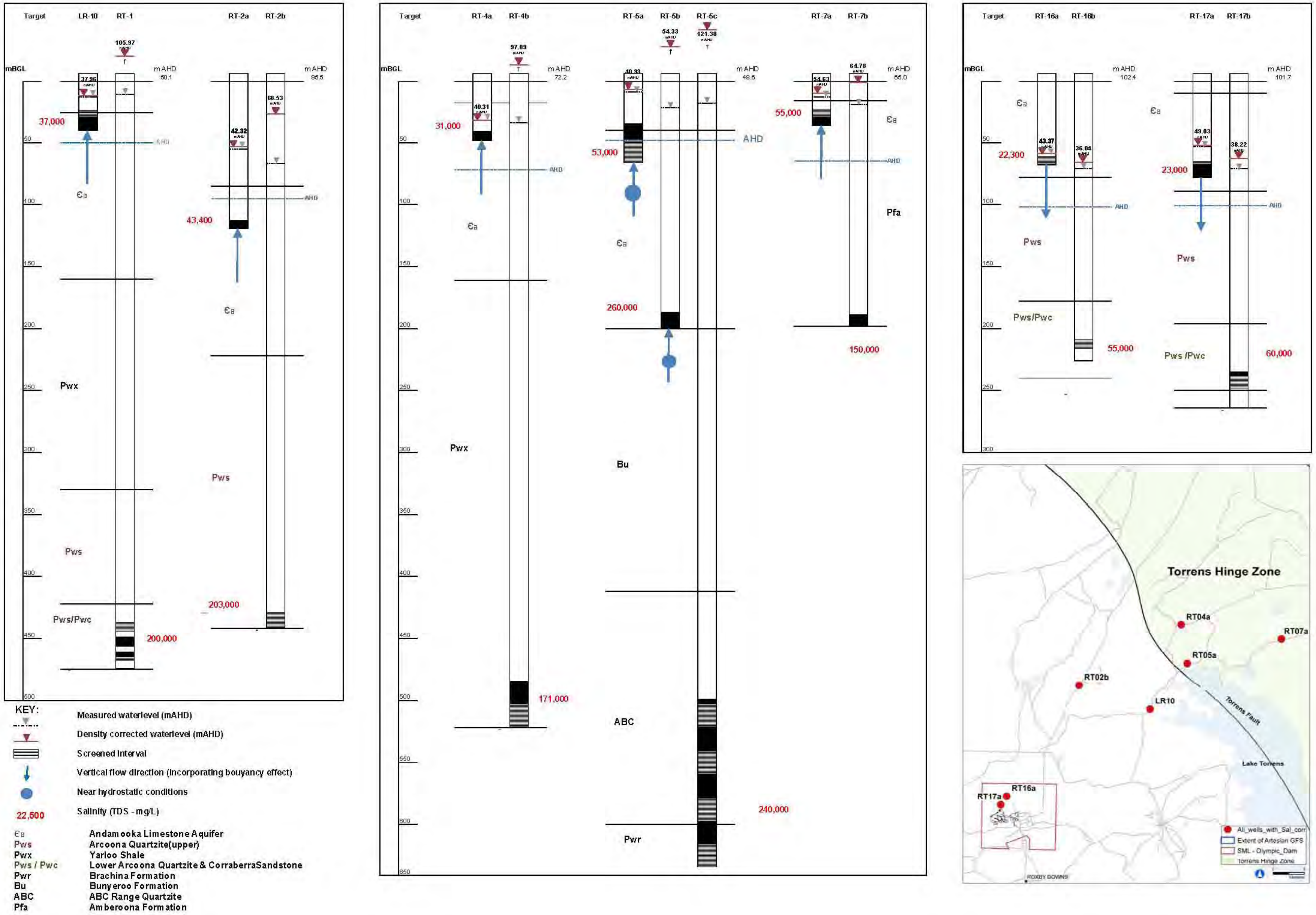

Figure 3.5
Nested monitoring sites

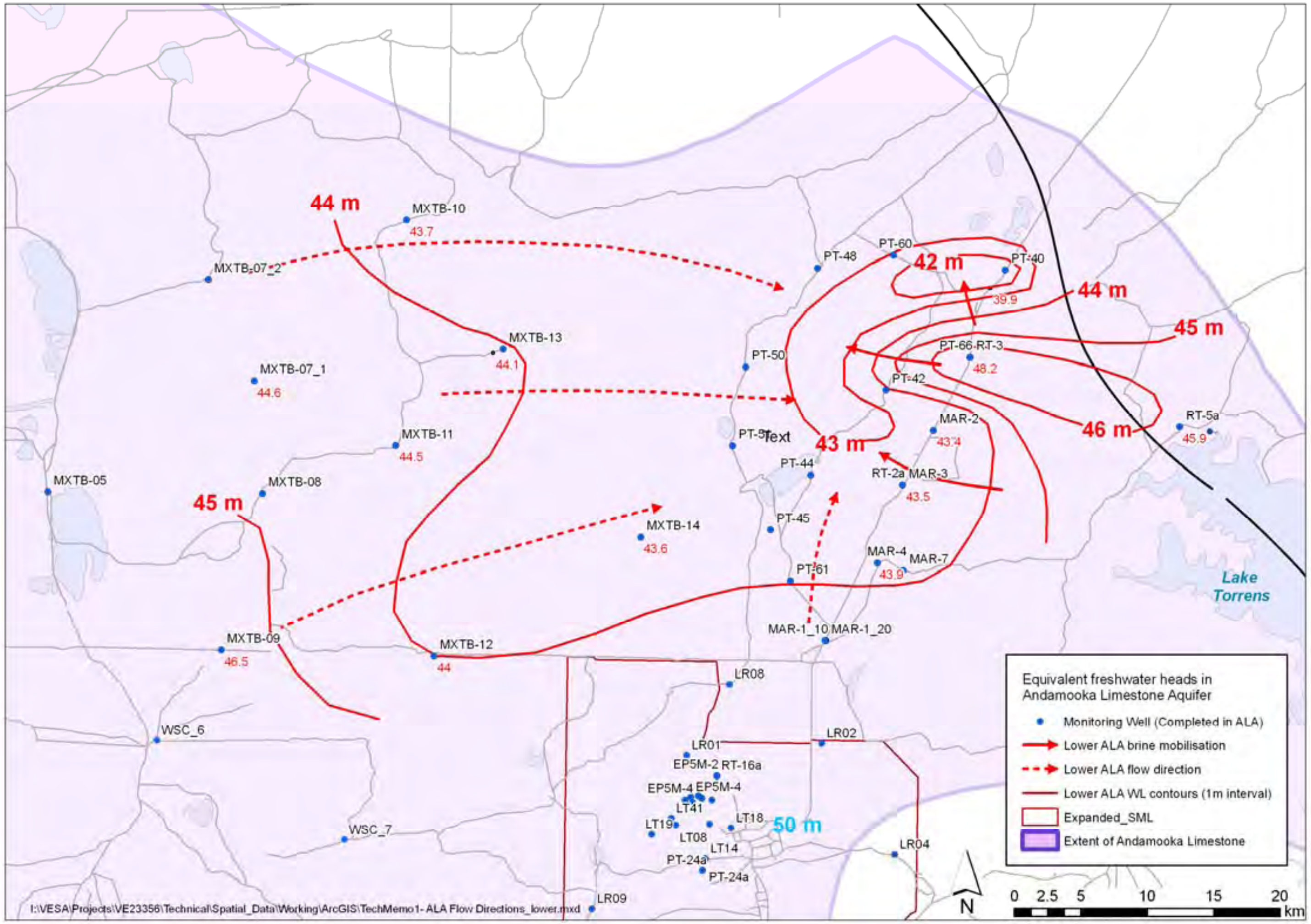

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Figure 3.6
Interpreted groundwater elevation contours for the lower ALA

The hydraulic gradient in the upper system lessens significantly through the central and eastern sections of the ALA, ranging from 3 x10^{-3} to 9x10^{-3}, corresponding with increased aquifer hydraulic conductivity as documented by pumping tests carried out at three sites in this area (MAR2, MAR3 and MAR4; SKM, 2010) and high airlift yields in other wells (e.g. greater than 20 L/s in PT40, PT42, PT44, PT48, PT51; SKM, 2010).

The lower system is characterised by corrected hydraulic gradients in a similar range to the overlying system (Figure 3.6). In contrast to the upper part of the aquifer, however, within 20 km of the northern end of Lake Torrens groundwater in the base of the ALA flows northwestward away from the playa toward the central portion of the ALA where drilling investigations show the base of the Andamooka Limestone is deeper than elsewhere on the Stuart Shelf.

The conceptual hydrostratigraphic cross-section schematic presented as Figure 3.7 shows brines ‘filling’ the deepest sections of the ALA and extending westward up to 50 km from Lake Torrens.

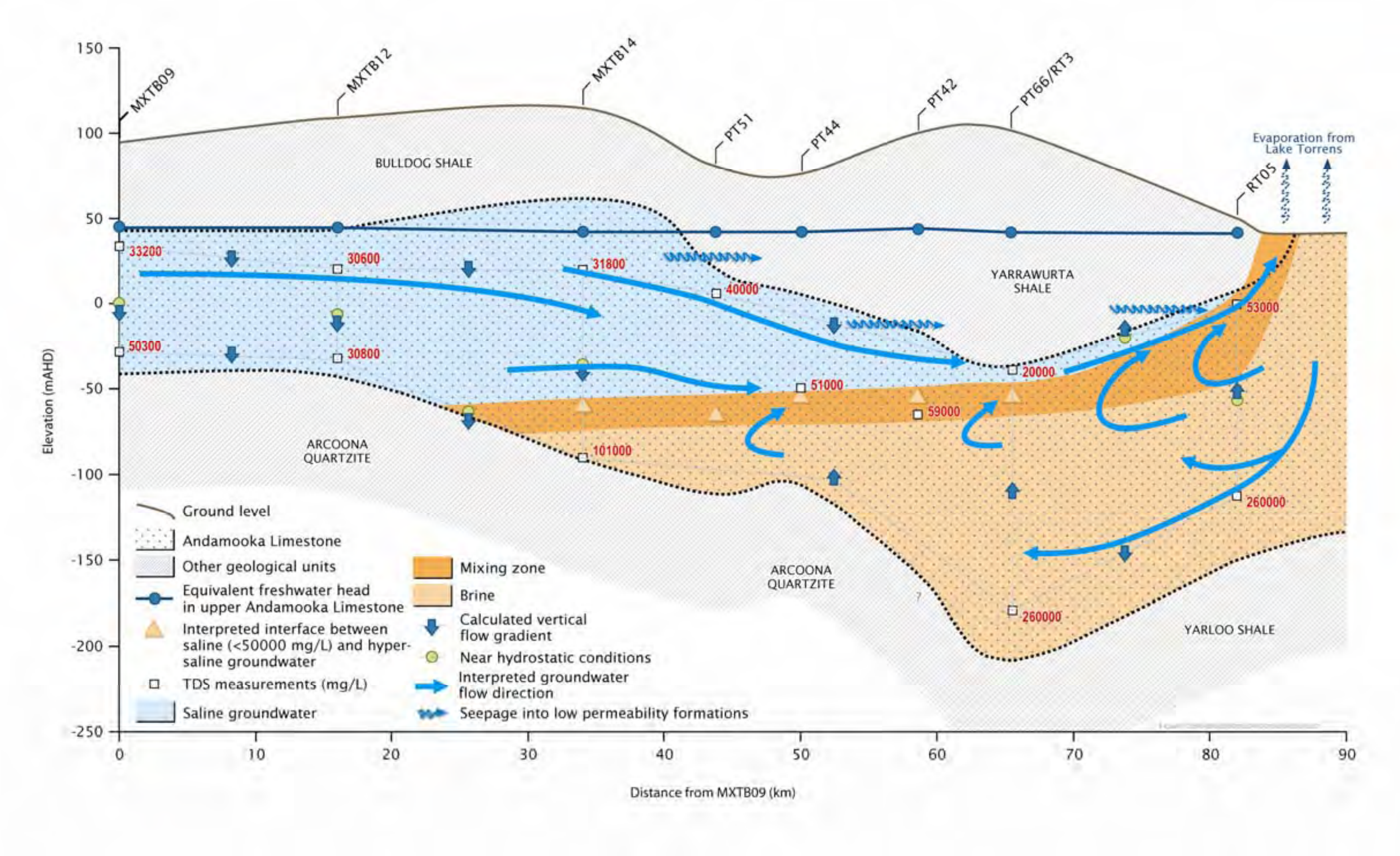
The location of the interface between saline waters and brine has been estimated from EC measurements made during drilling. At a distance of more than around 15 km from Lake Torrens, the interface appears to have a low gradient indicating a stable density stratified system. The interface is higher within the ALA closer to Lake Torrens. Saline groundwater moving towards the discharge zone is effectively forced upward by the density difference, as discussed earlier, and a thicker mixing zone develops. RT5a, located within a few kilometres of Lake Torrens, is screened at the top of the ALA and shows high salinity levels (TDS greater than 50,000 mg/L).

3.3.3. Tent Hill Aquifer (THA)

Figure 3.3 presents the interpreted groundwater elevation contours for the THA in the area of Olympic Dam. These contours are based on density corrected water level measurements (see Section 6).

Within the Olympic Dam SML, potentiometric data show the influence of more than 30 years of mine drainage through shafts and vent raises, as well as from the trial dewatering and depressurisation wellfield, which is now being operated as a site saline water supply.

Away from OD, groundwater salinity data for regional monitoring wells RT02b and RT01 (Figure 3.5) suggest hypersaline groundwater occurs at depth within the THA north of the SML, indicating brine from Lake Torrens is also collecting in the deeper hydrostratigraphic units north of Olympic Dam.



- **Figure 3.7 Schematic of shallow cross-sectional hydrostratigraphy and brine processes of the Stuart Shelf**

3.3.4. Potential vertical hydraulic gradients

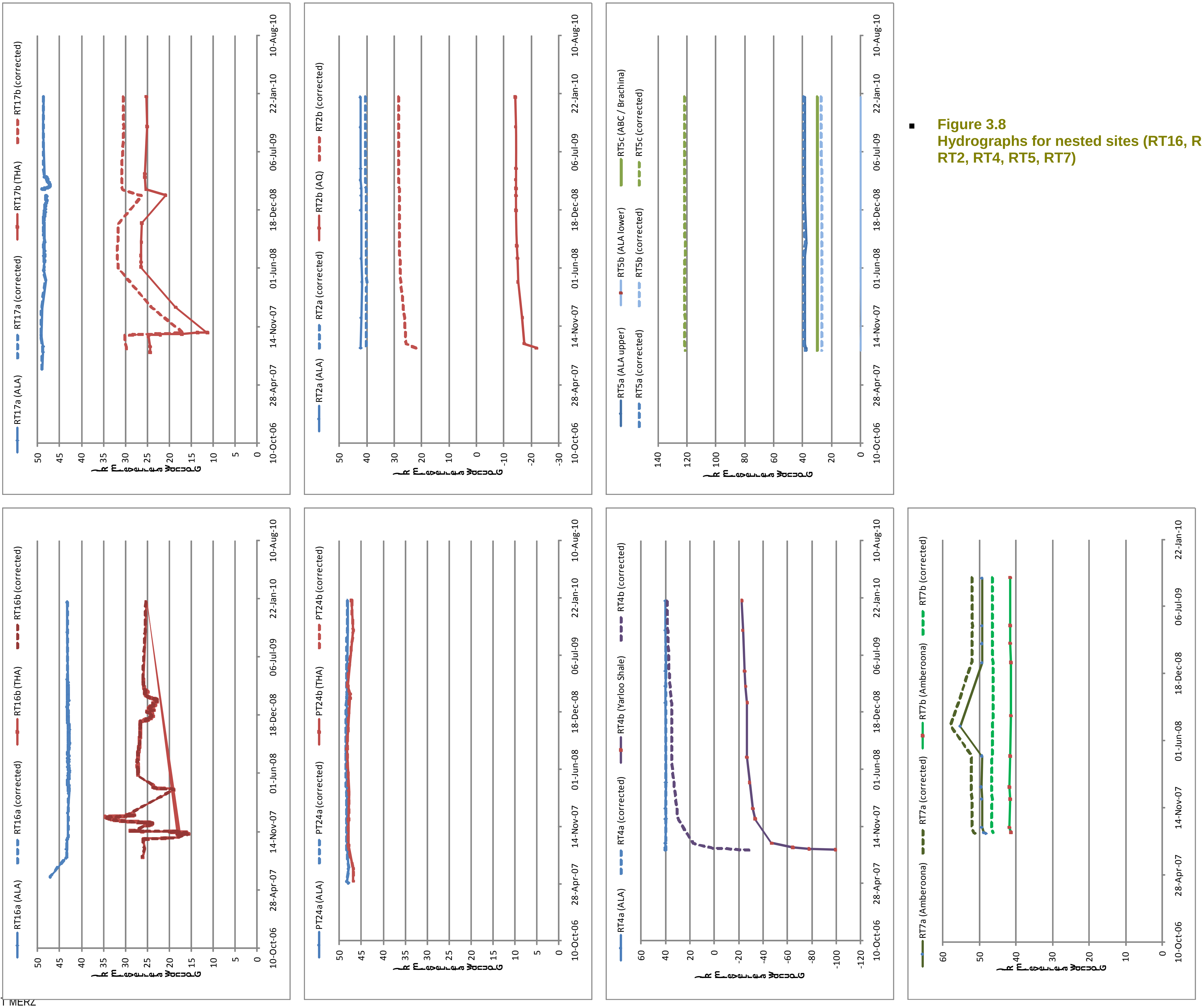
Figure 3.5 presents (corrected) fresh water heads and vertical gradients for nested groundwater monitoring sites screened across the Stuart Shelf and THZ. Attachment A presents the details of density corrections and vertical hydraulic gradients. Fresh water heads have also been calculated using the density conversion as outlined in Section 6.

At nested SML sites RT16 and RT17 (Figure 3.5) the corrected water levels within the ALA range from around 7 to 11 m higher than that of the underlying THA, indicating the potential for downward leakage from the ALA to the THA in this vicinity, through the Arcoona Quartzite aquitard (AQA). Density corrected hydrographs for RT16 and RT17 (Figure 3.8) support the above observation, indicating minimal connection between the ALA and underlying THA.

At sites RT-1 and RT-2, located north of the SML near to the northern end of Lake Torrens, density corrected water levels indicate the potential for upward leakage from the THA to the ALA (Figure 3.5 and 3.8).

For other regional nested sites, located north of the SML, corrected water levels also indicate the potential for upward leakage of groundwater from the deeper to shallower aquifers.

In considering overall groundwater flow patterns within the Arckaringa-Stuart Shelf GFS, it is likely that the brines beneath Lake Torrens (extending from the ALA down to, at least, the THA) cause ‘fresher’ groundwater moving to the east across the Stuart Shelf from the direction of the Arckaringa Basin groundwater system to move upward and discharge to the outer edges of Lake Torrens where the water table is typically less than a few metres deep.



- **Figure 3.8**
Hydrographs for nested sites (RT16, RT17, PT24, RT2, RT4, RT5, RT7)

3.4. Geological control on groundwater flow

3.4.1. Overview

The Neoproterozoic sedimentary rock sequences of the Stuart Shelf and Adelaide Geosyncline geological provinces are separated by the Torrens Hinge Zone (THZ). The western limit of the THZ is defined by the Torrens Fault, and the northern margin is defined by the Norwest Fault (Figure 3.9). The regional structures associated with the THZ are aligned along the north-south axis of Lake Torrens and strike to the northwest, running between Olympic Dam (OD) and Lake Eyre, through and beyond the Peake-Denison Inliers (Figure 3.9).

Two geological cross-sections (Figures 3.10 and 3.11) have been prepared, based primarily on available geological drillhole information (including a log of Margaret Creek Bore, which has been prepared based on very old drill cuttings stored by PIRSA; see SKM, 2010), and the Curdimurka (Callen et al., 1992), Billa Kalina (Ambrose and Flint, 1980) and Andamooka (Dalgarno, 1982) 1:250 000 Geological Map Sheets.

3.4.2. Stuart Shelf and *artesian* Eromanga Basin

General

The following presents information to support the interpretation that the Adelaide Geosyncline THZ forms a ‘barrier’ to interconnectedness between the Stuart Shelf and Great Artesian Basin.

Adelaide Geosyncline strata of the THZ occur in a broad zone extending from east of OD through to the northwest (Figure 3.9). The strata typically comprise of low permeability Neoproterozoic sediments that are folded and faulted. Because of the structure of these rocks the groundwater flow pathways are short and the groundwater flow systems are compartmentalised (Kellet et al, 1999). The low permeability of these strata, the compartmentalisation of the groundwater flow system, the topographic divide and, where available, observed groundwater elevations, provide compelling evidence for the presence of a groundwater divide between the Stuart Shelf GFS and the *artesian* Eromanga (GAB) GFS.

In Figure 3.10 the interpreted stratigraphic relationship between the various geological units of the region following a line from Olympic Dam in the south through to McEwin Bore in the north is shown. McEwin Bore is an artesian well that intersects the *artesian* Eromanga (GAB) aquifer. This well is located along the Margaret Creek drainage approximately 10 km northeast of the Welcome, Billa Kalina and Bakewell Springs.

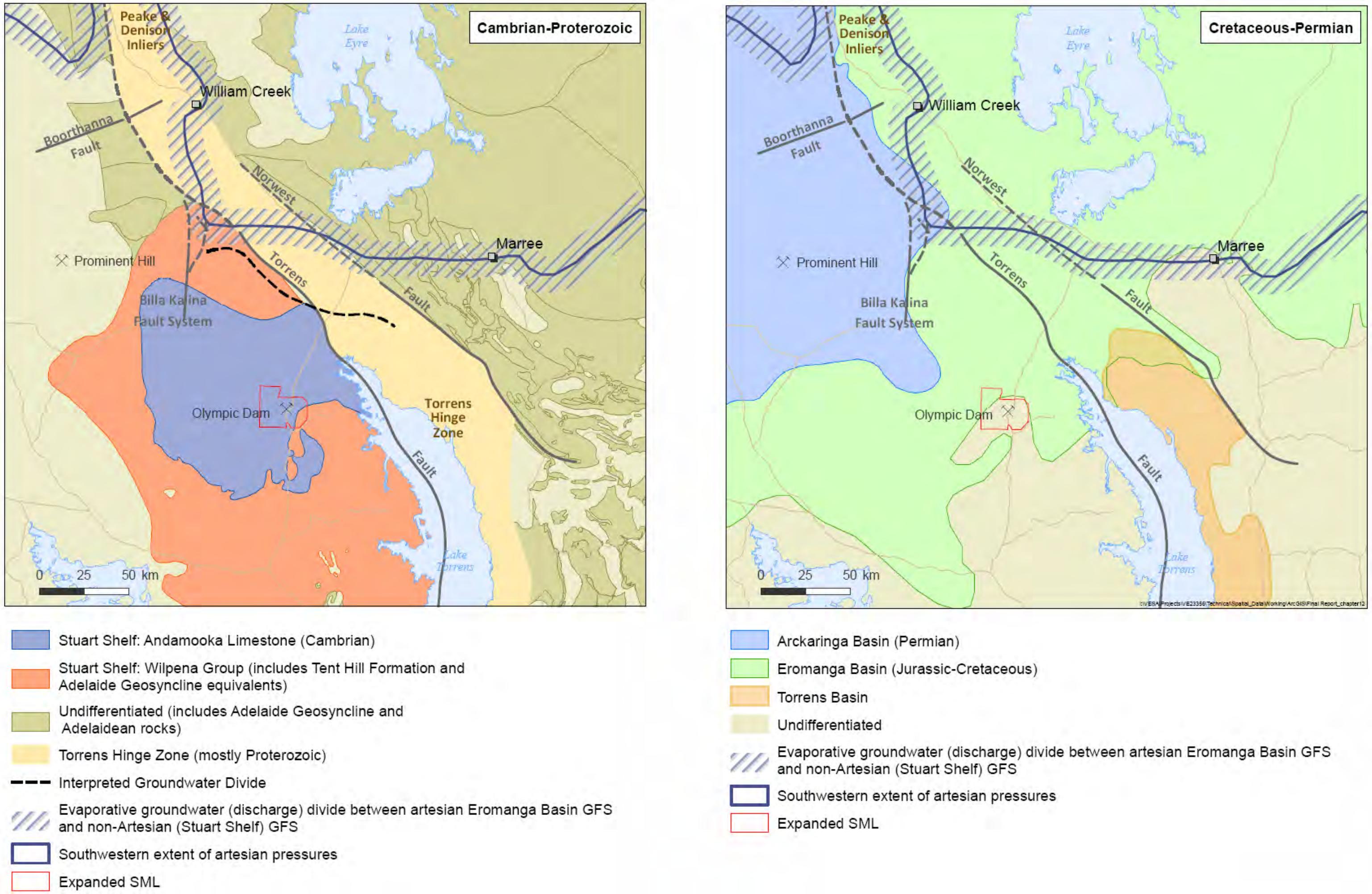


Figure 3.9 Geological locality plan

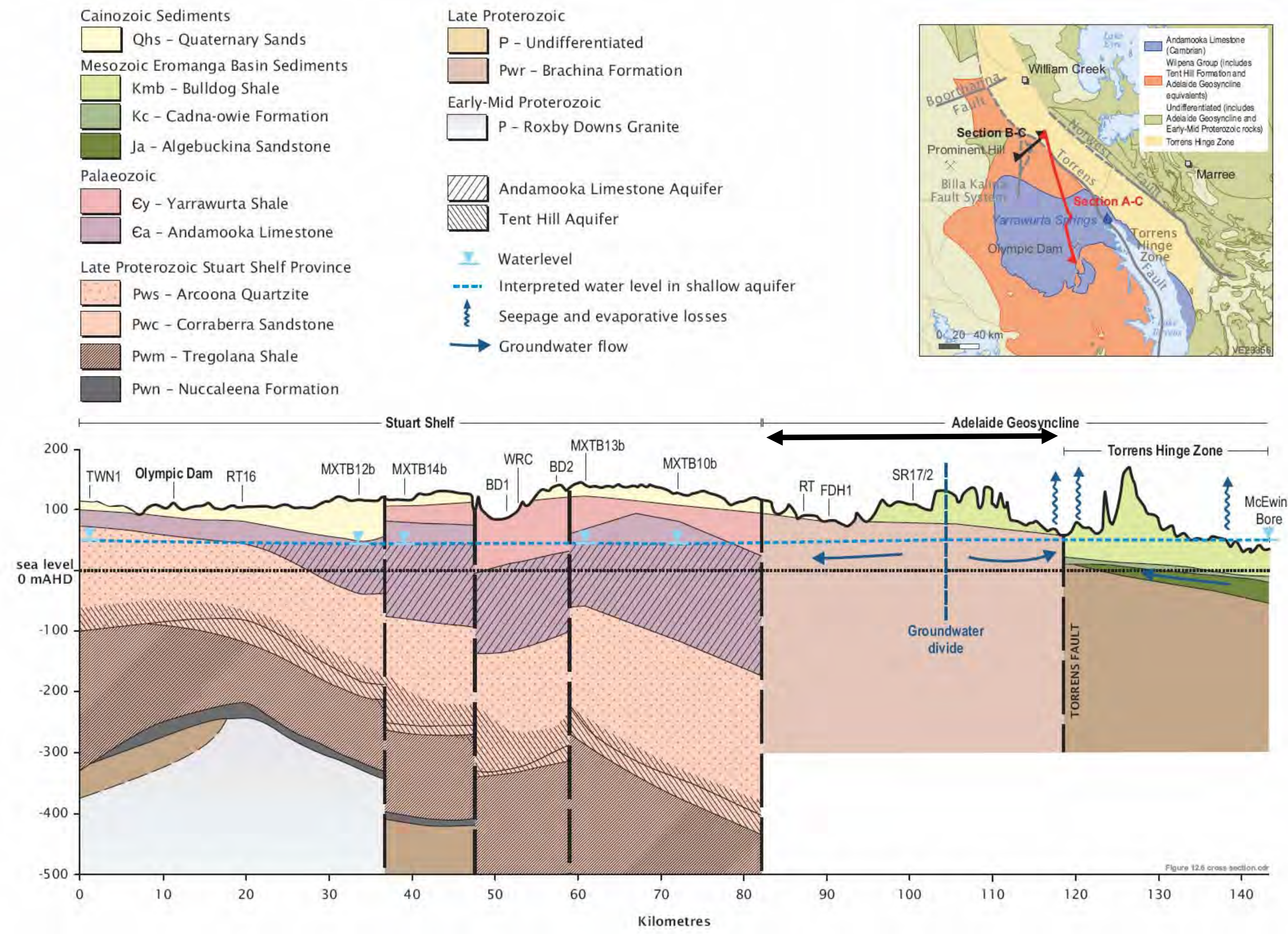


Figure 3.10 Cross-section A-C showing interpreted hydrostratigraphic and structural relationships north of OD

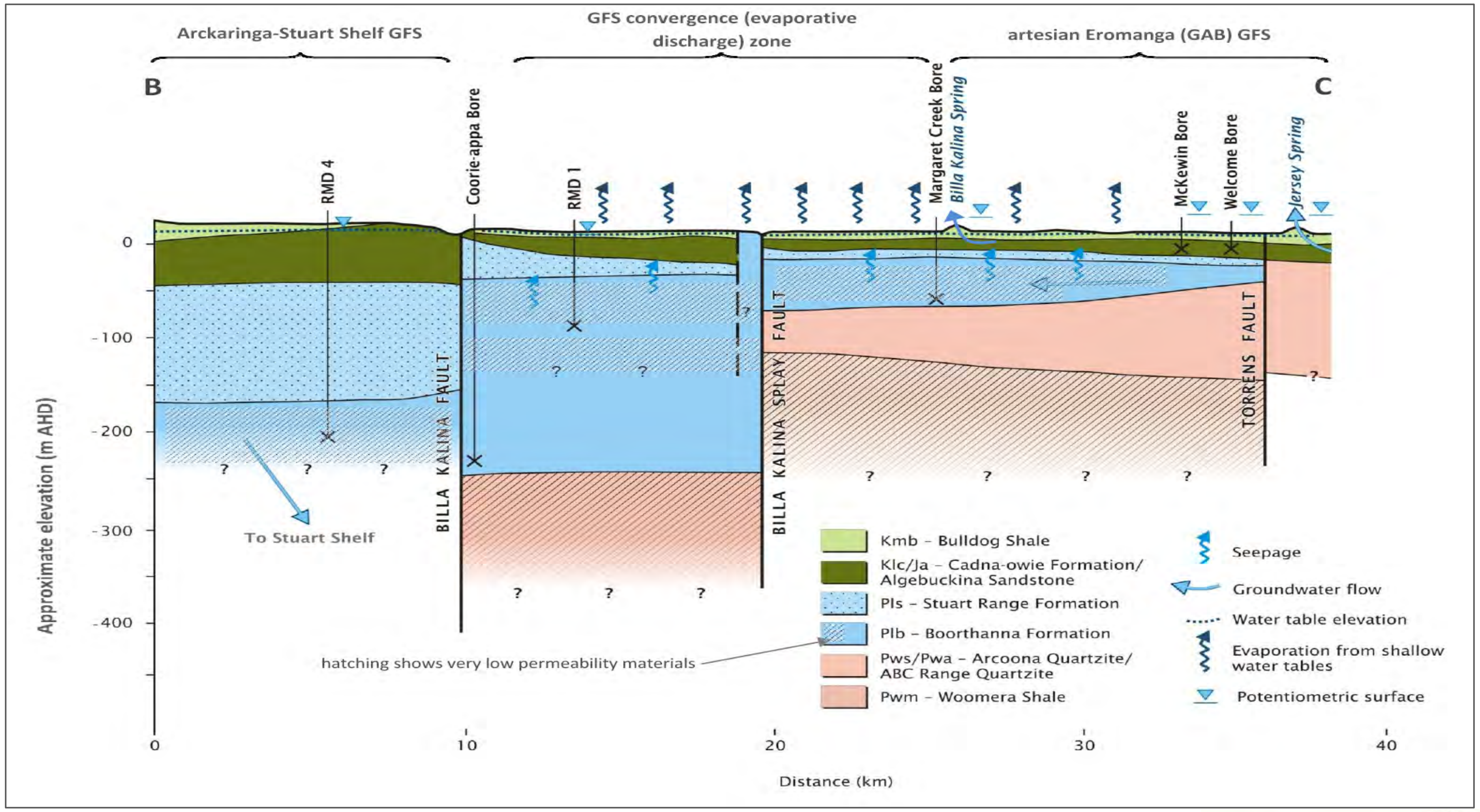
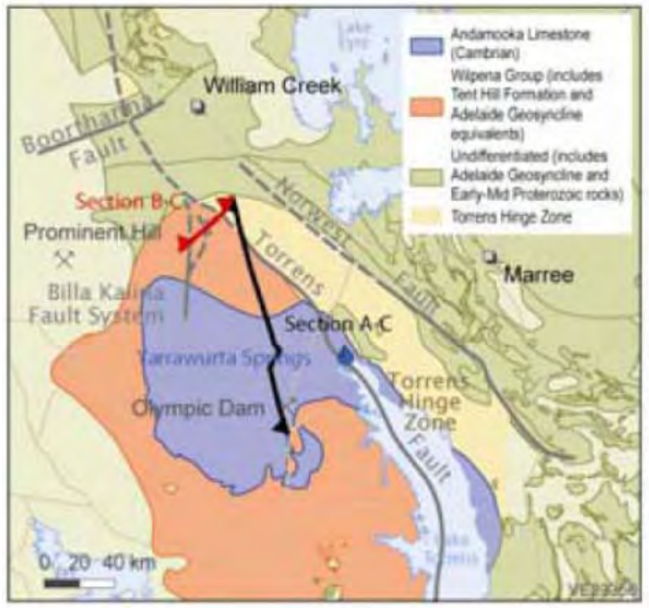
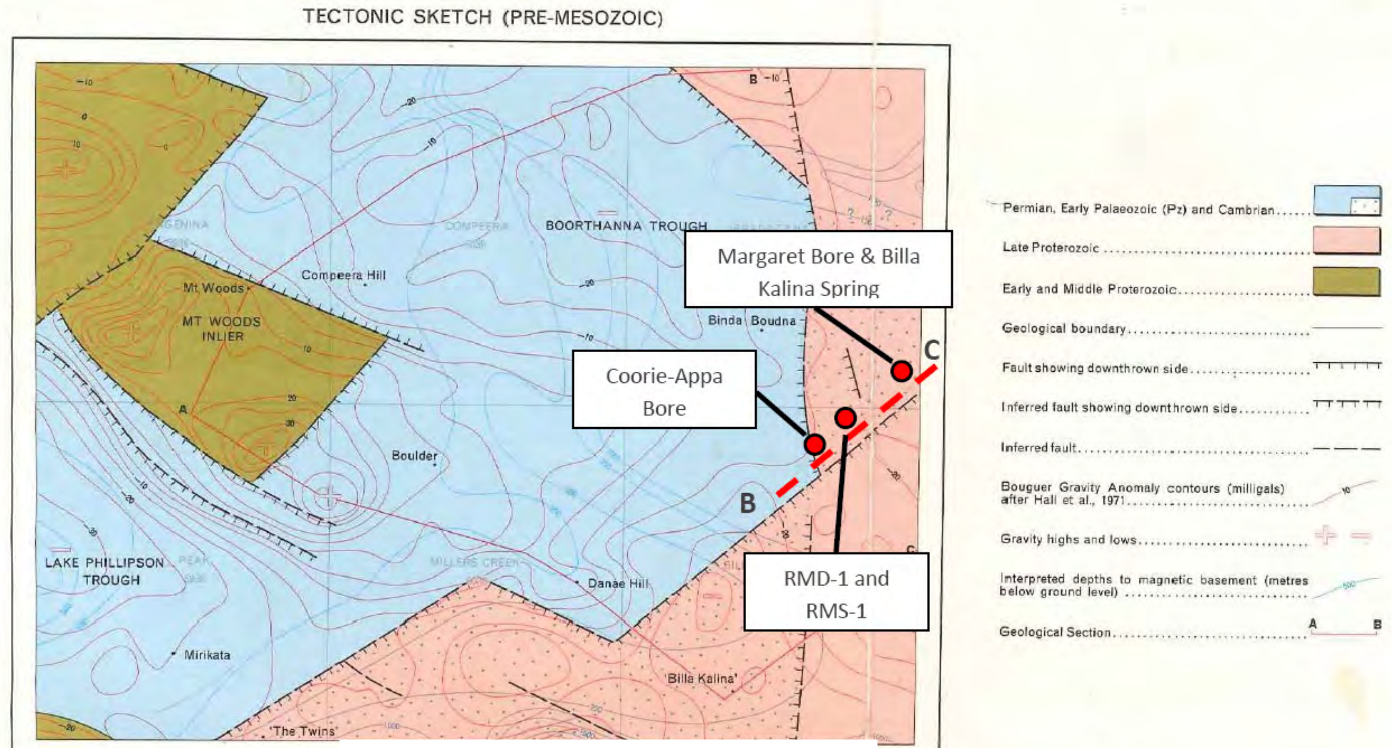


Figure 3.11
Cross-section B-C showing interpreted hydrostratigraphic and structural relationships from the Arckaringa Basin through to the Eromanga Basin





Tectonic section (after: Ambrose and Flint, 1980)

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The northern limit of the Stuart Shelf appears to be structurally controlled, where normally deeper Adelaidean sediments have been brought close to the surface, e.g. the Brachina Formation (including equivalents of the Tent Hill Formation). These sediments in turn are overlain unconformably and very close to surface by remnants of the Cretaceous Bulldog Shale of the Mesozoic Eromanga Basin.

Based on limited drillhole and available geological information in the immediate vicinity of McEwin Bore, it is apparent that Adelaidean THZ rocks (possibly the Brachina Formation) are present at depth. These are overlain unconformably by a significantly thicker cover of Eromanga Basin sediments, consisting primarily of Bulldog Shale underlain by the Cadna-owie Formation and Algebuckina Sandstone (the *artesian* Eromanga (GAB) aquifer). These Eromanga Basin sediments vary in thickness and extent, and are largely controlled by the contours of the erosional surface of the underlying Adelaidean sediments on which they were deposited. They generally thicken out to the north and east.

Permeability of Adelaide Geosyncline rocks

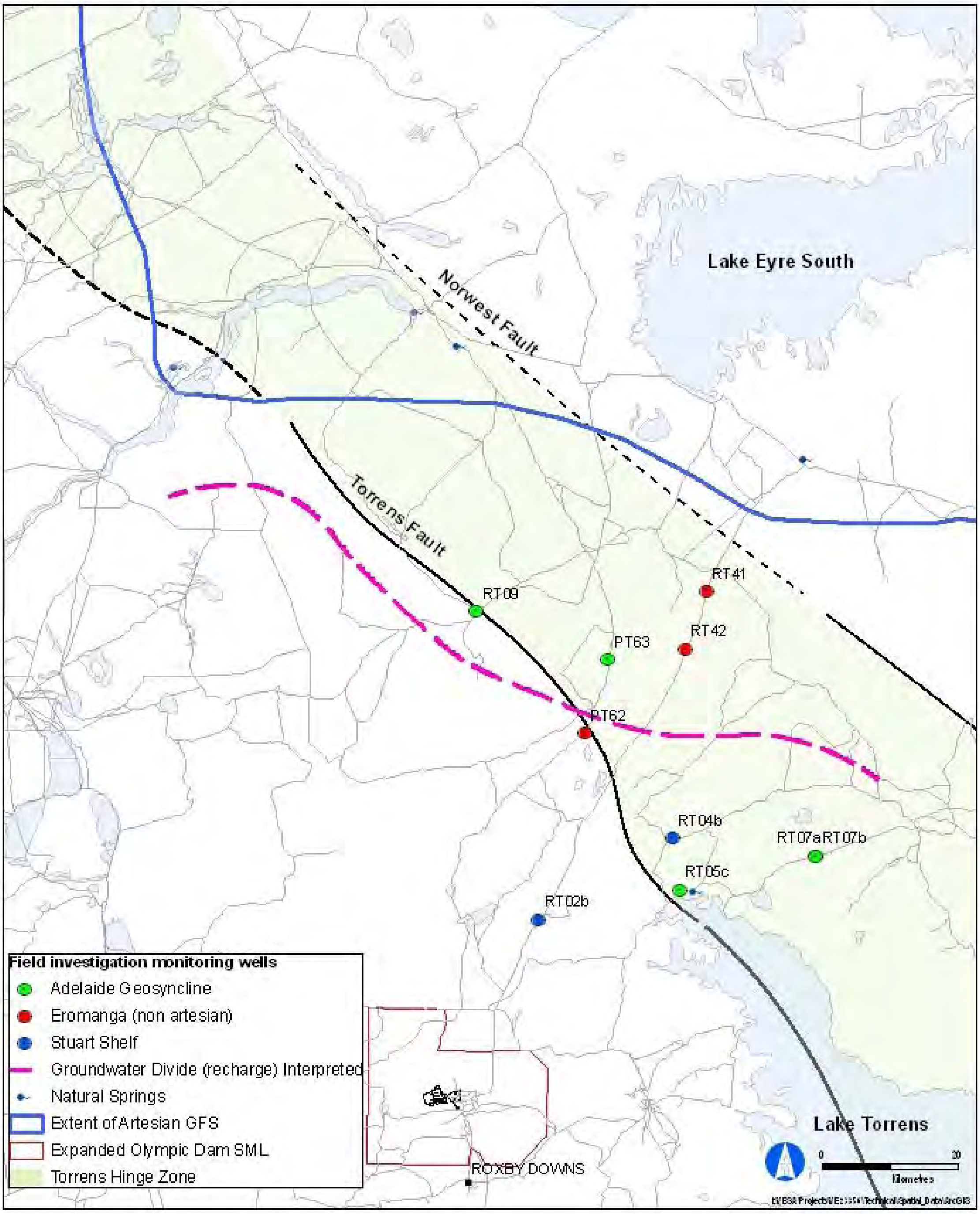
Falling head ‘slug tests’ were carried out at ten key groundwater monitoring wells intersecting Adelaide Geosyncline rocks within the THZ, as well as single wells intersecting Stuart Shelf rocks and remnant Eromanga sediments. Figure 3.12 presents a locality plan for the tests.

Table 3.1 summarises the hydraulic conductivity estimates derived for the ‘aquifers’ intersected by the wells. Attachment B presents details of the investigations, including procedures and data analysis.

Figure 3.13 presents a locality plan showing the range in hydraulic conductivity values for the regional aquifers. As shown, the permeability of Adelaide Geosyncline rocks in the area are typically orders of magnitude lower than either the Stuart Shelf aquifers or the *artesian* Eromanga (GAB) aquifer.

The results of the falling head tests are consistent with the results of other testing conducted in the broader area (in the case of the Cadna-owie Formation), lithologies tested and the literature (Freeze and Cherry, 1979).

Aquifer tests conducted near Olympic Dam mining lease provide estimates of hydraulic conductivity for the Tent Hill aquifer (THA) ranging between $3x10^{-2}$ and 2.2m/d, and for the ALA of around 7 m/d (SKM, 2010), but to the north of OD the permeability of this aquifer is much less possibly due to compression of the aquifer skeleton arising from deformation (Douglas et al, 2009).



- **Figure 3.12 Location of falling head tests**

- **Table 3.1 Falling head tests – summary of hydraulic conductivity estimates**

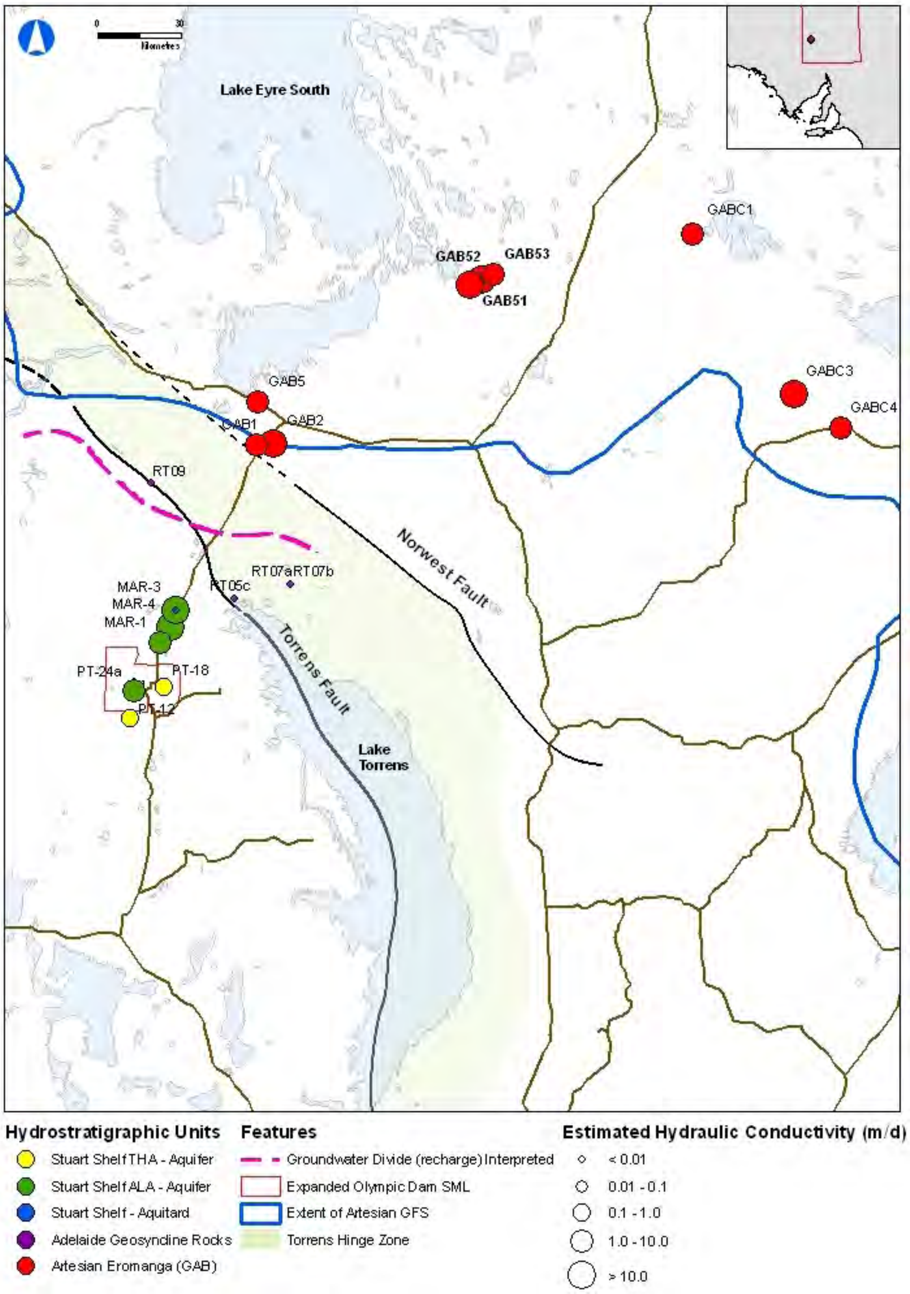
Hydrogeology	Well ID	Hydraulic Conductivity (m/d)	
		Bouwer & Rice	Hvorslev
Stuart Shelf			
Arcoona Quartzite aquitard	RT02b	2×10^{-3}	5×10^{-3}
Adelaide Geosyncline (THZ)			
ABC Quartzite / Brachina Formation	RT05c	4×10^{-3}	4×10^{-4}
Brachina Formation	RT09	1×10^{-4}	1×10^{-4}
Amberoona Formation	RT07a	1×10^{-3}	1×10^{-2}
Amberoona Formation	RT07b	2×10^{-3}	3×10^{-4}
Brachina Formation	PT63	4×10^{-2}	4×10^{-2}
Non artesian Eromanga Basin			
Bulldog Shale	PT41	7×10^{-1}	1.3×10^{0}
Bulldog Shale	PT42	1×10^{0}	1×10^{-1}
Cadna-owie Formation	PT62	3.3×10^{1}	323×10^{1}

Further north within the *artesian* Eromanga (GAB) GFS estimates of hydraulic conductivity are reported to range from around 5 to 40 m/d (REM, 2005; WMC Resources, 1997; AGC, 1982).

3.4.3. Arckaringa Basin and artesian Eromanga Basin

To the northwest of Olympic Dam in the vicinity of the Billa Kalina fault system and the Billa Kalina Spring, Proterozoic basement strata are overlain by Permian sediments of the Arckaringa Basin, which are in turn overlain by Eromanga Basin sediments (Figures 3.9 and 3.11).

Logging of very old samples taken during the construction of Margaret Creek Bore indicate almost 90 m of Boorthanna Formation underlie around 50 m of *artesian* Eromanga (GAB) Basin sediments and overlie Proterozoic quartzite (the Arcoona Quartzite or its equivalent). Figure 3.11 presents the interpreted geological cross-section between McEwin Bore and Coorie-Appa Bore, showing the interpreted stratigraphy and structural relationship of the Adelaidean (Adelaide Geosyncline), Permian (Arckaringa Basin) and Mesozoic (*non-artesian and artesian* Eromanga Basin) sediments. Note that the cross-section is aligned along the northern side of the inferred Margaret Creek Fault, to the south of which Proterozoic rocks sub-crop and outcrop, and occurs within what Costelloe et al. (2010) describe as the *transition* and *saturated* groundwater discharge zone, where evaporative losses for groundwater can be expected to range up to and beyond 100 mm/yr.



- **Figure 3.13 Range of hydraulic conductivity estimates for the different regional hydrostratigraphic units**

The primary aquifer within the Permian Arckaringa Basin suite of sediments within the area of interest occurs within the Boorthanna Formation, a diamictite. Drilling logs for the area show the formation is extremely heterogeneous in keeping with its depositional environment and aquifers, where they occur, are formed within discrete ‘pods’ of silty and sandy sediments that are separated both vertically and laterally by a low permeability siltstone / mudstone matrix. Drilling in the broader region shows significant structural displacement and block faulting of the Permian sediments.

The area of particular interest to this discussion is the Billa Kalina Spring, and nearby springs and wells. Not only does this location lie at the structurally and lithologically complex juncture of the *artesian* Eromanga (GAB) Basin and the Arckaringa Basin, it is also intersected by major faults that have dislocated most geological units in the region (Proterozoic through to Mesozoic; see Figure 3.11). The faults include the Torrens Fault zone, the Margaret Creek Fault (along the present alignment of Margaret Creek) and the Billa Kalina Fault system. These faults effectively form a triangle with Billa Kalina springs located at its eastern apex (Figure 3.11).

To the east of the Torrens Fault, toward McEwin Bore, there is a thicker sequence of Mesozoic Eromanga Basin sediments (the *artesian* Eromanga aquifers). Permian sediments (Ludbrook, 1961) occur immediately east of the Torrens Fault, but it is concluded from the information presented on map sheets, the convergence of two GFSs and hydrochemistry (see Section 3.5) that these sediments are isolated from the Arckaringa Basin proper.

Significant vertical displacement along the Margaret Creek Fault has brought Permian Arckaringa Basin and Mesozoic Eromanga Basin sediments into contact with Proterozoic strata, effectively forming a barrier to groundwater flow to the southeast. However, elsewhere, where the displacement is not so great (eg. along the Billa Kalina Fault system), Permian sediments (that do not necessarily form aquifers) possibly remain in contact.

Evidence from the Arckaringa Basin shows that structural control of aquifer response to groundwater abstractions is significant, and the Billa Kalina Fault in particular isolates the Arckaringa Basin groundwater system west of the fault from the systems occurring on the east side of the fault. OZ Minerals (2009) presents data supporting this observation. Groundwater potentiometric data for regional compliance monitoring wells are presented on Figure 3.14 (a locality plan for these wells is presented ion Figure 3.15). RMD-1 screens a thin sequence of aquifer material in the Boorthanna Formation to the east of Billa Kalina Fault, RMD-4 screens the Boorthanna aquifer west of the Billa Kalina Fault and RMD-7 screens the Boorthanna aquifer west of Prominent Hill’s wellfield. RMS wells screen the *non-artesian* Eromanga aquifer. The hydrographs show that groundwater levels at RMD-1 have not responded to abstractions from the Prominent Hill wellfield, whilst a downward trend is evident in the RMD-4 data. The hydrographs also show the shallower Eromanga aquifer (RMS wells) is not responding to abstractions.

3.5. Hydrogeochemistry

3.5.1. Overview

Groundwater data selected for analysis of regional hydrogeochemistry are sourced from public sources (e.g. OZ Minerals, 2008) and work conducted for BHP Billiton (SKM, 2010).

Groundwater sample locations for the assessment of aquifer connectedness using hydrogeochemical data are presented in Figure 3.16.

3.5.2. Salinity

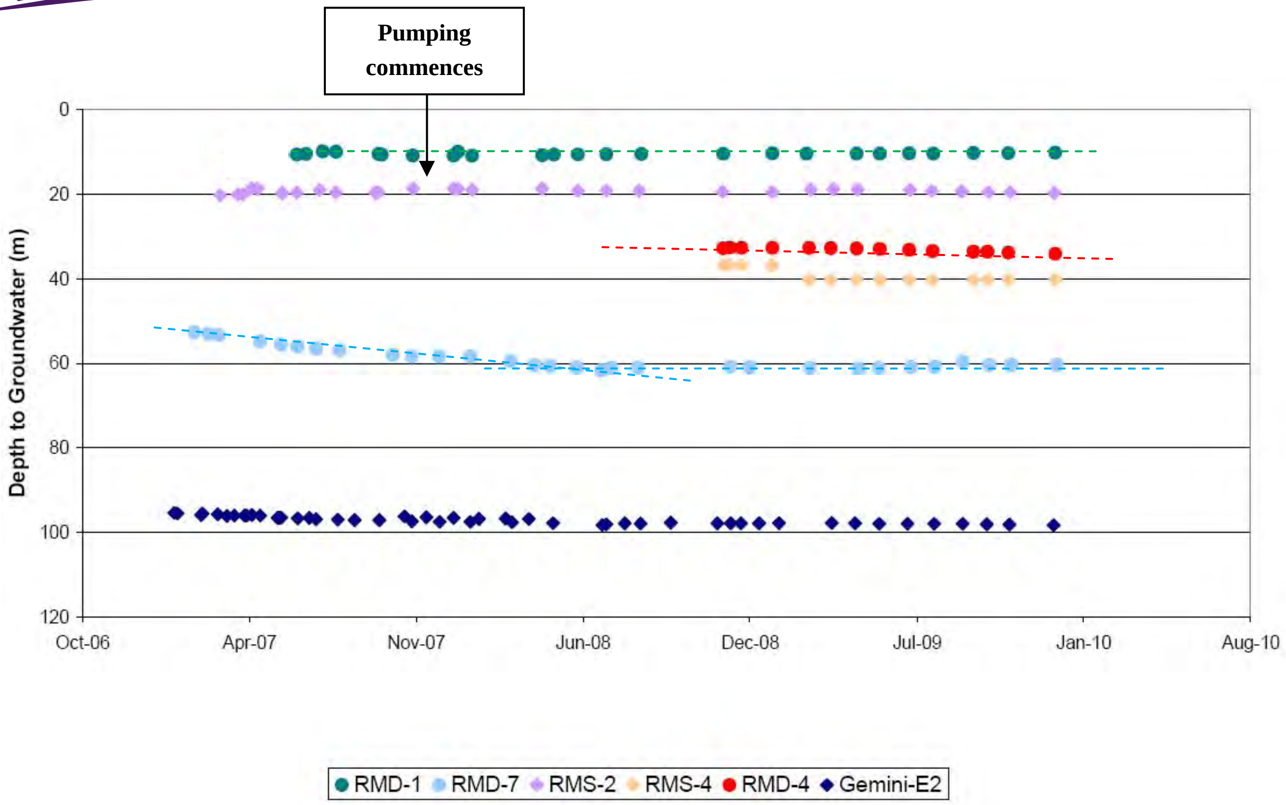
Figure 3.17 presents a comparison of reported groundwater salinities (as TDS) for the *artesian* Eromanga (GAB) aquifers (and stock wells supported by these aquifers), and the Boorthanna aquifer (Arckaringa Basin) from west of the Billa Kalina Fault system. The data, and the fact that an extensive evaporative groundwater discharge zone separates the two GFSs strongly suggests that *artesian* Eromanga (GAB) groundwaters are very unlikely to be supported by the Boorthanna aquifer to the west of the Billa Kalina Fault system.

3.5.3. Major ions

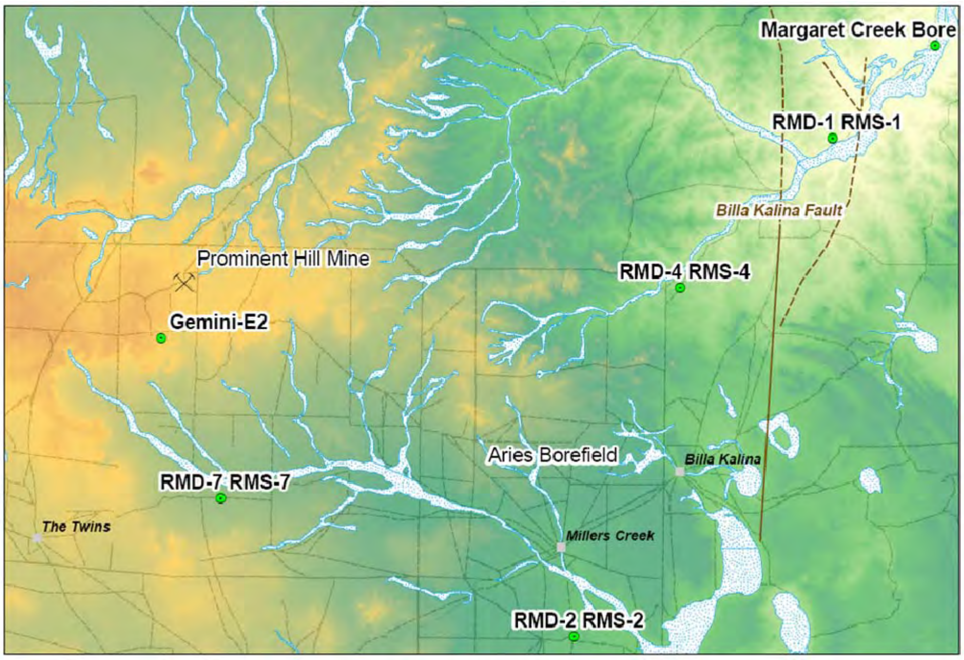
Major ion chemistry was analysed with the assistance of Piper plots. The data presented in Figure 3.18 (with components of calcium, magnesium, and carbonate multiplied by ten to better distinguish potential groupings) clearly show the hydrogeochemical distinctness of the *artesian* Eromanga (GAB) aquifers compared to other aquifers within the broader OD region.

The data support the conceptual hydrogeological model of the OD region, which identifies two primary groundwater flow systems (GFSs) with different groundwater origins, i.e. the Arckaringa-Stuart Shelf GFS and the *artesian* Eromanga (GAB) GFS. The *artesian* Eromanga (GAB) groundwaters consistently demonstrate a lower magnesium signature in terms of cations and are more bicarbonate enriched in regards to anions.

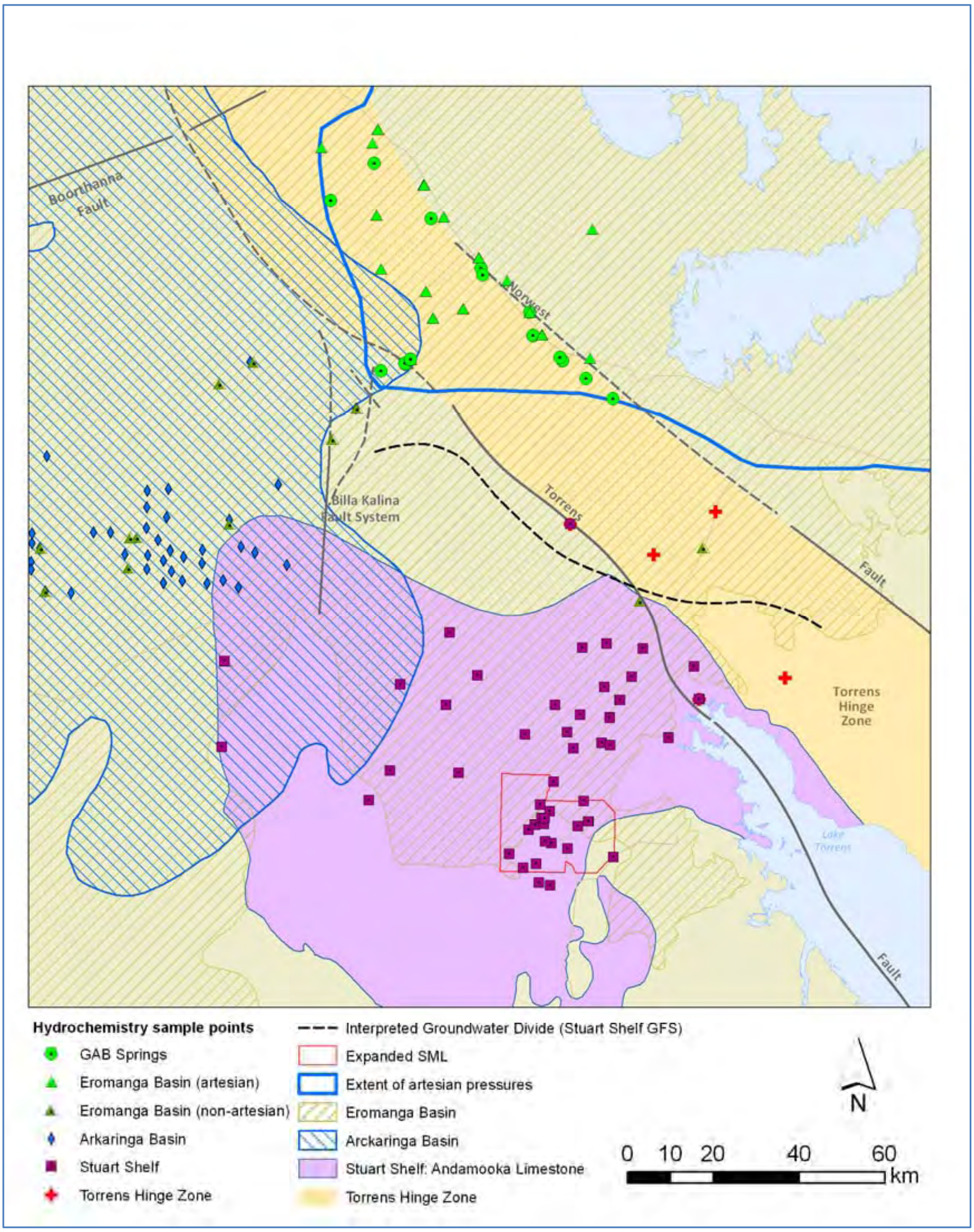
Detail of the water chemistry is provided in the Piper plot presented as Figure 3.19, which includes locations of water quality data points to illustrate major ion groundwater chemistry for samples taken from the Arckaringa Basin, *non-artesian* Eromanga Basin and *artesian* Eromanga (GAB) Basin.



- **Figure 3.14**
  Regional potentiometric response to operation of the Prominent Hill mine water supply (source: OZ Minerals, 2009)



- **Figure 3.15**
  Locality plan for well hydrographs presented on Figure 3.14



- Figure 3.16 Location of wells and GAB springs used for regional hydrogeochemical analysis

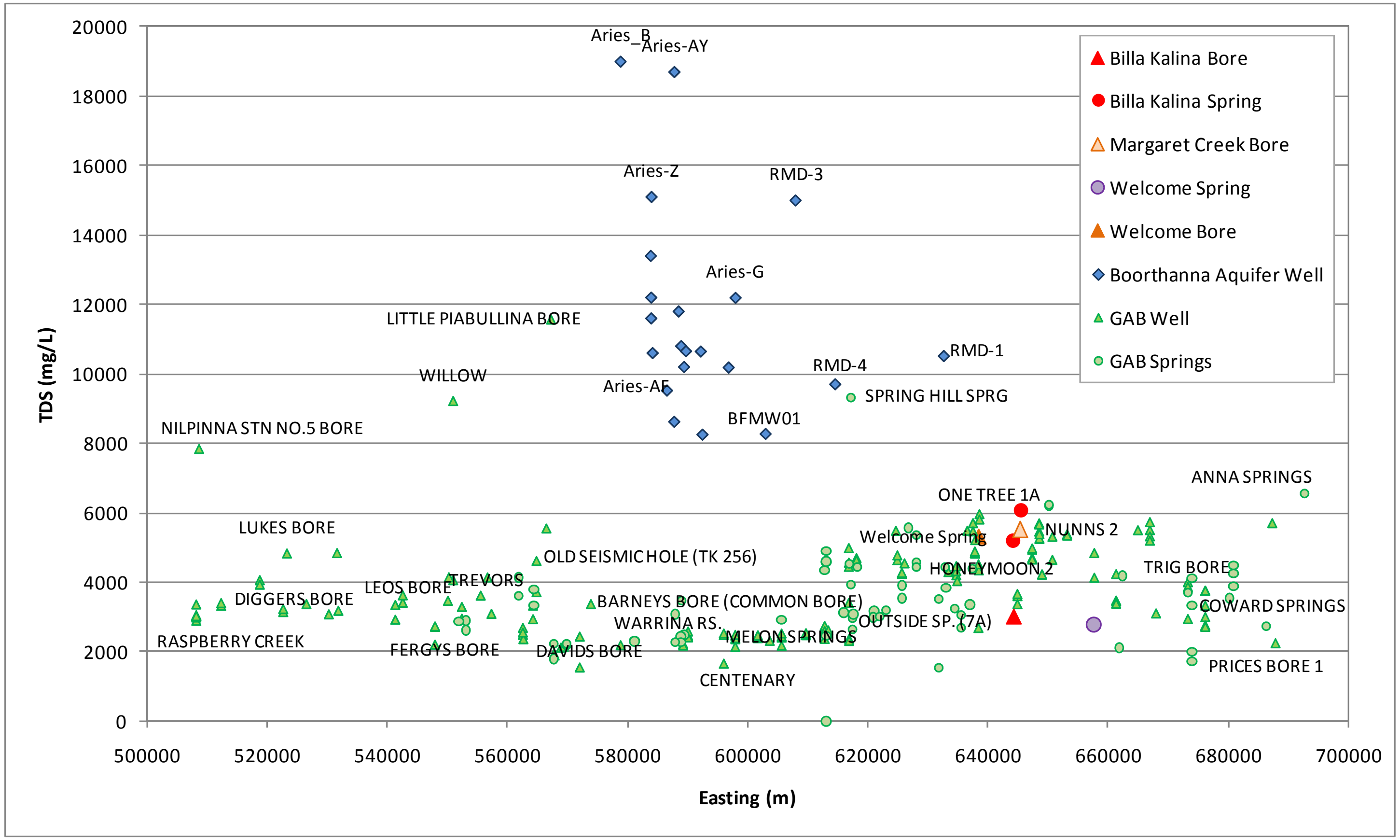


Figure 3.17
Comparison of TDS values for groundwater groups in the vicinity of the Billa Kalina springs

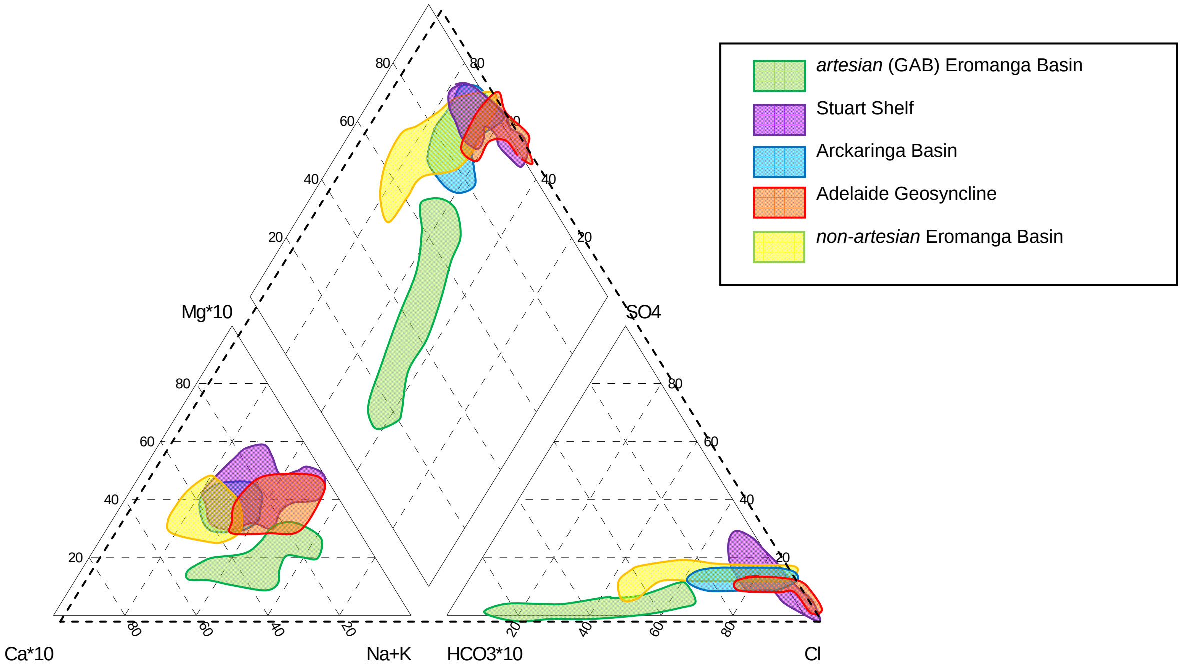


Figure 3.18 Piper plot presenting compiled regional major ion data

Figures 3.18 and 3.19 suggest four hydrogeochemical zones occur in the region:

1) The *artesian* Eromanga (GAB) Basin centred on Beautiful Valley.
2) The *artesian* Eromanga (GAB) Basin centred on Coward Springs.
3) The margins of the *artesian* Eromanga (GAB) and Arckaringa Basins, centred on the Billa Kalina spring group, including Margaret Creek and McEwin Bores, and the RMD1 monitoring well.
4) The Arckaringa Basin, west of Billa Kalina Fault system.

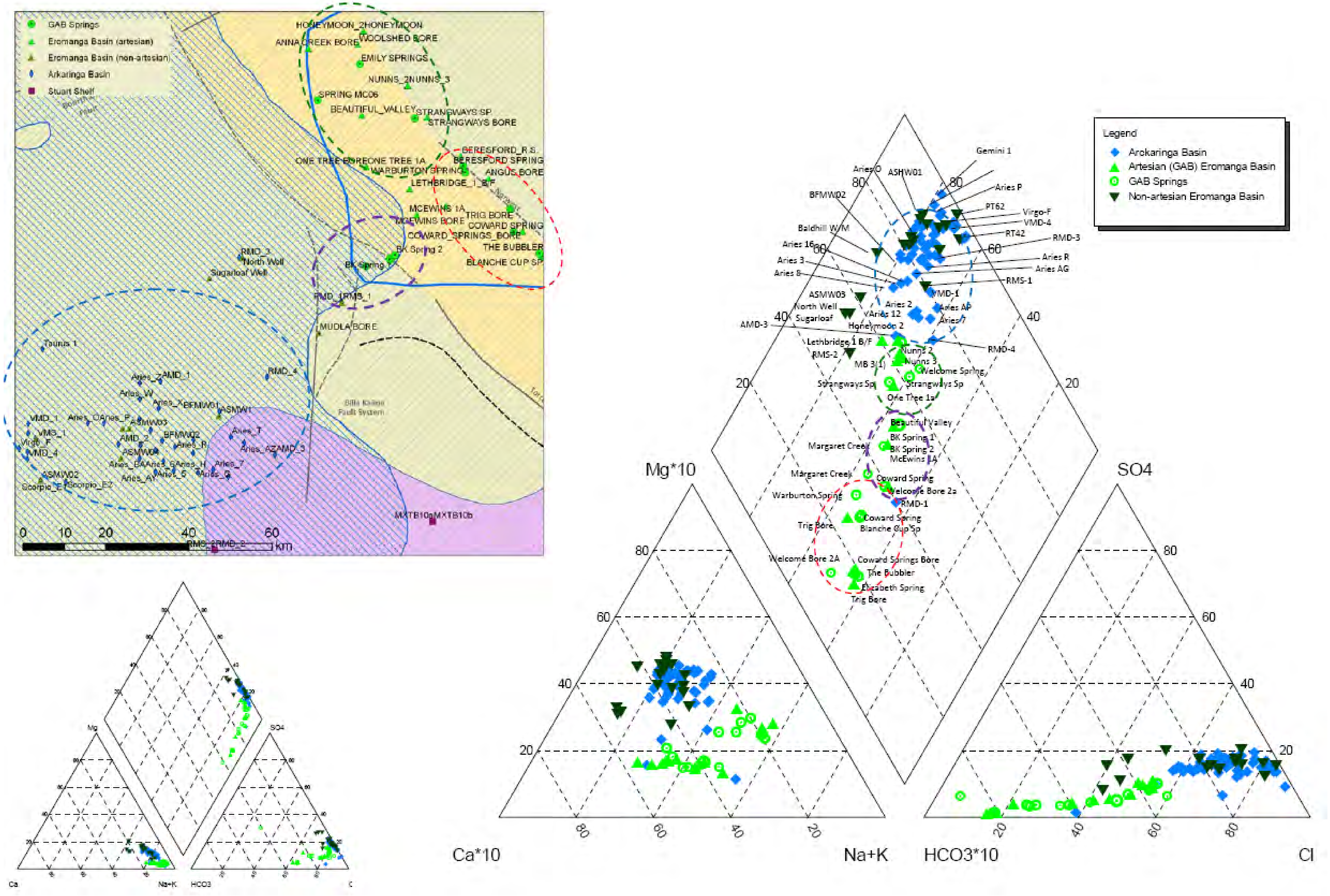


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Figure 3.19
Piper plot presenting regional major ion data in detail

note:
The data for Mg, Ca and HCO_3 have been multiplied by a factor of ten to spread the data on the plot. A smaller plot without the factor has been attached for comparison.

RMD1 well was constructed into the Boorthanna near the margin of the *artesian* Eromanga (GAB) Basin. Scatter plots of major ions (Attachment C) show that RMD1 groundwater has a very different hydrogeochemical signature to many other waters in the region, including the Billa Kalina Spring group and Arckaringa Basin waters (particularly with regard to Na-Ca, Cl-HCO_3, Ca+Mg-Na, Cl-K, Cl-Ca/Cl), although the Piper plot (Figure 3.19) shows RMD1 groundwater plots with data from Billa Kalina Spring and, even, Coward Springs (considered to be derived from *artesian* Eromanga (GAB) Basin). This disparity is possibly the result of complex hydrogeochemical interactions occurring with the *saturated zone*, as described by Costelloe et al. (2010), that separates the Arckaringa-Stuart Shelf and *artesian* Eromanga (GAB) GFSs.

Isotope analysis

Age dating of groundwaters can be used to provide an indication of the residence time of groundwaters within aquifers, distinguish between different groundwater groups, or identify mixing of groundwaters of different ages. The ^{36}Cl isotope is useful in hydrogeological studies due to its radioactive decay properties (half life $3x10^5$ years), such that ^{36}Cl:Cl ratios can be used to compare ages of groundwaters up to two million years old. Older groundwaters have a lower ^{36}Cl:Cl ratio, and lower concentrations of ^{36}Cl (atoms per litre) than comparatively younger groundwaters.

Available ^{36}Cl concentrations in groundwater, presented in Table C.1 (Attachment C, with references) and Figure 3.20, show a marked contrast between groundwaters from the *artesian* Eromanga (GAB) aquifers and other regional aquifers.

In particular, the results show:

- southwestern *artesian* Eromanga (GAB) groundwaters have significantly lower ^{36}Cl concentrations compared to groundwaters in the other regional groundwater systems;
- Stuart Shelf and Adelaide Geosyncline groundwaters report notably elevated ^{36}Cl values, which likely indicate more recent recharge; and
- the ^{36}Cl signature of Yarra Wurta Springs discharge and groundwater in the Amberoona Formation (an Adelaide Geosyncline formation) are very similar, suggesting the spring discharge is sourced largely from east of the Torrens Fault and not from the Stuart Shelf aquifers (consistent with the conclusions of Schmid (1985) and Johns (1968) concerning other Lake Torrens Springs). See Section 6 for further discussion.

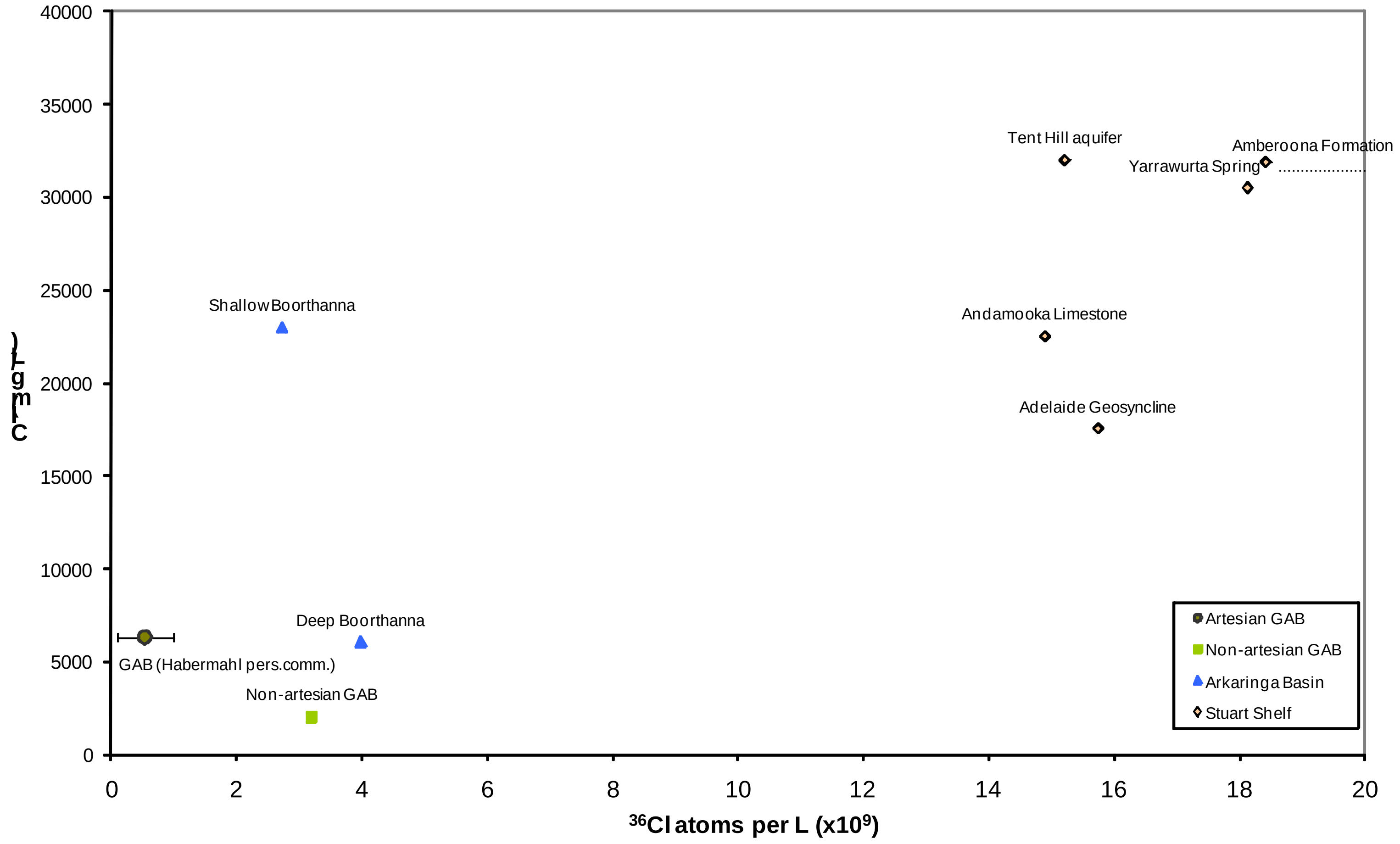


Figure 3.20
^{36}Cl concentrations in groundwater samples from regional groundwater systems

3.6. The potential for interaction between the artesian Eromanga (GAB) GFS and the Arckaringa-Stuart Shelf GFS

3.6.1. Overview

The potential for groundwater interaction between the Arckaringa-Stuart Shelf GFS and the GFS, which hosts the GAB springs, is a key question in the determination of the groundwater impact arising from the proposed OD expansion.

Sections 3.2 through 3.5 provide context for the following discussion concerning the potential for interaction between the *artesian* Eromanga (GAB) GFS and the Arckaringa–Stuart Shelf GFS.

3.6.2. Stuart Shelf and *artesian* Eromanga (GAB) Basin

The following presents a summary of the understanding developed from the various groundwater investigations undertaken to assess the hydrogeological setting of the OD region, including those presented in this report and by Kellet et al (1999):

- Low permeability rocks of the Adelaide Geosyncline within the intensely folded THZ separate the *artesian* Eromanga Basin and the Stuart Shelf.
- A groundwater divide aligned along the northern Stuart Shelf also separates the *artesian* Eromanga Basin and the Stuart Shelf groundwater systems. This divide is maintained by groundwater recharge.
- A regionally extensive groundwater discharge zone coincident with where the two GFSs converge separates the GFSs.
- Hydrogeochemical data, including ^{36}Cl isotope data show that two distinctly different water qualities occur within the GFSs.

In addition to the above, numerical modeling (SWS, 2010) demonstrates there is no interaction between the two GFSs.

3.6.3. Arckaringa Basin and *artesian* Eromanga (GAB) Basin

Much evidence of groundwater potential and chemistry of the Arckaringa Basin was collected as part of extensive hydrogeological investigations that supported the environmental approvals for the Prominent Hill Mine (refer Figure 1.1 for location). The demonstration of a lack of connection between the Arckaringa Basin and the *artesian* Eromanga (GAB) Basin was crucial to gaining approvals for the Prominent Hill mine.

Well hydrographs in the area of interest show there are no groundwater pressure responses on the east side of the Billa Kalina fault system to operation of the Prominent Hill mine wellfield.

Groundwater chemistry and potentiometric surface data for monitoring well RMD1, in conjunction with other locations where similar types of data exist, provides a valuable insight into groundwater flow dynamics in the Billa Kalina Fault area. RMD1 reports an unusual hydrogeochemical signature that is neither *artesian* Eromanga (GAB) Basin nor Arckaringa Basin-proper. Significant geological structure and hydraulic boundaries (such as the regional-scale evaporative discharge zone) is the likely cause of this. The available data support the conclusion that there is no groundwater interaction of any significance (between any of the regional groundwater systems) across the Billa Kalina Fault system.

3.6.4. Summary

The conclusions arising from the above analysis of available information and data are:

- there is little interaction of any significance between the *artesian* Eromanga (GAB) groundwater system and the groundwater systems of the Stuart Shelf and Arckaringa Basin; and
- the proposed open cut mine development at OD is very unlikely to alter this situation.

These conclusions are consistent with those of Kellet et al (1999) and Howe et al (2008), i.e. there is little to no hydraulic connection between the *artesian* Eromanga (GAB) Basin and the Stuart Shelf/Arckaringa Basin groundwater systems.

Geological structure, principally in the form of the Torrens Hinge Zone (THZ), but also other complex faults systems, groundwater divides between GFSs, and convergence of groundwater flow systems at a regional-scale evaporative discharge zone provide the basis for this lack of hydraulic interaction.

4. Beneficial use categories of regional aquifers

State and federal legislation has set water quality guidelines for the protection of various beneficial uses or values (eg. ANZECC/ARMCANZ, 2000; SA EPA, 2003; Victorian EPA, 1997). Groundwaters can therefore be classified according to beneficial use, based on specific analytes.

In relation to groundwater salinity, as measured by total dissolved solids (TDS), the Stuart Shelf, Adelaide Geosyncline and Arckaringa Basin aquifers are generally not suitable for irrigation, stock or recreational use (Table 4.1).

- **Table 4.1 Groundwater beneficial use categories for regional groundwater systems based on TDS (mg/L)**

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

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

In contrast, the lower salinities of the Eromanga Basin groundwaters, particularly in the GAB, generally permit stock and recreational use. In localised areas, there is even potential to use water from these aquifers for irrigation.

5. Water sampling protocols

5.1. Introduction

Samples of groundwater were collected from wells constructed as part of the OD expansion studies under the supervision of an SKM hydrogeologist. The samples were collected upon completion of drilling, construction and development. The samples were submitted to a NATA-registered laboratory for analysis of a range of analytes including total suspended solids (TSS).

In some cases the reported TSS value was very high, and some in the regulatory community suggested this was an indication that the collected samples would not be representative of in-situ groundwater quality.

The following section details the method of sampling undertaken and concludes that sample analysis is representative of in-situ groundwater chemistry.

5.2. Methodology of sample collection and laboratory analysis for groundwater quality

5.2.1. Standard procedure

Groundwater sampling involved removal of at least three wet bore volumes of water from the sampled well prior to sample collection, consistent with procedures outlined in NEPC (1999).

Groundwater samples were taken at the completion of well development or at the end of pumping tests. Boreholes were pumped by airlift typically for 1 to 2 hours, during which time some 5,000 to 20,000 L of water were removed from the aquifer (and in the case of 24 to 48 hour pumping tests, considerably more). These volumes were typically 20 to 30 times the wet bore volumes. During the development or testing works, EC and pH were measured to determine that these parameters were stable before samples were taken.

5.2.2. OD expansion drilling and testing programs

Each of the ‘new wells’ was drilled using conventional air-hammer techniques, whereby cuttings were lifted from the hole and penetration gained with the use of pressurised air and, in cases of low airlift yield, biodegradable drilling foam. Muds and chemicals were not used at any of the ‘new well’ sites.

Well completions ranged from placement of screens alongside the main aquifer production zone(s) (in observation wells completed as part of the regional EIS, saline water supply and mine pit dewatering/depressurisation trial programs) or open hole (test production wells completed for saline water supply and managed aquifer recharge programs).

After the completion of drilling and well construction, each well was developed using pressurised air with the airline set above the screened interval, typically around 50 m below the standing water level (SWL) . Prior to collection of water samples, each well was developed clean of cuttings and foam (where used), following which the quality of water lifted from the well was field tested every five to ten minutes for a minimum of an hour or until three consecutive readings stabilised to within 10% of previous readings. During this time, more than three wet bore volumes were removed from the well. Throughout the drilling programs, additional samples were also collected (SKM, 2010):

- during drilling; from the upper and lower sections of the ALA or other encountered geological units);
- using disposable bailers at least 3 days post-completion of drilling and airlifting; and/or
- during extended pumping tests.

Collected samples were filtered in the field for analysis of dissolved metals, but were not field filtered for analysis of pH, electrical conductivity (EC), total dissolved solids (TDS), TSS, turbidity, alkalinity, major ions and other analytes. The samples were collected into laboratory prepared containers, stored on ice and submitted to ALS Environmental Pty Ltd (ALS) for testing, under standard chain of custody arrangements and within holding times specified for each tested analyte.

5.3. Reported TSS results

Analytical results of TSS measured in groundwater samples collected from wells constructed as part of the works conducted by SKM are presented as Attachment D.

In cases where multiple samples were collected from a well, the last sample collected at the end of development is considered to be most representative of in-situ groundwater and the samples collected during the drilling of a well are considered less representative. On occasions, where production wells were pumped for extended periods of time, samples collected after pumping are considered most representative of in-situ groundwater.

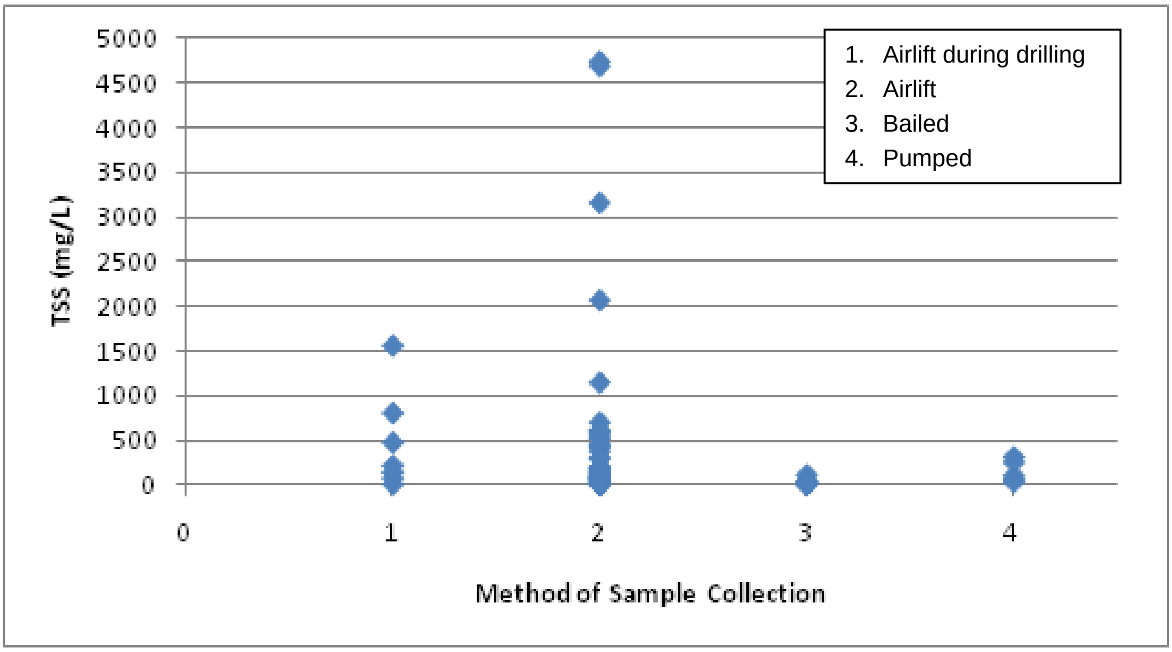
Attachment D displays the TSS results of wells that were sampled multiple times during drilling, development and testing:

- Wells drilled as part of Motherwell Extension (*MXT* nomenclature) reported TSS value up to two orders of magnitude higher when sampled during drilling than the equivalent airlift and bailed samples.

- Samples collected from production wells drilled for saline water supply (*TPW* nomenclature) and managed aquifer recharge (*MAR* nomenclature) studies report relatively similar TSS values after airlifting as after pumping.
- The airlifted sample collected from RT-*2a* reports a TSS value relatively similar to that of a sample taken during drilling, whereas the reported value for the PT-6 sample is significantly higher during drilling.
- A sample collected from PT-5a at completion of drilling reported a significantly higher TSS value compared to the sample collected after construction.

The observations outlined above and presented in Table 4.2 are consistent with the method of sample collection and well completion, that is:

- airlifted samples would be expected to result in higher reported TSS values than for bailed or pumped samples; and
- samples collected from openhole completions would be expected to result in higher reported TSS values than for those from wells constructed with screens.



- **Figure 4.1 Reported TSS values for Stuart Shelf groundwater samples vs. method of collection**

5.4. Discussion

Significantly higher reported TSS values have been reported for water samples collected on airlift pumping, either during drilling or following well construction, than for those samples collected using pumping or bailing. Similarly, higher reported TSS values have been reported for water samples collected from openhole completions then for constructed wells.

The extended development of all new wells was considered more than adequate to provide a representative groundwater sample. However, the process of airlifting, particularly within open holes, often resulted in sampled water containing suspended solids. Figure 4.1 presents the distribution of TSS values for different methods of sample collection.

6. Lake Torrens brine

6.1. Lake Torrens physical setting

As has been documented in the project baseline groundwater studies (Appendix K1, Draft EIS) the available data strongly suggest that the ALA and THA of the Stuart Shelf discharge to the margins of the major regional salt lake (Lake Torrens), which is identified as a groundwater-dominated playa (Schmid, 1985).

The lake is underlain by more than 200 m of Tertiary to Recent sediments, including sands and clays that have been laid down within a Cainozoic graben (Schmid, 1985; Johns, 1968). The graben is bounded to the west by north-south trending step faults that are likely coincident with the Torrens Fault that bounds the THZ (Risley, 1963; Schmid, 1985). A number of springs aligned along the axis of the lake and the Torrens Fault are driven by artesian pressures hosted by aquifers at the base of the lake sediments. Groundwater is released from these deep aquifers via fractures within the Cainozoic infill (Johns, 1968). Mountford Springs and other springs, located approximately in the mid-point of the lake, have similarities to typical GAB springs, in terms of driving mechanisms. The springs are sustained by groundwater discharge from the east (Johns, 1968).

The description of Mountford Springs by Johns (1968) bears similarity to Yarra Wurta Springs located at the north end of Lake Torrens (Figure 6.1), i.e. cauliflower-form gypsum precipitation, and it is considered possible that the saline Yarra Wurta Springs are sustained in the same way as these other Lake Torrens springs.

The lake sediments gradually shallow to the east from the step faults that are associated with the Torrens Fault, and are saturated with brine (greater than 100,000 mg/L TDS) to depths of around 60 m, below which hypersaline groundwater (30,000 to 70,000 mg/L TDS) resides (Johns, 1968).

Schmid (1985) concluded that the majority of the brine within Lake Torrens sediments is sourced from groundwater moving from the east (i.e. from the western flanks of the Flinders Ranges), and that groundwater contributions from the west are negligible. This conclusion is endorsed by the authors of this report and Golder (2010).

6.2. Conceptualisation of Lake Torrens brine processes

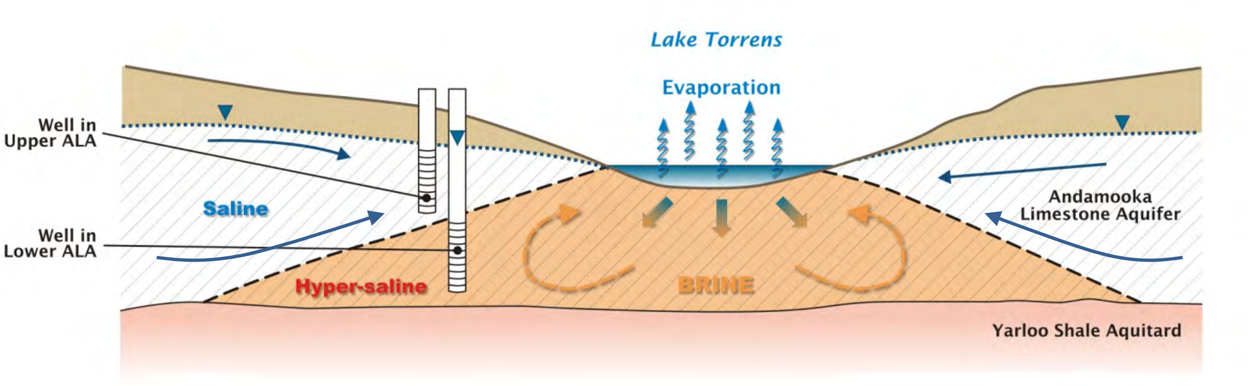
A number of exhaustive studies around Australia and internationally have helped improve the conceptual understanding of variable density flows in aquifers discharging to salinas (see Schmid, 1985; Macumber, 1991; Holzbecher, 2005; Field et al, 2008).

- **Figure 6.1 Locality plan for the Yarra Wurta Springs group**

Consistent with the observations further south (Schmid, 1985; Johns, 1968), nineteen groundwater wells installed within several kilometres of the lake's northerly extent, and others further west of the Lake, have encountered a salinity interface (halocline), above which saline groundwater typical of the regional aquifers occurs and below which brine emanating from Lake Torrens occurs.

Figure 6.2 presents a conceptual diagram of brine formation and circulation beneath a groundwater dominated playa. Brines produced by the evaporative concentration of salts in groundwater (or even surface water when it occurs) will sink as a consequence of higher density (so called "reflux" brines) and progressively extend outwards from salt lakes, displacing and mixing with ambient groundwaters. Over long timescales (i.e. tens of thousands of years, Nield *et al*. 2008), the interface between the lower salinity regional groundwater and the brines takes on a 'wedge' like appearance, similar to haloclines found in coastal regions. Regional flows of lower salinity groundwater towards these lakes are effectively forced upwards above the brine interface to discharge at the surface, and then lost by evaporation in the case of Lake Torrens.

Hydraulic head data and salinity profiles collected in 49 groundwater wells installed in the vicinity of Lake Torrens have been used to characterise groundwater flow patterns and demonstrate the existence of a large body of brine extending into the base of the ALA to the west and north of the northern part of the lake.



- **Figure 6.2 Conceptual schematic of groundwater circulation in the vicinity of a salt lake (adapted from Rodriguez-Rodriguez, 2005)**

The extent of the brine from Lake Torrens is partly controlled by the rate at which brine can be formed, which in turn is related to the discharge rate from contributing groundwater flow systems. It is likely that brines continue to accumulate below the lake and extend away from the lake. By comparison, salt-water wedges at coasts have infinite sources of saline water to intrude coastal aquifers, and are entirely controlled by hydrogeological conditions.

It is crucial that hydraulic head data collected in the field is interpreted in light of the variable groundwater densities. Traditionally, hydraulic heads (h_i) are 'corrected' by converting them to equivalent freshwater heads ($h_{f,i}$) using equation 1. Figure 6.3 presents the concept.

$$h_{f,i} = \frac{\rho_i}{\rho_f} h_i - \frac{\rho_i - \rho_f}{\rho_f} z_i$$

(Eq.1)

In certain analyses of groundwater flow patterns in variable density groundwater flow systems, this approach can nevertheless produce erroneous results. Vertical flows cannot be evaluated solely by freshwater heads as the buoyancy effect produced by the density contrast also needs to be considered. Additionally, in evaluating horizontal flows using data from wells screened at different depths, it should be noted that freshwater heads may vary with depth even for hydrostatic conditions.

Both these considerations apply to the ALA in the vicinity of Lake Torrens, where salinities vary from 20,000 to 260,000 mg/L, and where well screen levels are up to 200 m different in elevation.

Post et al (2007) has outlined more reliable methods for density correction. Where horizontal flow components are evaluated for piezometers screened at different depths, *'normalised'* freshwater heads ($h_{f,r}$) need to be calculated with respect to a suitable reference depth (z_r) using equation 2. (below). The average water density between measurement point z_i and the reference level z_r is denoted ρ_a, and is often poorly defined, thereby introducing a degree of uncertainty into the magnitude of the horizontal flow component.

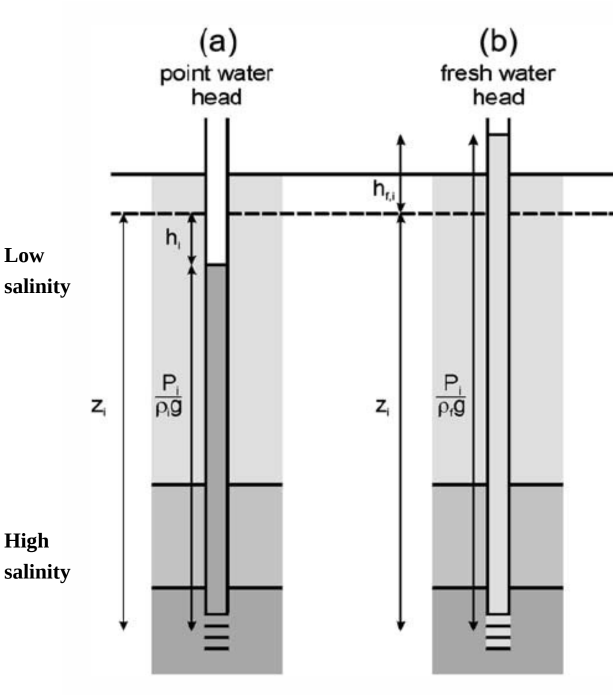


Figure 6.3
(a) Measured groundwater level in brine aquifer
(b) Corrected (freshwater) head in same well

$$h_{f,r} = z_r + \frac{\rho_i}{\rho_f}(h_i - z_i) - \frac{\rho_a}{\rho_f}(z_r - z_i)$$

(Eq.2)

As defined by equation 3 (below), the vertical flow component, q_z, needs to consider the vertical equivalent freshwater head gradient ($\Delta h_f / \Delta z$) as well as the buoyancy effect produced by the relative density contrast ($\rho_a - \rho_f / \rho_f$). Without the buoyancy term, nested piezometers in an aquifer under hydrostatic conditions will mistakenly indicate that there are head differences that could cause vertical flows.

$$q_z = -K_f \left[\frac{\Delta h_f}{\Delta z} + \left(\frac{\rho_a - \rho_f}{\rho_f} \right) \right]$$

(Eq.3)

6.3. Analysis of density corrected heads for the ALA

6.3.1. Lateral flow component

In order to assess the horizontal component of groundwater flow patterns in the ALA, measured hydraulic heads have been converted to equivalent freshwater heads for the upper and lower sections of the aquifer and normalised at specific reference levels to account for the different screen elevations in a variable density groundwater flow system.

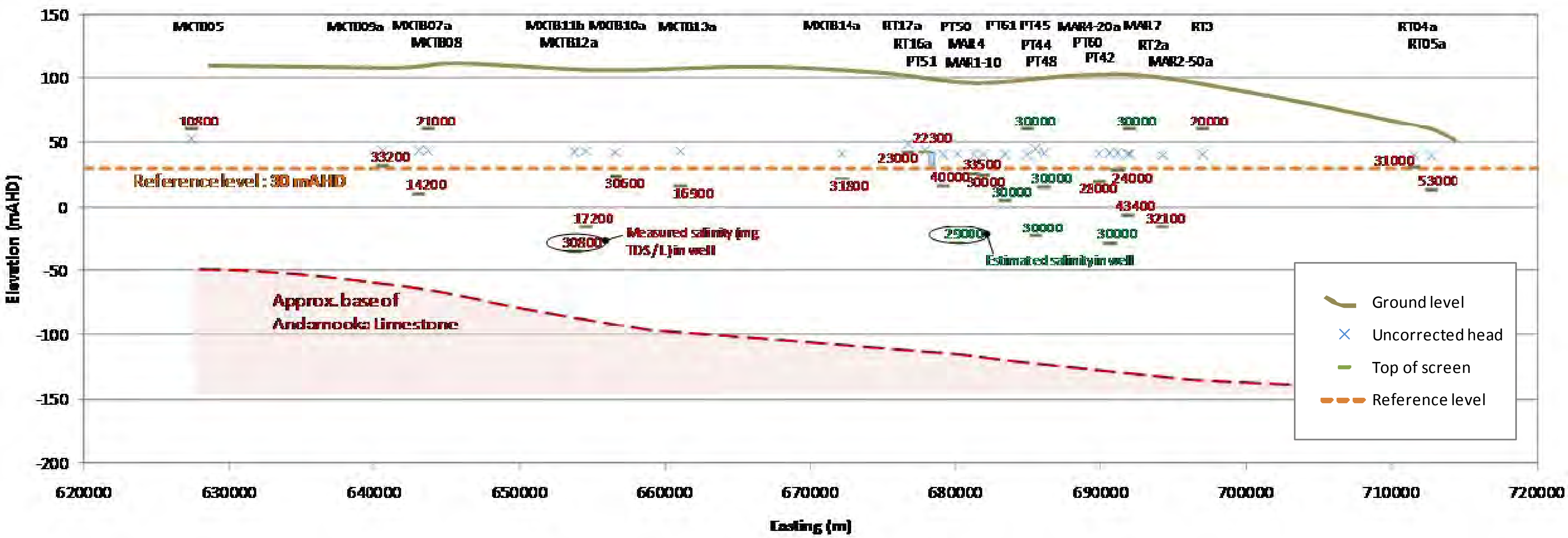
The upper ALA corresponds with lower salinity groundwater (typically less than 40,000 mg/L TDS) and the lower ALA with brines (up to 250,000 mg/L), a mixing zone and, to the west of the system, with lower salinity groundwater. As shown in Figure 6.4, reference levels (z_r) of 30 and -50 mAHD have been used to adjust levels in the upper and lower monitoring wells, respectively. While the use of reference levels normalises the measurements, it also introduces a level of uncertainty, due to the need to estimate the average groundwater density between the screened level and the reference point.

The reference level (z_r) for the upper ALA piezometers has been set near to the average mid-point of all well screens in this network, and it is assumed that ρ_a is equal to ρ_i. This is a reasonable assumption considering that the groundwater salinities in the upper section of the network are reasonably consistent (as shown by EC measurements taken during drilling; refer SKM, 2010).

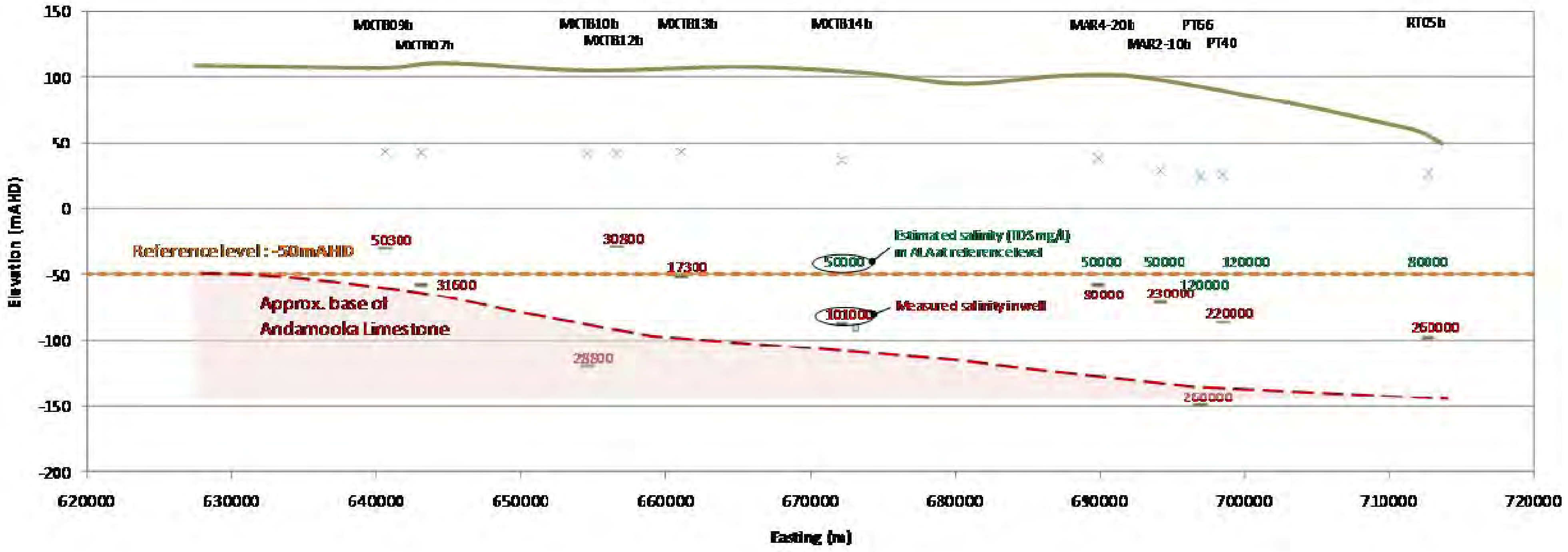
The reference level for the lower ALA has been set at the lowest possible point without descending below the base of the aquifer. Based on EC measurements taken during drilling, the density profile between z_r and z_i is characterised by a zone of sharp rise in density corresponding to the mixing zone between saline groundwater and underlying brine (Figure 6.5). Where the transition zone (z_b) occurs halfway between z_r and z_i, the average density, ρ_a, is directly related to the location of the centre of the transition zone (z_b) and is defined by equation 4 below, where ρ_i and ρ_r are assumed to be representative of conditions below and above the interface respectively. This assumption is reasonable considering the measured EC profiles in Figure 6.5. It should be noted that the salinity profile constructed from the EC measurements taken during drilling is likely to be skewed by previous groundwater inflows within the open drill hole. This introduces a level of uncertainty into the location of the transition zone, and therefore into ρ_a. The error margin in the calculation of $h_{f,r}$ is therefore estimated by taking the location of z_r to be ±20%, which is a reasonable arbitrary value based on the salinity profiles observed during drilling (Figure 6.5 and SKM, 2010).

$$\rho_a = \rho_i \times \frac{(z_b - z_i)}{(z_r - z_i)} + \rho_r \times \frac{(z_r - z_b)}{(z_r - z_i)} \qquad \text{(Eq. 4)}$$

The converted head data are presented in Attachment A.



- **Figure 6.4 a) Groundwater wells used to evaluate the lateral component of groundwater flow in the upper ALA**



- **Figure 6.4 b) Groundwater wells used to evaluate the lateral component of groundwater flow in the lower ALA**

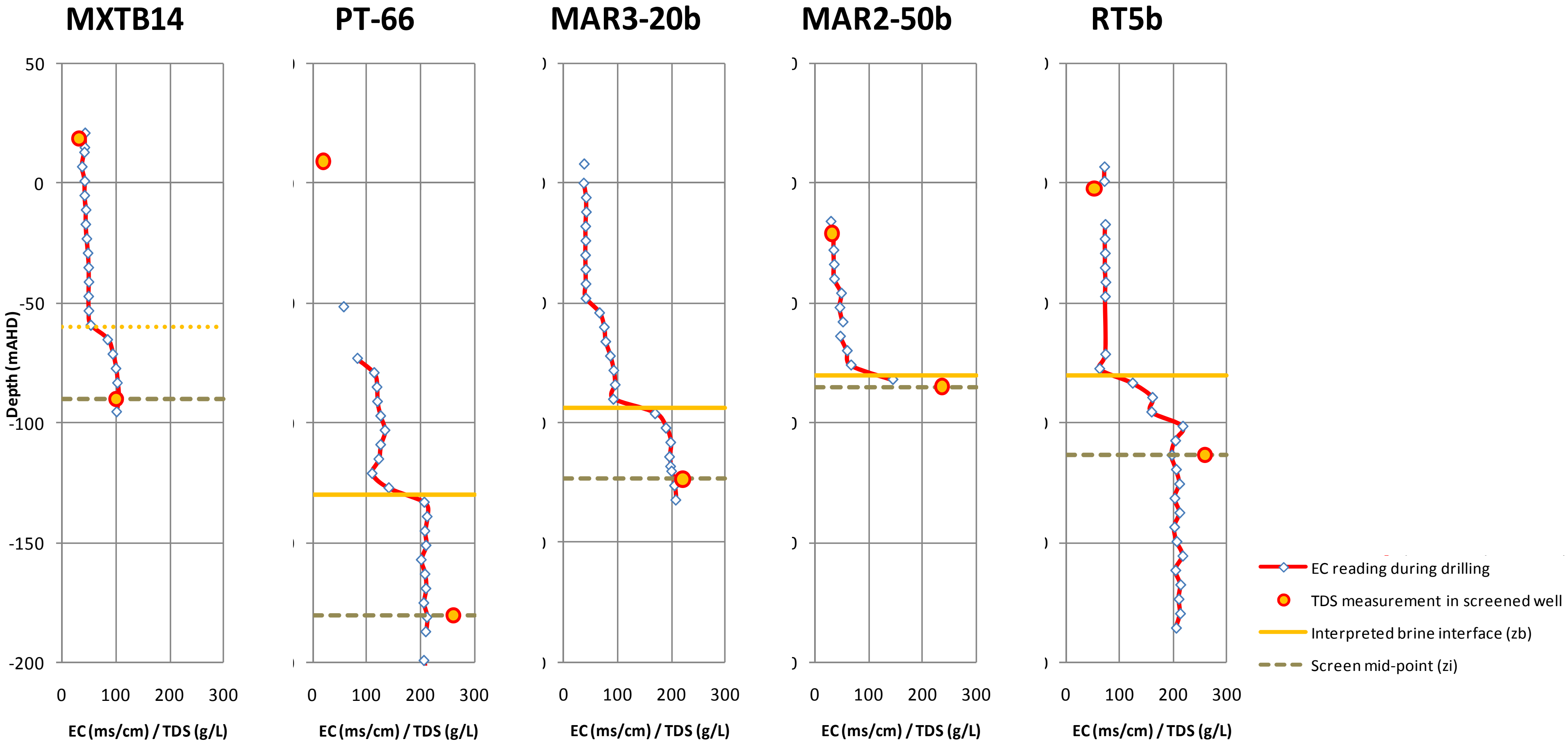


Figure 6.5 Interpreted salinity profile in selected wells near northern end of Lake Torrens

The interpreted contours in the upper system (Figure 3.2) indicate groundwater movement is moving west through the ALA toward the northern end of Lake Torrens. The hydraulic gradient lessens significantly through the central and eastern sections of the ALA and ranges from 3 x10^{-3} to 9x10^{-3}, corresponding with increased aquifer hydraulic conductivity as documented by pumping tests carried out at three sites in this area (MAR2, MAR3 and MAR4; SKM, 2010) and high airlift yields in other wells (e.g. greater than 20 L/s in PT40, PT42, PT44, PT48, PT51; SKM, 2010).

The lower system is characterised by corrected hydraulic gradients in a similar range to the overlying system (Figure 3.6). In contrast to the upper part of the aquifer, however, within 20 km of the northern end of Lake Torrens, groundwater in the base of the ALA flows northwestward away from the playa toward the central portion of the ALA where drilling investigations show the base of the Andamooka Limestone is deeper than elsewhere on the Stuart Shelf.

6.3.2. Vertical flow component

Attachment A presents corrected hydraulic heads and vertical gradients for the ALA at various nested groundwater monitoring sites. The data show the lower and upper ALA to be close to hydrostatic at most sites, indicating limited vertical movement within the aquifer. The directions of the vertical hydraulic gradients (Figure 3.5) are downward over the western section of the ALA and upward in four of the five sites located near to the northern end of Lake Torrens. The area of upward hydraulic gradients coincide with the ‘trough’ in normalised freshwater heads within the lower ALA (Figure 3.6), suggesting that there is potential for upwelling of brines and mixing with lower salinity groundwater.

6.3.3. Summary of flow directions in ALA

The conceptual hydrostratigraphic cross-section schematic presented as Figure 3.7 shows brines ‘filling’ the deepest sections of the ALA and extending westward up to 50 km from Lake Torrens. The location of the interface between saline waters and brine has been estimated from EC measurements made during drilling. At a distance of roughly more than 15 km from Lake Torrens, the interface appears to have a low gradient indicating a stable density stratified system. The interface is higher within the ALA closer to Lake Torrens. Saline groundwater moving towards the discharge zone is effectively forced upward by the density difference, as discussed earlier, and a thicker mixing zone develops. RT5a, located within a few kilometres of Lake Torrens, is screened at the top of the ALA and shows high salinity levels (TDS greater than 50,000 mg/L).

The level of uncertainty in calculating equivalent heads in the lower system indicates the flow system may be sensitive to variations in groundwater density.

The cross-section presented as Figure 3.7 illustrates how the saline ALA flow system reduces significantly in thickness whilst moving eastward towards Lake Torrens (i.e. a reduction in *effective* transmissivity). The aquifer is 80 to 100 m thick west of MXTB14, but is effectively less than 20 to 40 m thick within about 20 km of Lake Torrens as lateral groundwater flows towards the lake are constrained between the brine interface and the overlying lower permeability shale formations.

6.4. Inferred brine response to upper-ALA drawdowns

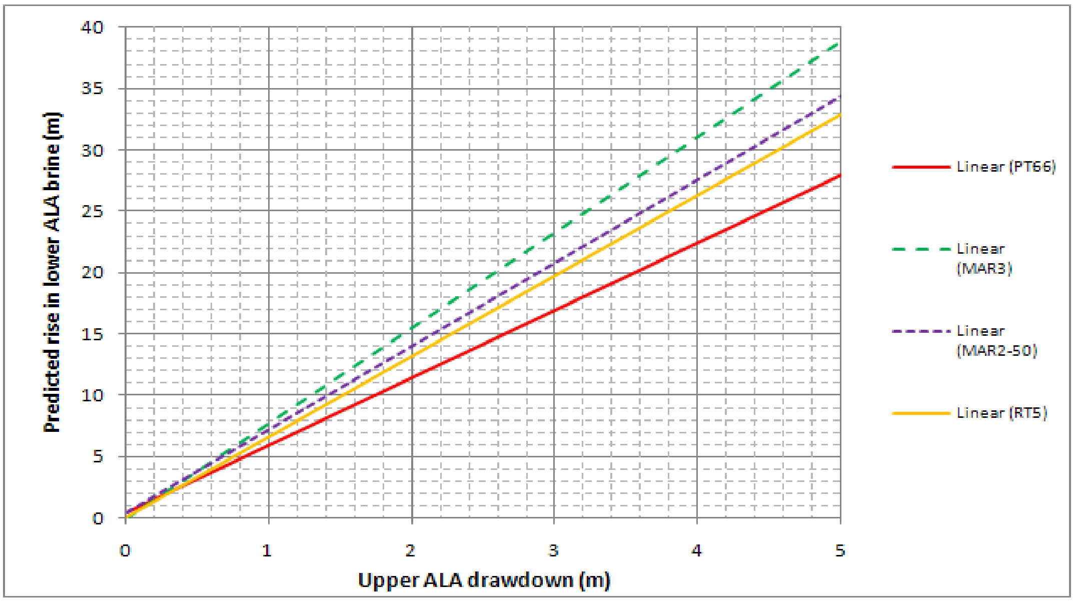
Water affecting activities associated with the proposed expansion of the Olympic Dam mine have the potential to cause drawdown in the regional ALA. The existence of brine at the base of some (deeper) parts of the ALA means there is the potential to displace brine upwards if water table drawdowns occur in those parts of the ALA that have a profile of upper groundwater of low salinity (and density) overlying deep brine of higher density.

It is possible to estimate the elevation of the brine interface using equation 4, whilst adopting the simplifying assumption that the system is hydrostatic (i.e. there is no vertical transfer of water within the groundwater system). As shown in Table 6.1, the brine interface predicted in this manner is similar to the observed salinity profile at several of the drill-sites (see Figures 6.4 and 6.5), suggesting the corrected freshwater heads are broadly representative of conditions in the upper and lower parts of the ALA at these sites. However, it is possible that the groundwater flow system is still evolving towards a state of equilibrium because predicted interface levels are higher than the observed interface.

- **Table 6.1 Predicted brine interface elevations (m AHD)**

Location (well)	Observed	Predicted	Drawdown (m)		
			1	2	5
PT66	-129	-60	7	11	28
MAR3	-94	-85	8	15	39
MAR2-50	-80	-54	7	15	34
RT5	-80	-56	7	13	33

When the hydraulic heads in the upper part of the aquifer are lowered because of drawdown, in this instance either associated with groundwater pumping or the long term effects of drainage of groundwater (with evaporative discharge) into the pit void, a new brine interface equilibrium can be estimated (assuming an unlimited source of brines). Table 6.1 and Figure 6.6 present estimated increases in brine interface elevations for a range of drawdowns at selected ALA locations (Figure 6.7).



- **Figure 6.6 Graphical presentation of calculated (and inferred) brine interface displacement for a range of upper-ALA drawdowns**

Figure 6.6 illustrates the upward movement of a brine interface that typically occurs when pumping from the groundwater above such an interface. The phenomenon is sometimes referred to as “upconing”.

The final pit void at Olympic Dam will be a long-term regional groundwater sink located some tens of kilometres from the area within which the brine interface has been demonstrated to occur. The groundwater that will drain into the pit and evaporate will almost all come directly from the THA, which underlies the ALA. The final pit void is located in an area where the base of the ALA is close to or above the regional water table.

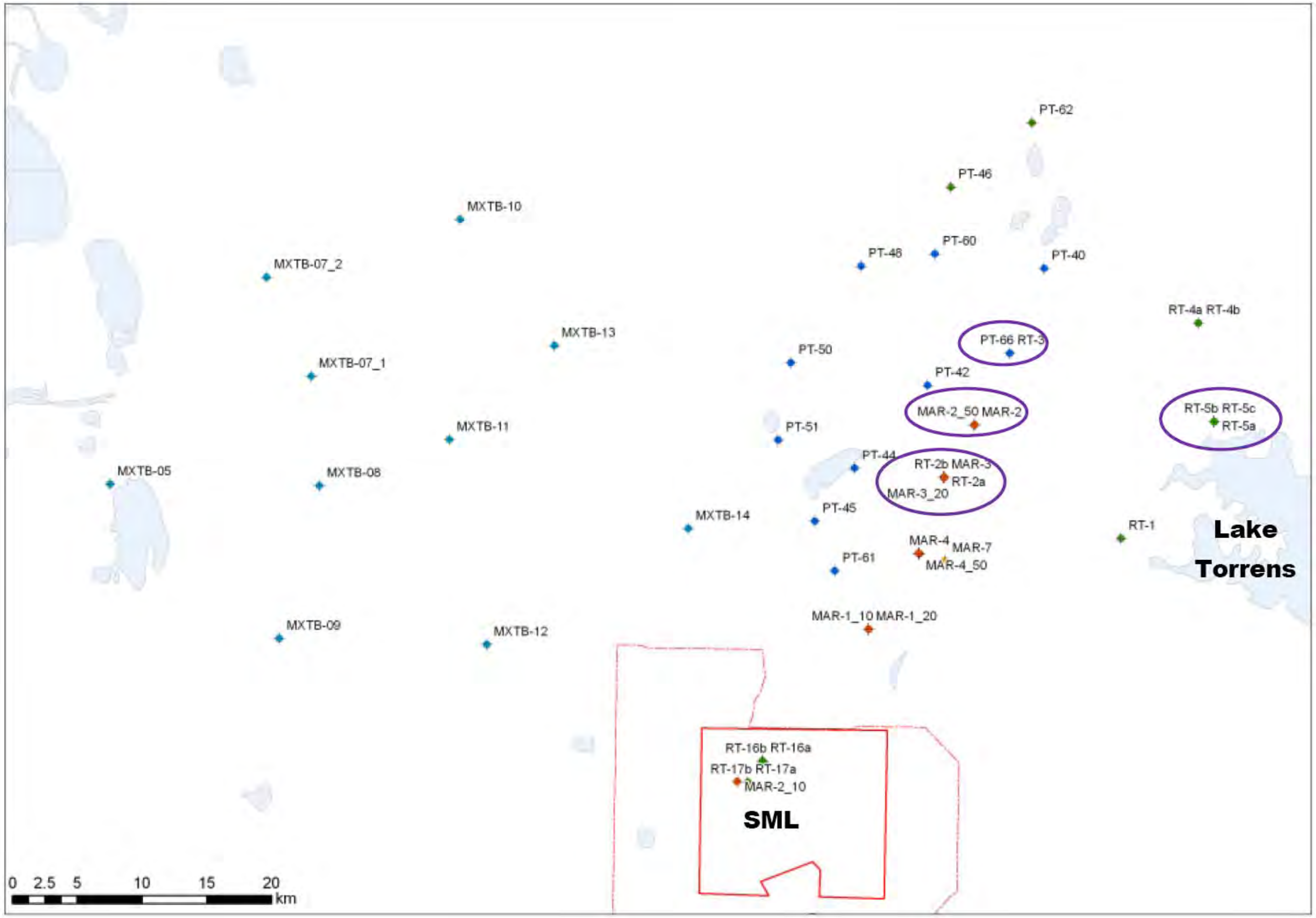


Figure 6.7
Locality plan for brine interface displacement calculations

It is anticipated, therefore, that even if drainage to the final pit void causes a measurable drawdown in the ALA in the area of brine occurrence, the brine interface will not rise because the effect of the drainage into the final pit void will be to underdrain the ALA. That is, drawdown will develop in the ALA because of leakage downward from the ALA in response to the lowered heads in the THA beneath the brine rather than because of withdrawals from the upper ALA above the brine.

7. Groundwater impact assessment

7.1. Introduction

To understand the level of potential impact posed to groundwater systems as a result of mine development, it is necessary to consider how operations such as dewatering, supply development, and tailings management might change the ‘natural’ groundwater regime and so impact upon groundwater systems and potential users of groundwater.

Direct groundwater effects of mining operations relate to the physical impacts of mine water affecting activities on groundwater systems. Four categories of direct effects have been identified by Brereton et al (2008), they are:

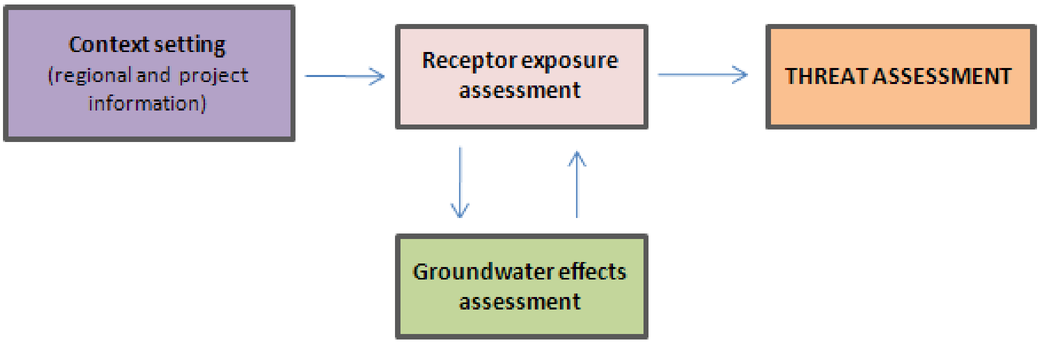
- *Groundwater quantity*;
  includes consideration of changes to groundwater levels / pressures and flux through systems under consideration.
- *Groundwater quality*;
  includes consideration of salinity and concentrations of other important water quality constituents (such as metals, pH, nutrients and radionuclides).
- *Groundwater – surface water interaction;*
  includes consideration of changes to the level of interaction between groundwater and surface water systems (such as stream baseflow and evaporative losses from saline lake systems).
- *Physical disruption of aquifers;*
  includes consideration of whether or not there will be permanent disruption of a groundwater system by mining, and to what extent.

Indirect effects relate to groundwater receptor response to the combined direct effects. The term *receptor* is used here to include environmental, social and economic users of groundwater resources. Examples of typical groundwater receptors that may be impacted by a mining operation include:

- *Environmental;*
  groundwater dependent ecosystems such as aquatic ecosystems that are maintained to some extent by baseflow, and terrestrial vegetation that utilises groundwater to meet some or all of its water requirements.
- *Economic;*
  agricultural enterprises that rely on groundwater for irrigation or stock watering, and other mining operations that utilise groundwater to meet all or some of their mine water requirements.

- *Social*
  includes recreational use of water resources, as well as urban and rural water supply.

Groundwater impact (threat) assessments for mining operations need to consider both the *direct* and *receptor* effects of a mining operation on local to regional scale groundwater systems within a regional context (Figure 7.1). For a threat to emerge there needs to be an exposure pathway linking direct effects with receptors.



- **Figure 7.1 Groundwater impact assessment framework (after Howe et al., 2010)**

A brief summary of each of the four key steps of the groundwater impact assessment is provided here:

- *Context setting*
  Involves placing the mining proposal into a regional context, eg. interactions between groundwater flow systems, climatic factors and preliminary identification of potential groundwater receptors (environment, social, economic) that might be impacted adversely by mine development within a region.
- *Groundwater effects assessment*
  Comprises identification of ‘direct effects’ to the groundwater system arising from mine water affecting activities.
- *Exposure assessment*
  Involves developing an understanding of the receiving environment that will potentially be altered by direct effects, and clearly identifying those receptors that are exposed to these effects.
- *Threat assessment*
  Involves an assessment of the degree to which direct effects will impact on receptors, both spatially and temporally.

7.2. Olympic Dam groundwater affecting activities

7.2.1. Overview

The following provides an overview of the Olympic Dam water affecting activities. Each of these has been discussed in more detail in the Draft EIS and accompanying appendices, but is again presented here for contextual reasons.

The existing Olympic Dam (OD) operation comprises an underground mine and associated infrastructure. The proposed expansion will comprise of both an underground and open cut mine, and associated infrastructure.

Table 7.1 presents a comparison of the current and proposed operation in terms of activities having the potential to impact on groundwater (groundwater affecting activities), with a focus on those activities described in the Draft EIS for the proposed expansion, that is:

- the mine void;
- dewatering requirements;
- rock and tailings storage facilities; and
- saline water supply wellfields.

As noted in Table 7.1, water affecting activities associated with the proposed expansion that do not exist for the existing operation include the mine pit, rock storage facility and off SML water supply wellfields.

7.2.2. Mine void

As discussed at length in the Draft EIS and associated appendices, post-mining, the underground workings will fill over a period of time and the mine pit void will act as an evaporative sink to the regional groundwater system such that a pit lake post-mining will have a maximum elevation around 650 m below ground level, that is more than 550 m below the pre-mine water table (refer Chapter 11, Chapter 12 and Appendix J2 of the Draft EIS).

- **Table 7.1 Comparison of existing and proposed future groundwater affecting activities [1]**

Water affecting activity	Existing	Future
Mine workings	☑ (underground)	☑ (combined underground and open cut)
Tailings storages	☑	☑
Rock storages	-	☑
Water storages	☑	☑
SML saline water supply wellfields [2]	☑	☑
Stuart Shelf saline water supply wellfields [3]	-	☑

Notes:
1. GAB Wellfields are not included in this analysis because (I) they will continue to operate under existing licences and therefore do not form part of the expansion project EIS, and (ii) there is a demonstrated lack of direct hydraulic connection between the Stuart Shelf and *artesian* Eromanga (GAB) GFSs (see Section 2)
2. Includes dedicated water supply wells as well as proposed future dewatering wells and expanded saline water supply wellfields (SML)
3. Andamooka Limestone aquifer (ALA)

7.2.3. Groundwater abstractions

Depressurisation

In the vicinity of the mine site, the THA has responded to drainage into the underground workings by a number of raise bores constructed to intersect the underground workings, operation of the Saltwater Wellfield, and leakage through the Tregolana Shale under vertical hydraulic gradients established as a result of drainage of the basement rocks. Appendix K of the Draft EIS notes that raise bores, alone, have drained, on average, at rates between 14 and 24 L/s from the THA since 1984. Figure 2.3 presents interpreted March 2009 groundwater elevations, showing a cone of depression within the THA centred on the underground workings as a result of drainage through the vent raises and minor groundwater withdrawals.

The proposed expansion includes open cut mining methods and dewatering requirements to ensure safe and efficient mining. Pumping rates are expected to be around 40 L/sec in the long-term (Douglas et al, 2009).

The low permeability rocks underlying the THA will also be depressurised through the use of in-pit sumps and horizontal drain holes.

Saline water supplies - SML

Wellfields will be operated on the SML to supplement the supplies drawn from mine dewatering, to meet mine and process water requirements. One of these wellfields will be located to the southwest of the mine pit, near the Mining and Metallurgical Infrastructure Area (MMIA), and the other to the east of the mine pit near the proposed new location of the Roxby Downs airport. Abstractions from these wellfields could total up to 5 ML/day.

The effect of the SML sourced saline water supply will assist in dewatering of the Tent Hill aquifer (THA) and so assist in mine pit depressurisation. The existing cone of depression within the THA arising from underground mining operations is expected to expand as a result of these new (expanded) abstractions. The extent of influence of these wellfields on the groundwater system will be constrained by geological structure, as well as the hydraulic conductivity and storativity of the different hydrostratigraphic units, but locally large drawdowns relative to the zone of influence of the mine itself can be expected due to typically low to moderate hydraulic conductivities.

On decommissioning of the wellfields, it could be expected that some recovery of groundwater levels/pressures will occur. The extent to which this recovery occurs will, however, be dependent on the influence imposed on the local to regional-scale groundwater system by the drainage of groundwater into the decommissioned mine pit.

Saline water supplies - ALA

The primary saline water supply to be developed for the OD construction period is proposed to be sourced from the ALA to the north of the SML. The “Motherwell’ wellfield, which is proposed to be located to the north of the SML, is anticipated to provide supplies ranging between 15 and 25 ML/day, peaking at 28 ML/d. At this stage, it is proposed to operate the Motherwell Wellfield for the construction and pre-mine phase only.

The ALA is a highly transmissive aquifer. Groundwater supply development will likely result in limited drawdown relative to the zone of influence. Groundwater level recovery following decommissioning of the wellfield will likely be slow given the large abstraction rates in comparison to low recharge rates (rainfall and throughflow from the Arckaringa Basin groundwater system to the west). It is likely, though, that the mine will impose a greater influence than the Motherwell Wellfield on the ALA in the long-term (post-closure).

Summary

At the end of mining (50 years), drawdowns of around 1 m are predicted for the ALA 5 km north of the SML (SWS, 2010). Operation of the Motherwell wellfield is predicted to result in around 2 to 4 m of drawdown outside the footprint of the wellfield, but water level recovery will occur following decommissioning of this supply in 2017 (SWS, 2010).

7.2.4. Rock storages

Background recharge rates in the OD region are very low, much less than 0.1% (less than 0.5 mm/yr).

However, the quarrying of the mine pit and subsequent placement of overburden and other rock materials within the RSF (Rock Storage Facility) will provide a surface with different hydraulic properties from the natural ground. The RSF materials will have greater porosity (effective as well as total) and permeability than those of the undisturbed material. It is possible that there will be an increase in rainfall recharge rates over the RSF footprint via preferential flow paths, the rate perhaps ranging between 1 and 5% of average rainfall (i.e. 2 to 10 mm/yr; SRK, 2010a). These higher recharge rates near to the mine pit will serve to offset the impact of mine pit evaporative losses (post-mining) on regional groundwater levels, in particular those of the ALA.

However, RSF design, water management, trafficking and closure design will help to militate against these higher levels of recharge that may be experienced in the post-closure period.

Recharge over the RSF footprint is unlikely to be significant at the regional-scale, other than reducing the zone of mine pit influence on the groundwater system during and post-mining (SWS, 2010).

7.2.5. Tailings storages

Whilst tailings thickening and engineered design will serve to minimise seepage from the TSF, successive tailings lifts will effectively increase the driving head on seepage outside the lined decant area. Seepage rates could range up to those levels observed for the latter cells of the existing TSF (i.e. around 30 mm/yr; SRK, 2010b).

At cessation of mining, it is proposed to cap the TSF to effectively reduce seepage rates back to around background rainfall recharge rates that occur in the OD region (around 0.1 mm/yr; SRK, 2010b).

Tailings seepage will result in the mounding of groundwater within the ALA, as is already observed to be occurring. Geochemical assessments presented as Appendix F5 of the SEIS and in the Draft EIS (Appendix K4) demonstrate the effectiveness of the materials underlying the TSF and RSF to neutralise seepage and aid in the sorption and co-precipitation of seepage constituents. However, some residual groundwater quality change is expected due to tailings percolate reaching the water table aquifer (ALA).

7.3. Receptor identification

7.3.1. Study area definition

The Study Area for the impact assessment is consistent with the geological Stuart Shelf and encompasses the likely hydrogeological interactions with other groundwater systems (e.g. the Torrens Basin, the Arckaringa Basin, and the *artesian* (GAB) and *non-artesian* Eromanga Basin).

7.3.2. Potential receptors

Environmental

GAB Springs

Artesian Eromanga (GAB) aquifers support the ecologically significant GAB Springs. On the basis of the information presented in this document as well as the Draft EIS and supporting appendices, in particular the observation that a groundwater divide separates the Arckaringa-Stuart Shelf GFS from the Hinge Zone GFS and, ultimately the *artesian* Eromanga (GAB) GFS, it is concluded that the Springs will not be impacted by groundwater affecting activities associated with the proposed expansion of OD.

Lake Torrens Springs

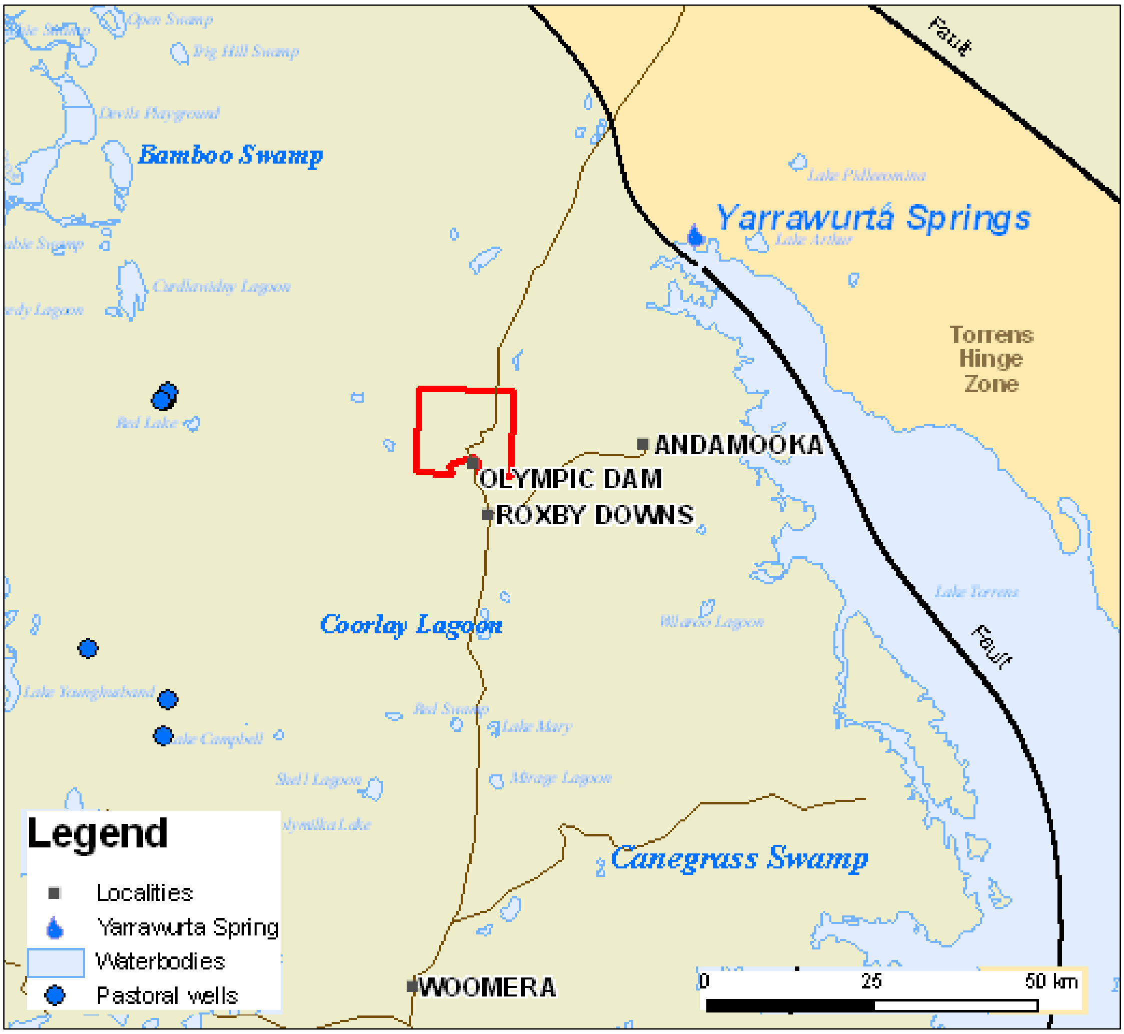
A number of hypersaline springs / seeps are located around Lake Torrens, many of them hypersaline.

The Yarra Wurta Springs are located at the northern end of Lake Torrens (Figure 8.2) and occur within the THZ, where the ALA is underlain by Adelaide Geosyncline rocks. The pools at these springs support bacterial mats, filamentous green algae and the Lake Eyre Hardyhead fish, which does not have a conservation significance listing. However, Yarra Wurta Springs is one of few known refuge populations that exist within the Lake Torrens surface water catchment.

Studies of the flora and fauna of the Yarra Wurta Springs conducted as part of the Draft EIS established there are no species afforded additional protection under Commonwealth or State legislation inhabiting the area that have a dependence on the hypersaline springs.

Located at the northern end of Lake Torrens, Yarra Wurta Spring occurs where regional groundwater flow lines converge from west, north and east (Figure 3.4). However, there is evidence to suggest the springs are primarily supported by groundwater originating from northeast and/or east of Lake Torrens, discharging along regional geological structures controlled by the Torrens Fault (refer Section 6 and Golder, 2010).

Work undertaken by Johns (1968) and Schmid (1985) suggest that the Lake Torrens springs are supported by groundwater moving into the lake sediments from the east (i.e. from the western flanks of the Flinders Ranges. This conclusion is supported by ^{36}Cl isotope data (Section 2.4.4). The hydrological and structural geological setting of Lake Torrens appears to control the presence of Yarra Wurta Springs, thereby mitigating against any adverse effects associated with any drawdown impacts imposed on the ALA as a result of the proposed expansion of OD.



Legend

- ■ Localities
- 💧 Yarrawurta Spring
- ▭ Waterbodies
- ● Pastoral wells

- **Figure 7.2 Locality plan for potential receptors**

Freshwater swamps

A number of ‘freshwater’ swamps, including Bamboo Swamp, are located between 50 and 100 km west-northwest of the northern extent of Lake Torrens (Figure 8.2). The ‘swamps’ are terminal drainage features of Millers Creek and become inundated following rainfall events that are large enough to result in large runoff volumes.

The depth to water table beneath these ‘swamps’ exceeds 30 m and, as a result, any (riparian) vegetation fringing them is expected to utilise soil water and are unlikely to demonstrate any form of groundwater dependence.

Terminal drainage features of the Arcoona Plateau

A number of terminal drainage features occur on the Stuart Shelf, for example Coorlay Lagoon and Canegrass Swamp (Figure 8.2). Coorlay Lagoon is located approximately 30 km south of OD and is a terminal lake for a number of watercourses that drain the Arcoona Plateau to the south. The water table at this location occurs within the Arcoona aquitard and lies very close to the ground surface (probably less than 5 m in some areas depending on topography). Fringing riparian vegetation to the lagoon reportedly includes *Melaleuca* sp.

Coorlay Lagoon fills after major storms and runoff, 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 infiltration.

Judging from groundwater salinity within the Arcoona aquitard, typically being greater than 50,000 mg/L, it is considered very unlikely that riparian vegetation surrounding Coorlay Lagoon relies on regional groundwater at all. The fact that most occurrences of *Melaleuca* are saplings of fairly uniform age with a few occurrences of mature trees, supports the conclusion that the fringing vegetation to Coorlay Lagoon is dependent on occasional surface water inundation of the lagoon following significant rainfall runoff events to provide for environmental water requirements.

Canegrass Swamp is an ephemeral freshwater swamp located approximately 35 km north of OD (Figure 8.2) where the depth to groundwater is probably tens of metres. It is considered very unlikely that any ecosystems associated with this drainage feature demonstrate any form of groundwater dependence because of the depth to the water table and high groundwater salinity.

Terrestrial vegetation

The dominant terrestrial vegetation communities around OD are:

- chenopod shrubland; and

- acacia woodlands with an understory of chenopod shrubs.

The observed depth to, and salinity of, groundwater around OD (typically greater than 50 m and 50,000 mg/L, respectively) strongly suggest that these vegetation communities and associated ecosystems are not reliant on groundwater. There is no evidence that the lowered groundwater in the area around the existing mine has had any effects on vegetation.

Economic

Pastoralists

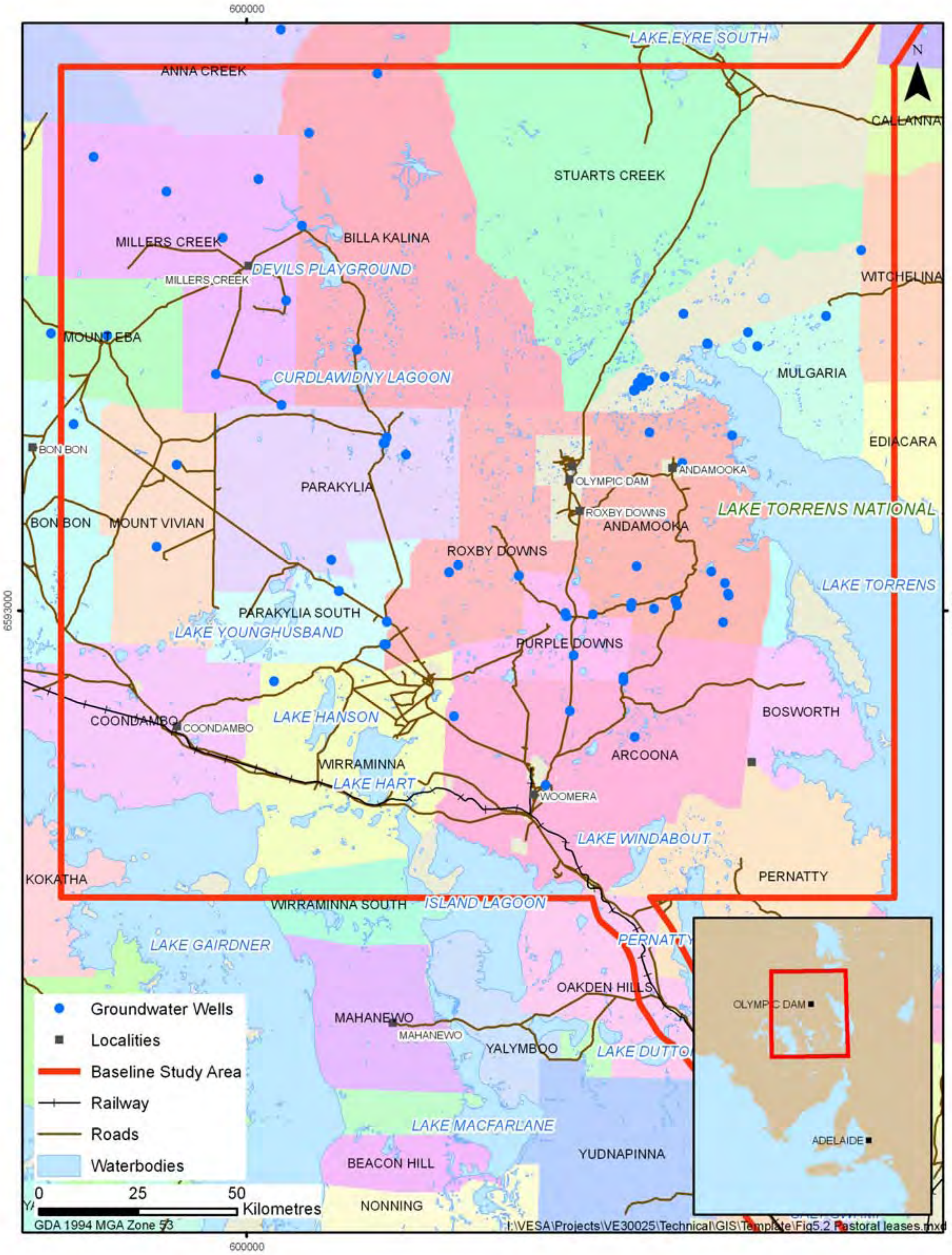
Stockwater supplies on pastoral stations on the Stuart Shelf are typically reliant on rainfall runoff into dams. Groundwater is rarely relied upon for these types of water supplies primarily because salinity concentrations exceed what can safely be used by humans and stock without some form of treatment.

Figure 8.3 presents a plan showing the locations of wells that are known to provide stockwater supplies. Seven of these are located on pastoral leases held by BHP Billiton (Andamooka, Purple Downs and Roxby Downs), four are located on Parakylia and three are located on Parakylia South. Comparison of water quality data (salinity) and well completion depths for these wells (refer Draft EIS, Appendix K2) against the results of various groundwater investigations undertaken by BHP Billiton (SKM, 2010) indicates the pastoral wells do not draw on the regional aquifers (THA or ALA). For example, Comet Well to the west of the SML (Figure 2.1) reports groundwater salinity of around 2,200 mg/L and a completion depth of around 29 m (Draft EIS, Appendix K2), whereas ALA investigation well MXTB09 (Figure 2.1) reports groundwater salinity in excess of 50,000 mg/L and a standing water level of 48 m (SKM, 2010, Attachment D.2).

It is reasonably concluded, then, that these wells draw water from lenses of groundwater perched above the regional aquifers, most likely from sandy lenses within the Bulldog Shale.

Other miners

The Stuart Shelf and broader Gawler Craton geological provinces are subject to growing mineral exploration activities. However, apart from OD the only other mining operation in production or under development within 200 km and within the Stuart Shelf groundwater catchment is the Prominent Hill mine. The mine water supply for the Prominent Hill mine is sourced from the southeastern portion of the Arckaringa Basin's Boorthanna aquifer.



■ **Figure 7.3 Pastoral lease locality plan**

Oil & gas

Oil and gas exploration and production activities take place some 300 km to the northeast of OD in the Cooper Basin, a part of the *artesian* Eromanga (GAB) GFS. No impact on these receptors will occur.

On the basis of information presented above, Table 7.2 presents a summary of the groundwater dependence status of the possible receptors identified within the OD Study Area.

- **Table 7.2 Likely groundwater receptors for OD expansion impact assessment**

Receptor	Groundwater dependent
Bamboo Swamp	☒
Canegrass Swamp	☒
Terrestrial vegetation	☒
Coorlay Lagoon	☐
Yarra Wurta Springs	☑
Pastoral water supply wells	☑
Prominent Hill Mine water supply	☑

Notes: ☒ - no ☑ - yes ☐ - unlikely

7.4. Groundwater impact assessment

Section 7.1 identifies the mine water affecting activities associated with the proposed OD expansion. Table 7.3 lists these activities and their potential to affect groundwater systems with respect to the direct effects of quantity, quality, aquifer disruption of aquifers and groundwater surface water interaction.

Table 7.3 shows that there is potential for a number of mine water affecting activities to have direct effects on the regional groundwater system. Section 7.2 discusses these effects on the groundwater system in relation to the groundwater receptors identified in Table 7.2.

- **Table 7.3 Direct groundwater effects associated with proposed OD expansion water affecting activities**

Water affecting activity	Potential direct effects			
	Quantity	Quality	Aquifer disruption	Groundwater-surface water interaction
Mine workings (dewatering during mining)	☑		☑	☑
Mine workings (post-mining pit lake evaporation)	☑	☑	☑	☑
Tailings storages	☑	☑		
Rock storages	☑	☑		
Water storages				
SML saline water supply wellfields	☑			☑
Stuart Shelf saline water supply wellfields	☑	☑		☑

The following provides brief details of the potential effects:

- ***Mine workings during mining***

Quantity:	Dewatering operations during mining and development of the mine pit (resulting in the intersection of a number of Stuart Shelf aquifers) will result in dewatering and depressurisation of the regional groundwater system, in both water table and confined aquifers.
Aquifer disruption:	The development of a mine pit will disrupt the groundwater system within the SML.
Groundwater – surface water interaction:	Mine workings will not directly impact on interaction between groundwater and surface water systems.

- ***Mine workings after mining***

Quantity:	The mine pit will result in permanent dewatering and depressurisation of the regional groundwater system, in both water table and confined aquifers. This is likely to significantly reduce the flux through the ALA toward Lake Torrens. 500 years after mining at OD is completed, drawdowns of around 1 m are conservatively predicted to extend as far as Yarra Wurta Springs (SWS, 2010).

Quality:	The permanent mine pit may result in brine formation within the host rocks of the OD orebody (i.e. below the THA), which are already very saline, as a result of evaporative concentration of salts.
Aquifer disruption:	The development of a mine pit will permanently disrupt the groundwater system within the SML.
Groundwater – surface water interaction:	Evaporation from the post-mining pit lake will not directly impact on interaction between existing groundwater and surface water systems. However, drawdown within the ALA as a result of mine pit evaporative losses will occur, which has the potential to impact upon Yarra Wurta Springs (see 'quantity' discussion above).

- ***Tailings storages***

Quantity:	Tailings seepage recharges the underlying groundwater system at rates until post-closure capping takes place.
Quality:	Tailings seepage is likely to alter ambient groundwater quality of the underlying groundwater system.

- ***Rock storages***

Quantity:	Seepage from the rock storage facility will recharge the underlying groundwater system at rates higher than background recharge until natural sealing takes place through weathering processes.
Quality:	Seepage from the rock storages will alter ambient groundwater quality of the underlying groundwater system.

- ***SML saline water supply wellfields***

Quantity:	Operation of the water supply wellfields on the SML will result in a depressurisation of, primarily, the THA during operation. This is likely to be insignificant compared to dewatering operations.

- ***Stuart Shelf saline water supply wellfield***

Quantity:	Operation of the ALA water supply wellfields will result in a depressurisation of the ALA during operation, and for some time after whilst recovery occurs. This is likely to significantly reduce the flux through the ALA toward Lake Torrens. In addition, drawdown at the western extent of the Stuart Shelf is expected, but not to the extent that operation of the Prominent Hill Mine water

	supply is compromised.
Quality:	Depressurisation of the shallow ALA may result in the brine interface rising from the deep ALA.
Groundwater – surface water interaction:	Wellfield operation has the potential to reduce the potentiometric head that generates Yarra Wurta Springs discharges in the order of one metre by 500 years post-closure.

Threat assessment

Based on the above discussion concerning potential direct groundwater effects, the following presents an assessment of those groundwater receptors potentially threatened by these effects:

- The threat posed to the Coorlay Lagoon environmental receptor by groundwater drawdown in response to mine dewatering and post-mine evaporation from the pit lake is unlikely to be significant as, on the basis of groundwater salinity alone, it is considered that ecosystems associated with the lagoon are not dependent on groundwater.
- The Yarra Wurta Springs environmental receptor, an obligate GDE, is possibly threatened by the proposed expansion of OD in the long-term (i.e. after mine closure) because the Springs are located at the discharge end of the Arckaringa-Stuart Shelf GFS. Note, however, that hydrogeochemical evidence (see Section 2.3) supported by findings of Johns (1968) and Schmid (1985) strongly suggests that spring discharges are sourced from Adelaide Geosyncline groundwater systems to the east of the Torrens Fault or from deep groundwater beneath Lake Torrens discharging via structural conduits in the lake sediments.
- Pastoral wells located within 50 km of OD, and on BHP Billiton held leases, may be exposed to small groundwater drawdowns that could impact on the pumping efficiency of windmill or small electro-submersible pumps, if the wells are operational in the long-term (i.e. greater than 50 years). However, the perched stockwater aquifers are likely to be in poor hydraulic connection with the regional groundwater system and so the threat of interrupted supply is considered small.
- The Prominent Hill Mine water supply wellfield draws water from the Boorthanna aquifer, a deeply confined aquifer of the Arckaringa Basin. Available drawdowns in the Boorthanna aquifer are such that any drawdown caused by operation of the Stuart Shelf saline water supply wellfield is likely to be mitigated such that the Prominent Hill water supply will not be compromised.

8. Conclusions

8.1. Stuart Shelf groundwater dynamics

On the Stuart Shelf, the ALA forms the dominant water table aquifer. Regional flow, both shallow and deep, in the aquifer is towards the northern end of Lake Torrens where groundwater likely discharges via evaporation near to the margins of the lake. There is deep movement of brine derived from Lake Torrens. This brine is moving slowly outwards from the lake through the deeper ALA and THA.

In the vicinity of the mine lease, groundwater within the THA is already influenced by mining activities with a cone of depression centred on the underground workings and a small number of abstraction wells.

Vertical hydraulic gradients for nested sites across the Stuart Shelf and THZ all appear to be close to hydrostatic, indicating limited to no vertical flow between the ALA and THA, and between the deep brines and shallower saline groundwaters of the ALA.

8.2. Conceptual hydrogeological model

The proposed expansion of OD will operate within the Arckaringa-Stuart Shelf GFS, the primary aquifers of which are separated from the *artesian* Eromanga (GAB) GFS by a groundwater divide. North and south of this divide the Arckaringa-Stuart Shelf GFS is characterised by low permeability rocks of the Adelaide Geosyncline. An extensive regional groundwater discharge/evaporation zone also separates the *artesian* Eromanga (GAB) GFS from the Arckaringa-Stuart Shelf GFS, effectively forming an hydraulic (discharge) boundary that mitigates against any significant interaction between the two flow systems.

The Arckaringa-Stuart Shelf GSF receives very low rates of rainfall recharge, and extends from the Arckaringa Basin in the west (with throughflow moving onto the Stuart Shelf) and Lake Torrens in the east where evaporative discharge occurs at the lake edge. A component of groundwater discharge from this GFS also occurs along the southwest margin of the *artesian* Eromanga (GAB) Basin.

The evaporative discharge of groundwater from Lake Torrens has caused salinity stratification (and brine formation) near and beneath the lake. Very high groundwater salinity observed at depth in the ALA and in the THA north of Lake Torrens is evidence of density driven brine discharge from the sedimentary aquifers beneath Lake Torrens.

The available hydrogeochemical data strongly suggest that Yarra Wurta Springs is supported by groundwater discharging from Adelaide Geosyncline rocks to the northeast of Lake Torrens. Work undertaken by Johns (1968) suggests that these Springs may even be supported by artesian aquifers hosted by deep sediments within the Lake Torrens graben that are recharged from the east, consistent with the hydrogeochemical data.

8.3. The potential for interaction between the *artesian* Eromanga (GAB) aquifers and aquifers of the Stuart Shelf and Arckaringa Basin

In addition to intervening low permeability rocks of the THZ, more than 50 km north of Olympic Dam a groundwater divide separates the primary aquifers of the Arckaringa-Stuart Shelf GFS from the *artesian* Eromanga (GAB) GFS. It is concluded that the proposed expansion of OD will not impact at all on GAB Springs that are located at the discharge end of the *artesian* Eromanga (GAB) GFS.

Further to the northwest, the contact between the Arckaringa Basin and *artesian* Eromanga (GAB) Basin occurs within a structurally and lithologically complex environment. The displacement of different formations against each other and hydraulic boundaries (such as possible fault gouge and a regional scale groundwater discharge/evaporation zone) all serve to limit interaction between the two flow systems. Hydrogeochemical data support this conclusion.

The overriding conclusions arising from the above analysis of available information presented in this report are:

- there is little interaction of any significance between the *artesian* Eromanga (GAB) groundwater system and the groundwater systems of the Stuart Shelf and Arckaringa Basin; and
- the proposed open cut mine development at OD is very unlikely to alter this situation.

8.4. Beneficial use categories for regional aquifers

Available groundwater salinity data show that the main aquifers of the Arckaringa-Stuart Shelf GFS (i.e. the ALA and THA) in general do not have any beneficial use other than for industrial water supplies.

8.5. Water sampling protocols and TSS

Water sampling protocols adopted for the groundwater studies undertaken for the proposed OD expansion environmental studies are consistent with industry practice (eg. methods of sample collection, preservation and shipment, holding times, analysis by NATA-registered laboratories). Reported laboratory data (salinity, pH, metals and other analytes) are considered to representative of in-situ groundwater quality.

8.6. Lake Torrens

8.6.1. Hydrology

Work completed by Schmid (1985) shows that the brines beneath Lake Torrens are largely sourced from the evaporative concentration of groundwaters moving from east of the lake. Schmid further concluded that groundwater discharge to Lake Torrens from west of the Torrens Fault is negligible.

Johns (1968) studied the Springs occurring in the central portion of Lake Torrens and, consistent with the findings of Schmid (1985), found that Springs discharges are sourced from deep sediments at the base of the Lake Torrens graben that are recharged from creek lines, and fractured rock and sedimentary aquifers east of the lake. Based on this, and ^{36}Cl isotope data, it is reasonable to assume that Yarra Wurta Springs function similarly to other Lake Torrens Springs, possibly mitigating the risk of potential drawdown impacts associated with post-closure drainage of groundwater into the final pit void, from which it evaporates.

8.6.2. Brine

Groundwater wells installed across much of the eastern portion of the Stuart Shelf have encountered a halocline within the ALA, which represents a contrast with lower ALA brine. Closer to Lake Torrens, the THA also shows evidence of density driven brine discharge. The brine arises largely as a result of the evaporative concentration of salts in groundwater.

The brine causes the saline (fresher) groundwater moving towards Lake Torrens to be effectively forced upward by the density difference, reducing the *effective* transmissivity of the ALA (the aquifer is 80 to 100 m thick in the western portion of the Stuart Shelf, but is effectively less than 20 to 40 m thick within about 20 km of the Lake), as flow is constrained between the halocline and the overlying lower permeability shale formations.

Fresh water corrected hydraulic heads and vertical gradients for the ALA at various nested groundwater monitoring sites show the lower (hypersaline) and upper (saline) ALA to be hydrostatic or close to hydrostatic at most sites, indicating limited vertical movement takes place between the upper and lower parts of the aquifer.

Numerical modeling has shown that operation of the proposed Motherwell saline water supply wellfield (which will draw water from the Andamooka Limestone aquifer) is likely to have the greatest influence on regional groundwater drawdowns during operation of the proposed expanded mine (up until 2017 when the wellfield is planned to be decommissioned). The impact of the mine pit on groundwater in this area in the long-term will not be as great as that associated with operation of this proposed water supply (SWS, 2010).

In terms of the potential change in vertical hydraulic gradients and brine mobilisation, analytical modeling suggests the impact of the proposed Motherwell wellfield will not be extensive. Further, if some mobilisation of brine does occur it will not impact adversely on any sensitive receptors.

8.7. Groundwater impact assessment

A number of receptors have been identified as being possibly threatened by groundwater effecting activities associated with the proposed OD expansion, many of which have been shown to not have any significant exposure pathway between them and groundwater affecting activities associated with the proposed expansion, e.g. Coorlay Lagoon, the freshwater swamps and pastoral water supply wells.

However, groundwater impact assessment for the project shows that Yarra Wurta Springs, an obligate GDE, may be exposed to reduced discharge effects due to ALA drawdowns that may arise because of evaporative discharges from the mine pit water body (post-closure). Conservative numerical groundwater flow modeling (that does not consider a possible east-of-Lake Torrens source of Springs discharge) predicts that drawdowns of around 1 m may be encountered at the location of the Springs 500 years from mine closure. As such, the threat posed to Yarra Wurta Springs by the proposed OD expansion cannot be ruled out, although an adverse effect is unlikely.

The Prominent Hill Mine water supply wellfield draws water from the Boorthanna aquifer, a deeply confined aquifer of the Arckaringa Basin. Available drawdowns in the Boorthanna aquifer are such that any drawdown caused by operation of the proposed Motherwell wellfield through to 2017 will not compromise the mines water supply.

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Attachment A

Regional groundwater data & density corrections

Table A.1 Density corrected hydraulic heads for the upper ALA

	Midpoint of screen	Measured salinity	Estimated salinity at z_r	Density in well	Ambient gw density at z_r	Average density	Measured hydraulic head	Freshwater head at z_r	Freshwater head at screen	$h_{f,r} – h_{f,i}$
Well ID	z_i	TDS i	TDS r	ρ_i	ρ_r	ρ_a	h_i	$h_{f,r}$	$h_{f,i}$	
	(m)	(mg/L)	(mg/L)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(m)	(m)	(m)	(m)
MAR 4 [2]	-25.15	33500	33500	1025	1025	1025	40.15	40.41	41.79	-1.39
MAR 7 [2]	35.83	30000 [1]	30000	1023	1023	1023	40.83	41.07	40.94	0.13
MAR1-10	-3.17	30000 [1]	30000	1023	1023	1023	41.09	41.34	42.09	-0.75
MAR1-20	-2.86	30000 [1]	30000	1023	1023	1023	41.09	41.34	42.08	-0.74
MAR2-10a	-19.98	31700	31700	1024	1024	1024	41.25	41.52	42.71	-1.19
MAR2-50a	-21.00	32100	32100	1024	1024	1024	39.86	40.10	41.33	-1.23
MAR4-20a	4.86	28000	28000	1021	1021	1021	40.69	40.91	41.44	-0.53
MAR4-50a	7.55	28000 [1]	28000	1021	1021	1021	40.81	41.04	41.51	-0.47
MXTB05	47.47	10800 [1]	10800	1008	1008	1008	52.47	52.65	52.51	0.14
MXTB07a	7.36	14200	14200	1011	1011	1011	43.41	43.55	43.79	-0.24
MXTB08	38.14	21000 [1]	21000	1016	1016	1016	43.14	43.35	43.22	0.13
MXTB09a	28.81	33200	33200	1025	1025	1025	43.72	44.06	44.09	-0.03
MXTB10a	-18.75	17200	17200	1013	1013	1013	42.89	43.06	43.69	-0.63
MXTB11b	-37.82	30800	30800	1023	1023	1023	42.39	42.68	44.24	-1.57
MXTB12a	20.45	30600	30600	1023	1023	1023	42.04	42.32	42.54	-0.22
MXTB13a	13.34	30800	30800	1023	1023	1023	42.95	43.11	43.33	-0.21

■ Table A.1 Density corrected hydraulic heads for the upper ALA (cont.)

	Midpoint of screen	Measured salinity	Estimated salinity at z_r	Density in well	Ambient gw density at z_r	Average density	Measured hydraulic head	Freshwater head at z_r	Freshwater head at screen	$h_{f,r} - h_{f,i}$
Well ID	z_i	TDS i	TDS r	ρ_i	ρ_r	ρ_a	h_i	$h_{f,r}$	$h_{f,i}$	
	(m)	(mg/L)	(mg/L)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(m)	(m)	(m)	(m)
MXTB14a	18.81	31800	31800	1024	1024	1024	40.82	41.08	41.34	-0.27
PT42 [2]	-28.87	30000 [3]	30000	1023	1023	1023	41.68	41.94	43.27	-1.32
PT44 [2]	0.2	30000 [3]	30000	1023	1023	1023	40.33	40.56	41.23	-0.67
PT45 [2]	24.42	30000 [3]	30000	1023	1023	1023	40.03	40.26	40.38	-0.13
PT48 [2]	39.68	29000	29000	1022	1022	1022	44.68	45.00	44.79	0.21
PT50 [2]	-28.56	30000 [3]	39000	1023	1029	1026	40.71	40.75	42.27	-1.52
PT51 [2]	16.04	40000	40000	1030	1030	1030	40.29	40.60	41.02	-0.42
PT60 [2]	28.92	24000	24000	1018	1018	1018	41.11	41.31	41.33	-0.02
PT61 [2]	4.67	30000 [3]	30000	1023	1023	1023	40.65	40.89	41.46	-0.57
RT04a	22.16	31000	31000	1023	1023	1023	39.9	40.13	40.31	-0.18
RT05a	-2.18	53000	53000	1040	1040	1040	39.28	39.65	40.93	-1.28
RT16a	38.42	22300	22300	1017	1017	1017	43.27	43.49	43.35	0.14
RT17a	30.56	23000	23000	1017	1017	1017	48.7	49.02	49.01	0.01

Table A.1 Density corrected hydraulic heads for the upper ALA (cont.)

	Midpoint of screen	Measured salinity	Estimated salinity at z_r	Density in well	Ambient gw density at z_r	Average density	Measured hydraulic head	Freshwater head at z_r	Freshwater head at screen	$h_{f,r} - h_{f,i}$
Well ID	z_i	TDS i	TDS r	ρ_i	ρ_r	ρ_a	h_i	$h_{f,r}$	$h_{f,i}$	
	(m)	(mg/L)	(mg/L)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(m)	(m)	(m)	(m)
RT2a	-15.42	43400	43400	1033	1033	1033	40.5	40.84	42.32	-1.48
RT3	9.10	20000	20000	1015	1015	1015	40.19	40.34	40.66	-0.31

Notes: 1 Estimated from EC measurements taken during drilling with a conversion factor of EC = 0.6 x TDS

2 Open hole & fully penetrating wells used, with hydrostatic conditions assumed and water table = h_i at top of 'screen' (i.e. open section drillhole with potential inflows)

z_i = (h_i - 5m) when h_i is below base of collar or top of Andamooka Limestone; z_i = top of screen when h_i is above base of collar or top of Andamooka Limestone

3 Estimated values at top of aquifer; published TDS data measured using low flow sampling technique at deeper levels within open hole well

Table A.2 Density corrected hydraulic heads for the lower ALA

	Midpoint of screen	Measured salinity	Estimated salinity at z_r	Depth of brine interface [1]	Density in well	Ambient gw density at z_r	Average density	Measured hydraulic head	Freshwater head at z_r		Error margin [2]	Freshwater head at screen	$h_{f,r} – h_{f,i}$
Well ID	z_i	TDS i	TDS r	z_b	ρ_i	ρ_r	ρ_a	h_i	$h_{f,r}$			$h_{f,i}$	
	(m)	(mg/L)	(mg/L)	(m)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(m)	(m)			(m)	(m)
MXTB07b	-57.60	31600	31600		1024	1024	1024	42.39	44.58	±	0.00	44.76	-0.18
MXTB09b	-33.13	50300	50300		1038	1038	1038	43.00	46.51	±	0.00	45.87	0.64
MXTB10b	-122.68	28800	28800		1022	1022	1022	41.72	43.70	±	0.00	45.27	-1.57
MXTB11b	-37.82	30800	30800		1023	1023	1023	42.39	44.52	±	0.00	44.24	0.28
MXTB12b	-31.52	30800	30800		1023	1023	1023	41.91	44.03	±	0.00	43.61	0.43
MXTB13b	-54.63	17300	17300		1013	1013	1013	42.85	44.05	±	0.00	44.11	-0.06
MXTB14b	-90.19	101000	[1]50000	-60	1076	1038	1066	36.62	43.57	±	0.23	46.23	-2.65
MAR2-10b	-78.98	230000	[1]50000	-79	1173	1038	1038	28.76	46.26	±	0.00	47.35	-1.09
MAR2-50b	-85.00	237000	[1]50000	-80	1178	1038	1058	27.74	45.77	±	0.14	47.78	-2.01
MAR3-20	-123.54	221000	[1]80000	-94	1166	1060	1102	26.21	43.50	±	0.62	51.03	-7.53
MAR4-20b	-66.64	80000	[1]50000	-50	1060	1038	1060	38.54	43.85	±	0.00	44.85	-1.00
MAR4-50b	-67.45	[1]80000	[1]50000	-50	1060	1038	1059	38.47	43.79	±	0.01	44.83	-1.04
PT40	-128.00	220000	[1]150000	-71	1165	1113	1151	26.18	39.85	±	0.60	51.62	-11.77
PT66	-180.21	260000	[1]120000	-129	1195	1090	1131	25.18	48.16	±	1.07	65.23	-17.07
RT05b	-113.52	260000	[1]80000	-80	1195	1060	1132	26.94	45.93	±	0.92	54.33	-8.40

Notes: [1.] Estimated from EC measurements taken during drilling

[2.] Calculated by raising or lowering level of brine interface (z_b) by 20%: upper $z_b = z_b \times 1.2$; lower $z_b = zb \times 0.8$

Table A.3 Compiled data

Well ID	Easting (MGA94 Z53)	Northing (MGA94 Z53)	h_i (mAHD)	TDS (mg/L)	$h_{f,i}$ (mAHD)
Tent Hill Aquifer using reference level : -5mAHD					
QT2	676,529	6,631,873	17.53	33,085	18.14
QR1	675,631	6,636,423	44.83	20,540	45.45
PT6	686,936	6,632,520	25.43	19,900	25.53
PT3_4b	673,204	6,624,297	49.44	52,000	51.54
PT2	671,735	6,621,617	50.20	66,200	54.17
RT02b	691,849	6,656,795	28.50	203,000	48.43
PT5A	674,761	6,628,083	49.74	44,400	51.71
PT17	684,464	6,631,390	3.33	34,500	3.68
PT18	687,332	6,629,082	22.51	64,200	24.79
RT16b	677,884	6,634,860	30.59	55,000	32.91
RT17b	676,759	6,633,225	30.54	60,000	33.65
PT14	682,089	6,626,155	36.86	29,000	37.71
PT31	692,701	6,624,120	43.23	15,000	43.40
PT5d	675,651	6,624,933	48.30	28,900	49.36
PT24b	676,805	6,627,765	47.22	63,800	51.18
PT9	677,991	6,617,546	51.52	37,500	53.34
PT15	678,297	6,627,345	48.74	65,000	52.83
PT7	683,526	6,614,555	53.65	51,600	56.17
PT12	675,342	6,618,130	49.85	61,300	53.87
PT1	671,433	6,622,612	49.17	73,000	53.95
RT1	705,530	6,652,112	39.59	200,000	71.17
Andamooka Limestone Aquifer (Upper) using reference level : 30mAHD					
MAR 4	681,280	6,626,162	40.15	33,500	40.41
MAR 7	691,933	6,650,330	40.83	30,000	41.07
MAR1-10	686,082	6,645,061	41.09	30,000	41.34
MAR1-20	686,049	6,645,060	41.09	30,000	41.34
MAR2_10a	694,211	6,660,897	41.25	31,700	41.52
MAR2-50a	694,220	6,660,890	39.86	32,100	40.10
MAR4-20a	689,906	6,650,917	40.69	28,000	40.91
MAR4-50a	689,910	6,650,920	40.81	28,000	41.04
MXTB05	627,372	6,657,629	52.47	10,800	52.65
MXTB07a	643,061	6,664,637	43.41	14,200	43.55
MXTB08	643,694	6,656,148	43.14	21,000	43.35
MXTB09a	640,590	6,644,363	43.72	33,200	44.06
MXTB10a	654,540	6,676,732	42.89	17,200	43.06
MXTB11b	653,737	6,659,751	42.39	30,800	42.68
MXTB12a	656,594	6,643,891	42.04	30,600	42.32
MXTB13a	661,036	6,666,725	42.95	16,900	43.11
MXTB14a	672,154	6,652,840	40.82	31,800	41.08
PT42	690,623	6,663,940	41.68	30,000	41.94
PT44	684,970	6,657,514	40.33	30,000	40.56
PT45	681,922	6,653,391	40.03	30,000	40.26
PT48	685,471	6,673,126	44.68	29,000	45.00
PT50	680,065	6,665,665	40.71	30,000	40.75
PT51	679,082	6,659,712	40.29	40,000	40.60
PT60	691,178	6,674,079	41.11	24,000	41.31
PT61	683,385	6,649,659	40.65	30,000	40.89
RT04a	711,528	6,668,764	39.90	31,000	40.13
RT05a	712,701	6,661,139	39.28	53,000	39.65
RT16a	677,879	6,634,872	43.27	22,300	43.49
RT17a	676,746	6,633,220	48.70	23,000	49.02
RT2a	691,869	6,656,802	40.50	43,400	40.84
RT3	696,949	6,666,399	40.19	20,000	40.34
Andamooka Limestone Aquifer (Lower) using reference level : -50mAHD					
MXTB07b	643,061	6,664,637	42.39	31,600	44.58
MXTB09b	640,590	6,644,363	43.00	50,300	46.51
MXTB10b	654,540	6,676,732	41.72	28,800	43.70
MXTB11b	653,737	6,659,751	42.39	30,800	44.52
MXTB12b	656,594	6,643,891	41.91	30,800	44.03
MXTB13b	661,036	6,666,725	42.85	17,300	44.05
MXTB14b	672,154	6,652,840	36.62	101,000	43.95
MAR2-10b	694,211	6,660,897	28.76	230,000	43.76
MAR2-50b	694,220	6,660,890	27.74	237,000	43.36
MAR3-20	691,905	6,656,771	26.21	221,000	42.18
MAR4-20b	689,906	6,650,917	38.54	80,000	44.04
MAR4-50b	689,910	6,650,920	38.47	80,000	43.97
PT40	698,472	6,671,656	26.18	220,000	40.80
PT66	696,951	6,666,422	25.18	260,000	45.21
RT05b	712,703	6,661,139	26.94	260,000	44.56

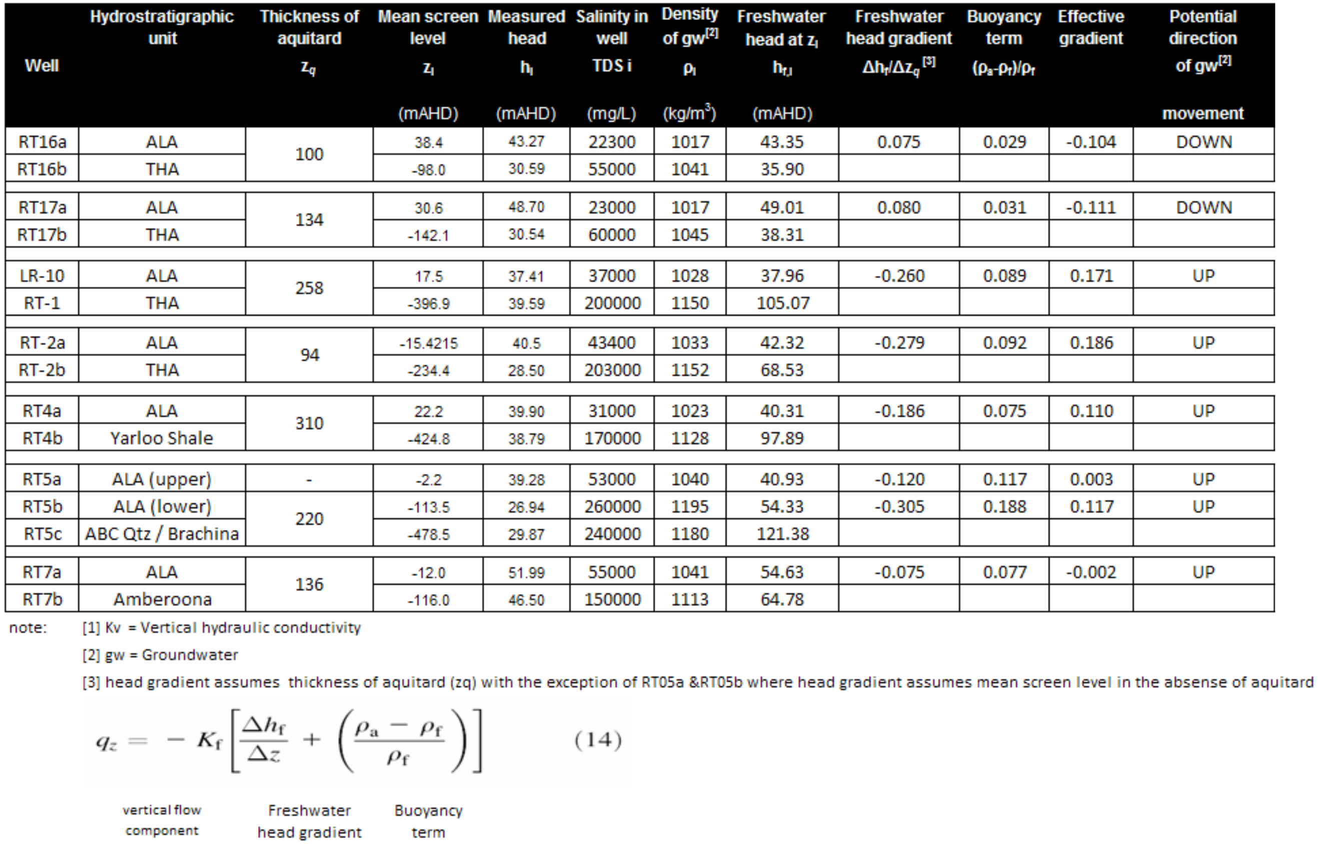
$$h_{\mathrm{f},r} = z_r + \frac{\rho_i}{\rho_\mathrm{f}}(h_i - z_i) - \frac{\rho_\mathrm{a}}{\rho_\mathrm{f}}(z_r - z_i) \quad (12)$$

Equivalent freshwater head
with well screens normalised to
reference level, z_r (from Post et al., 2007)

Well ID	Easting (MGA94 Z53)	Northing (MGA94 Z53)	h_i (mAHD)
Regional Watertable			
LR10	705,533	6,652,117	37.69
LR11	701,712	6,651,124	40.33
Sister Well	746,377	6,667,481	57.46
Apollo Bore	755,246	6,684,084	86.73
Yarra Wurta Well	710,295	6,668,066	40.92
WP1	698,789	6,650,555	40.48
MS4	700,009	6,649,692	38.80
MSWB 2	699,893	6,651,955	40.44
MSWB	697,824	6,648,562	40.44
Census Dam Spring	728,998	6,659,843	39.38
Rocky Creek Spring	726,670	6,663,338	38.54
Yarra Wurta East Springs 1	716,365	6,660,490	37.38
Yarra Wurta East Springs 2	716,372	6,660,505	37.44
Yarra Wurta East Springs 3	716,439	6,660,515	37.52
Yarra Wurta East Springs 4	716,440	6,660,474	37.64
Yarra Wurta East Springs 5	716,396	6,660,367	37.49
Yarra Wurta East Springs 6	716,393	6,660,414	37.35
Flowing Bore Spring	717,427	6,602,732	52.91
Nick of Time	720,304	6,589,909	62.41
Mulga Well	697,104	6,593,670	76.27
Wirrda Well	698,508	6,604,109	73.87
Pine Bore 6336-40	697,311	6,594,788	82.58
Whip Well 6336-1	708,352	6,595,400	67.19
Centenary Well	720,840	6,599,756	59.29
Rubbish Dump Well	710,018	6,630,333	65.99
Myall Well	721,612	6,597,128	60.93
Coorlay Well	687,491	6,591,897	79.39
Tod Ridge Well 6	708,680	6,594,213	66.22
North Dam Bore	701,765	6,638,001	55.30
Miracle Dam Bore	702,888	6,593,317	100.43
Myall Bore	721,740	6,596,610	59.23
WMC Bore	722,665	6,637,239	32.49
Purple Swamp 1	680,515	6,592,138	77.49
Purple Swamp 2	680,519	6,592,131	77.53
Purple Swamp 3	680,845	6,591,395	78.00
Wilson Well	695,215	6,575,986	98.31
WB6	682,578	6,581,471	92.67
Horse Well	695,156	6,575,031	99.06
Chances Well	668,815	6,601,717	78.17
Chances Well 2	668,824	6,601,718	78.29
Sister Well 1	651,171	6,602,566	72.59
Sister Well 2	651,174	6,602,600	71.07
Boundary Well	635,241	6,584,243	93.58
Bambridge Well	653,452	6,604,383	71.82
Lower Nth Creek Well	608,700	6,740,074	60.90
Curdlawidny Well	627,888	6,659,000	53.63
Hunts Bore	633,042	6,728,952	52.21
Tuckers Bore	615,810	6,713,833	56.62
North Homestead Bore	564,878	6,662,537	106.46
Margaret Bore	550,598	6,663,080	117.32
No. 1	561,372	6,707,781	183.09
No. 1 Bore	579,831	6,698,977	
Pinchega Well	606,977	6,574,949	117.82
Mount Ernest Well	556,389	6,640,074	128.19
Arcoona Clave Well	621,477	6,605,711	91.45
Red Lake bore	640,272	6,632,422	52.43
19 Mile Bore	608,853	6,644,932	69.26
New Parakylia Bore	634,734	6,635,361	53.07
Comet Well	634,947	6,635,354	51.75
Old Homestead Well	635,432	6,636,758	51.17
Alex's Bore	623,343	6,597,795	94.64
Alex's Bore 2	623,340	6,597,790	94.63
Knoll Well	635,446	6,589,967	94.30
Knoll Well 2	635,446	6,590,041	94.15
No. 1 Well	634,760	6,584,260	94.50
Homestead Bore	614,014	6,690,319	67.79
BFT 001	603,024	6,702,099	68.00
Trig Bore	593,970	6,687,292	72.19
Moodlampnie Bore	610,030	6,671,362	66.46
No. 11 Bore	592,289	6,652,807	75.86
White Nob Bore	533,326	6,695,256	123.00
CRA Bore	543,020	6,713,220	118.26
McDoual Peak Homestead We	537,767	6,681,748	161.24
Fishers Well	582,384	6,629,783	132.08
Lively Well	577,303	6,608,995	134.82
Mungapote Well	652,424	6,566,031	103.73
MW4	675,576	6,548,631	118.52
WB7	681,631	6,567,414	114.56
Engine Well	698,068	6,560,786	119.45

Note: Density correction not carried out for water table waterlevels

Table A.4 Predicted direction of vertical groundwater movement at nested sites



Well	Hydrostratigraphic unit	Thickness of aquitard z_q	Mean screen level z_i (mAHD)	Measured head h_i (mAHD)	Salinity in well TDS i (mg/L)	Density of gw[2] ρ_i (kg/m^3)	Freshwater head at z_i $h_{f,i}$ (mAHD)	Freshwater head gradient $\Delta h_f/\Delta z_q$ [3]	Buoyancy term $(\rho_a-\rho_f)/\rho_f$	Effective gradient	Potential direction of gw[2] movement
RT16a	ALA	100	38.4	43.27	22300	1017	43.35	0.075	0.029	-0.104	DOWN
RT16b	THA		-98.0	30.59	55000	1041	35.90				
RT17a	ALA	134	30.6	48.70	23000	1017	49.01	0.080	0.031	-0.111	DOWN
RT17b	THA		-142.1	30.54	60000	1045	38.31				
LR-10	ALA	258	17.5	37.41	37000	1028	37.96	-0.260	0.089	0.171	UP
RT-1	THA		-396.9	39.59	200000	1150	105.07				
RT-2a	ALA	94	-15.4215	40.5	43400	1033	42.32	-0.279	0.092	0.186	UP
RT-2b	THA		-234.4	28.50	203000	1152	68.53				
RT4a	ALA	310	22.2	39.90	31000	1023	40.31	-0.186	0.075	0.110	UP
RT4b	Yarloo Shale		-424.8	38.79	170000	1128	97.89				
RT5a	ALA (upper)	-	-2.2	39.28	53000	1040	40.93	-0.120	0.117	0.003	UP
RT5b	ALA (lower)	220	-113.5	26.94	260000	1195	54.33	-0.305	0.188	0.117	UP
RT5c	ABC Qtz / Brachina		-478.5	29.87	240000	1180	121.38				
RT7a	ALA	136	-12.0	51.99	55000	1041	54.63	-0.075	0.077	-0.002	UP
RT7b	Amberoona		-116.0	46.50	150000	1113	64.78				

note: [1] Kv = Vertical hydraulic conductivity

[2] gw = Groundwater

[3] head gradient assumes thickness of aquitard (zq) with the exception of RT05a &RT05b where head gradient assumes mean screen level in the absense of aquitard

$$q_z = -K_f\left[\frac{\Delta h_f}{\Delta z} + \left(\frac{\rho_a - \rho_f}{\rho_f}\right)\right] \qquad (14)$$

vertical flow component

Freshwater head gradient

Buoyancy term

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- **Table A.5 Predicted direction of vertical groundwater movement at nested sites**

Well	Mean screen level z_i (mAHD)	Measured head h_i (mAHD)	Salinity in well TDS i (mg/L)	Density in well ρ_i (kg/m^3)	Freshwater head at z_i $h_{f,i}$ (mAHD)		Freshwater head gradient $\Delta h_f/\Delta z$	Buoyancy term $(\rho_a-\rho_f)/\rho_f$	Effective gradient	Predicted direction of gw movement
MAR2-10a	-19.98	41.25	31700	1024	42.71		-0.08	0.10	-0.020	DOWN
MAR2-10b	-78.98	28.76	230000	1173	47.35					
MAR2-50a	-21	39.86	32100	1024	41.33		-0.10	0.10	0.000	
MAR2-50b	-85.00	27.74	237000	1178	47.78					
MAR4-20a	4.86	40.69	28000	1021	41.44		-0.05	0.04	0.007	UP
MAR4-20b	-66.64	38.54	80000	1060	44.85					
MAR4-50a	7.55	40.81	28000	1021	41.51		-0.04	0.04	0.004	UP
MAR4-50b	-67.45	38.47	80000	1060	44.83					
MXTB07a	7.36	43.41	14200	1011	43.79		-0.01	0.02	-0.002	DOWN
MXTB07b	-57.60	42.39	31600	1024	44.76					
MXTB09a	28.81	43.72	33200	1025	44.09		-0.03	0.03	-0.003	DOWN
MXTB09b	-33.13	43	50300	1038	45.87					
MXTB10a	-18.75	42.89	17200	1013	43.69		-0.02	0.02	-0.002	DOWN
MXTB10b	-122.68	41.72	28800	1022	45.27					

- **Table A.5 Predicted direction of vertical groundwater movement at nested sites (cont.)**

Well	Mean screen level z_i (mAHD)	Measured head h_i (mAHD)	Salinity in well TDS i (mg/L)	Density in well ρ_i (kg/m^3)	Freshwater head at z_i $h_{f,i}$ (mAHD)	Freshwater head gradient $\Delta h_f/\Delta z$	Buoyancy term $(\rho_a-\rho_f)/\rho_f$	Effective gradient	Predicted direction of gw movement
MXTB12a	20.45	42.04	30600	1023	42.54	-0.02	0.02	-0.002	DOWN
MXTB12b	-31.52	41.91	30800	1023	43.61				
MXTB13a	13.34	42.95	30800	1023	43.63	-0.02	0.02	-0.002	DOWN
MXTB13b	-54.63	42.85	30800	1023	45.10				
MXTB14a	18.81	40.82	31800	1024	41.34	-0.04	0.05	-0.005	DOWN
MXTB14b	-90.19	36.62	101000	1076	46.23				
RT05a	-2.18	39.28	53000	1040	40.93	-0.12	0.12	0.003	UP
RT05b	-113.52	26.94	260000	1195	54.33				
RT3	9.10	40.19	20000	1015	40.66	-0.13	0.11	0.025	UP
PT66	-180.21	25.18	260000	1195	65.23				
RT2a	-15.42	40.5	43400	1033	42.32	-0.21	0.11	0.098	UP
MAR3	-123.54	26.21	221000	1195	65.23				

- **Table A.6 Estimated hydraulic conductivities for nested groundwater monitoring wells**

Hydrogeology	Well Location	Hydraulic Conductivity (m/d)	Data Origin
Andamooka Limestone Aquifer	RT5a and RT5b	6.5×10^{-1} to 1.7×10^{2}	SKM (2010)
Arcoona Quartzite Aquitard	RT16a, RT16b, RT17a, RT17b, RT02a, RT02b	9×10^{-4} to 2×10^{-3}	SKM (2010)
Yarloo Shale	LR10, RT01, RT04a, RT04b	2×10^{-5} to 9×10^{-3}	Estimated (BHP-B 2008) and Section 2.3
Adelaide Geosyncline Rocks	RT07a and RT07b, RT05c	$1 \text{ X } 10^{-4}$ to 1×10^{-2}	Section 3.4

Attachment B
Falling & rising head hydraulic testing results

B.1 Procedure and data analysis

Procedure

Falling head tests were used to obtain estimates of hydraulic conductivity for hydrostratigraphic units predominately within the THZ (Figure 3.12). The procedure involved introducing a solid PVC ‘slug’ to the water column of each well and then recording water level recovery using downhole pressure transducers.

The pressure transducer was lowered to approximately 5 m below the static water level and set to record water pressure at intervals ranging from 0.5 to 30 seconds.

Data analysis

Time series groundwater level data were downloaded from the logger and imported into a spreadsheet template for the Hvorslev solution (Fetter, 1988), which is suitable for providing ‘near well’ estimates of hydraulic conductivity values for confined aquifers. Analysis of the falling head data was also evaluated using the Bouwer-Rice method (Bouwer, 1989), again with the use of a spreadsheet template. The data are presented as Attachment B.2 and B.3.

Stuart Shelf

Falling head slug tests were conducted at two groundwater monitoring wells (RT02b and RT04b) screened within the Arcoona Quartzite Aquitard and the Yarloo Shale respectively. Estimated hydraulic conductivity values for RT02b range between 2 x 10^{-3} and 5 x 10^{-3} m/d.

Estimated hydraulic conductivity values for RT04b range between 2 x 10^{-5} and 2 x 10^{-2} m/d. During the falling head test a blockage was encountered within the well at a depth of approximately 35 m below ground level (bgl) and, as such, the results may not be representative (and have been excluded from the summary presented in Table 3.1).

Adelaide Geosyncline

Falling head tests were conducted on five groundwater monitoring wells (RT05c, RT07a, RT07b, RT09 and PT63) screened within Adelaide Geosyncline rocks of the THZ (ABC Range Quartzite, Brachina Formation and Amberoona Formation). Estimated hydraulic conductivity values range between 1 x 10^{-4} and 1 x 10^{-2} m/d.

Non-artesian Eromanga Basin

Falling head tests were conducted on four groundwater monitoring wells (RT41, RT42 and PT62) screened within the Bulldog Shale and the remnant Cadna-owie Formation of the *non-artesian* Eromanga Basin (i.e. south of the artesian springs zone).

Hydraulic conductivity estimates for RT41 and RT42 range between 7 x 10^{-1} and 1.5 m/d. The hydraulic conductivity estimates for PT62, screened within the Cadna-owie Formation, are the highest of any of the tests conducted during this program of work, ranging between 23 and 33 m/d. (note: PT62 is the only location drilled on the Stuart Shelf as part of the BHP Billiton work programs that encountered significant intersections of saturated / partially saturated Cadna-owie Formation.

B.2 Bouwer-Rice method

Aquifer Test Solutions: Slug Tests Bouwer Rice

Project Name: **BHP-B SEIS Field Investigations**
Client: **BHP-B**

Date: 02-May-10
Time: 13:38

Well No. / Name: **RT02b**

Depth to equilibrium water level (m RL)**:** 51.78 mPVC

Type of test:
Rising head ☐
Falling head ▤ (enter "3" against appropriate test type)

Type of test:
$L_w = H$ ▤ (enter "3" against solution constraint)
$L_w < H$ ☐

Depth to Water at Time '0': 51.65 (m)
$Y_0 =$ 0.13 (m)

500

Data point	Elapsed time (mins)	Depth to water (m)	Drawdown * (Y_t)	
1	0.0050	51.65	0.126	
500	2.5000	51.689	0.091	*
1000	5.0000	51.697	0.083	*
1500	7.5000	51.704	0.076	*
2000	10.0000	51.708	0.072	*
2500	12.5000	51.711	0.069	*
3000	15.0000	51.712	0.068	*
3500	17.5000	51.713	0.067	*
4000	20.0000	51.717	0.063	*
4500	22.5000	51.715	0.065	*
5000	25.0000	51.717	0.063	*
5500	27.5000	51.720	0.060	*
6000	30.0000	51.725	0.055	*
6500	32.5000	51.723	0.057	*
7000	35.0000	51.727	0.053	*
7500	37.5000	51.729	0.051	*
8000	40.0000	51.728	0.052	*
8500	42.5000	51.729	0.051	*
9000	45.0000	51.730	0.050	*
9500	47.5000	51.733	0.047	*
10000	50.0000	51.734	0.046	*
10500	52.5000	51.739	0.041	*
11000	55.0000	51.737	0.043	*
11500	57.5000	51.738	0.042	*
12000	60.0000	51.739	0.041	*
12500	62.5000	51.741	0.039	*
13000	65.0000	51.744	0.036	*
13500	67.5000	51.743	0.037	*
14000	70.0000	51.746	0.034	*
14500	72.5000	51.746	0.034	*
15000	75.0000	51.751	0.029	*
15500	77.5000	51.753	0.027	*
16000	80.0000	51.751	0.029	*
16500	82.5000	51.753	0.027	*
17000	85.0000	51.754	0.026	*
17500	87.5000	51.760	0.020	*
18000	90.0000	51.761	0.019	*
18500	92.5000	51.760	0.020	*
19000	95.0000	51.759	0.021	*
19500	97.5000	51.759	0.021	*
20000	100.0000	51.765	0.015	*
20500	102.5000	51.762	0.018	*
21000	105.0000	51.765	0.015	*
21500	107.5000	51.766	0.014	*
22000	110.0000	51.768	0.012	*
22500	112.5000	51.770	0.010	*
23000	115.0000	51.771	0.009	*
23500	117.5000	51.775	0.005	*
24000	120.0000	51.772	0.008	*
24500	122.5000	51.774	0.006	*
25000	125.0000	51.775	0.005	*
25500	127.5000	51.774	0.006	*
26000	130.0000	51.778	0.002	*
26500	132.5000	51.780	0.000	*
27000	135.0000	51.781	-0.001	*

* Includes residual drawdown for falling head test

Aquifer Test Solutions: Slug Tests Bouwer Rice

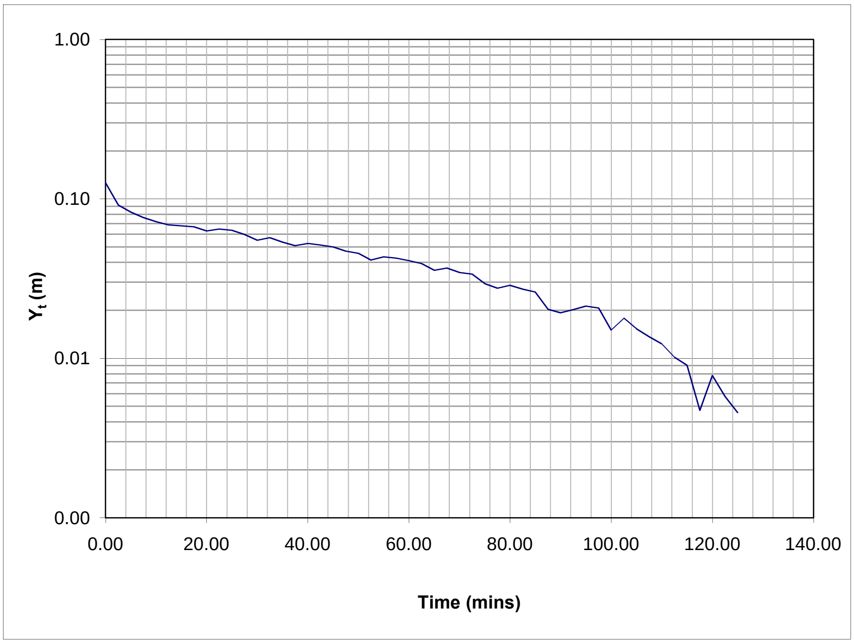
Project Name:	**BHP-B SEIS Field Investigations**	Date:	02-May-10
Client:	**BHP-B**	Time:	13:38

Well No. / Name: **RT02b**

Depth to equilibrium water level (m RL)**:** 51.78 mTOC

Type of test:
Rising head
Falling head ☒

Well Completion:
Fully Penetrating ☒
Partially Penetrating



r_c =	casing radius	0.025
r_w =	radial distance between undisturbed aquifer and well centre	0.1015
L_e =	length of intake	24
H =	saturated thickness of aquifer	24
L_w =	distance b/n water table and bottom of intake	290
R_e =	effective well radius	36.46
t =	time	40
Y_o =	initial drawdown	0.13
Y_t =	vertical distance between the water level in well at time t and equilibrium level	0.06
L_e/r_w =		236.453202
A =	dimensionless co-efficient that is a function of L_e/r_w, and L_w < H	6.45
B =	dimensionless co-efficient that is a function of L_e/r_w, and L_w < H	1.25
C =	dimensionless co-efficient that is a function of L_e/r_w, and L_w = H	7.5

If $L_w < H$

$$\ln(R_e/r_w) = \{1.1 \,.\, [\ln(L_w/r_w)]^{-1} + A+B \,.\, \ln[(H-L_w)/r_w] \,.\, (L_e/r_{w)}{}^{-1}\}^{-1}$$

= **Lw = H** m

If $L_w = H$

$$\ln(R_e/r_w) = \{1.1 \,.\, [\ln(L_w/r_w)]^{-1} + C \,.\, (L_e/r_{w)}{}^{-1}\}^{-1}$$

= **5.88** m

Produced by: Alistair Walsh Date: 7/05/2010

Checked by: Kate Furness Date: 10/05/2010

$$K = [r_c{}^{2} \cdot \ln(R_e/r_w)]\ 2L^{-1} \,.\, t^{-1} \,.\, \ln(Y_o/Y_t)$$

= 1.48E-06 m/min

= **0.002** m/d

Produced by: Alistair Walsh Date: 7/05/2010

Checked by: Kate Furness Date: 10/05/2010

Ref.
Bouwer H. 1989. *The Bouwer and Rice Slug Test - an Update.* Ground Water. Vol.27, No.3. May - June 1989.
Brown D.L. & T.N. Narasimhan. 1995. *An evaluation of the Bouwer and rice method of slug test analysis.* Water Resources Research. Vol. 31, No. 5, pp 1239-1246.
Kruseman G.P. and N.A. de Ridder. 1991. *Analysis and Evaluation of Pumping Test Data.* 2nd Ed. Int. Inst. For Land Reclamation and Improvement. Wageningen. The Netherlands.

Aquifer Test Solutions: Slug Tests Bouwer Rice

Project Name:	**BHP-B SEIS Field Investigations**	Date:	30-Apr-10
Client:	**BHP-B**	Time:	09:11

Well No. / Name: **RT05c**

Depth to equilibrium water level (m RL): 18.667 mPVC

Type of test:
Rising head ☐
Falling head ▤
(enter "3" against appropriate test type)

Type of test:
$L_w = H$ ▤
$L_w < H$ ☐
(enter "3" against solution constraint)

Depth to Water at Time '0': 17.81 (m)
$Y_0 =$ 0.857 (m)

10

Data point	Elapsed time (mins)	Depth to water (m)	Drawdown * (Y_t)	
1	0.05	17.81	0.854	
10	0.5	17.97	0.695	*
20	1	18.05	0.621	*
30	1.5	18.11	0.561	*
40	2	18.15	0.513	*
50	2.5	18.21	0.462	*
60	3	18.25	0.414	*
70	3.5	18.29	0.377	*
80	4	18.33	0.340	*
90	4.5	18.36	0.309	*
100	5	18.39	0.280	*
110	5.5	18.41	0.252	*
120	6	18.44	0.228	*
130	6.5	18.46	0.206	*
140	7	18.48	0.185	*
150	7.5	18.50	0.166	*
160	8	18.52	0.149	*
170	8.5	18.53	0.134	*
180	9	18.55	0.118	*
190	9.5	18.56	0.104	*
200	10	18.58	0.091	*
210	10.5	18.59	0.079	*
220	11	18.60	0.069	*
230	11.5	18.61	0.059	*
240	12	18.62	0.048	*
250	12.5	18.63	0.040	*
260	13	18.635	0.032	*
270	13.5	18.642	0.025	*
280	14	18.649	0.018	*
290	14.5	18.656	0.011	*
300	15	18.662	0.005	*

* Includes residual drawdown for falling head test

Aquifer Test Solutions: Slug Tests Bouwer Rice

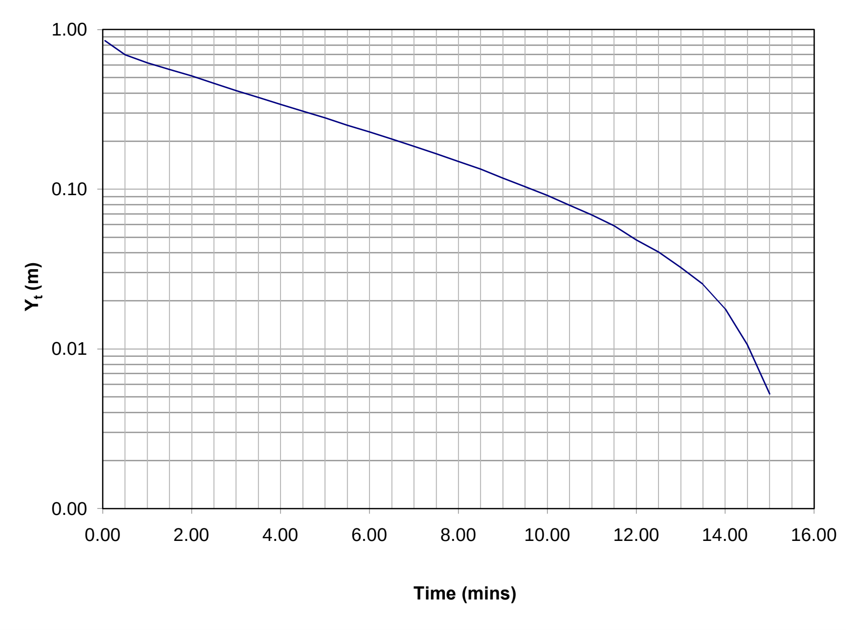
Project Name:	**BHP-B SEIS Field Investigations**	Date:	30-Apr-10
Client:	**BHP-B**	Time:	09:11

Well No. / Name: **RT05c**

Depth to equilibrium water level (m RL)**:** 18.667 mTOC

Type of test: Rising head
Falling head ☒

Well Completion: Fully Penetrating ☒
Partially Penetrating



r_c =	casing radius	0.025
r_w =	radial distance between undisturbed aquifer and well centre	0.1015
L_e =	length of intake	214
H =	saturated thickness of aquifer	214
L_w =	distance b/n water table and bottom of intake	615.333
R_e =	effective well radius	192.82
t =	time	6.5
Y_o =	initial drawdown	0.857
Y_t =	vertical distance between the water level in well at time t and equilibrium level	0.2
L_e/r_w =		2108.374384
A =	dimensionless co-efficient that is a function of L_e/r_w, and L_w < H	10
B =	dimensionless co-efficient that is a function of L_e/r_w, and L_w < H	3.3
C =	dimensionless co-efficient that is a function of L_e/r_w, and L_w = H	13

If $L_w < H$

$$\ln(R_e/r_w) = \{1.1 \,.\, [\ln(L_w/r_w)]^{-1} + A{+}B \,.\, \ln[(H-L_w)/r_w] \,.\, (L_e/r_{w)}{}^{-1}\}^{-1}$$

= **Lw = H** m

If $L_w = H$

$$\ln(R_e/r_w) = \{1.1 \,.\, [\ln(L_w/r_w)]^{-1} + C \,.\, (L_e/r_{w)}{}^{-1}\}^{-1}$$

= **7.55** m

Produced by: Alistair Walsh Date: 6/05/2010

Checked by: Kate Furness Date: 10/05/2010

$$K = [r_c^{2\cdot} \ln(R_e/r_w)]\ 2L^{-1} \,.\, t^{-1} \,.\, \ln(Y_o/Y_t)$$

= 2.47E-06 m/min
= **0.004** m/d

Produced by: Alistair Walsh Date: 6/05/2010

Checked by: Kate Furness Date: 10/05/2010

Ref. Bouwer H. 1989. *The Bouwer and Rice Slug Test - an Update*. Ground Water. Vol.27, No.3. May - June 1989.
Brown D.L. & T.N. Narasimhan. 1995. *An evaluation of the Bouwer and rice method of slug test analysis.* Water Resources Research. Vol. 31, No. 5, pp 1239-1246.
Kruseman G.P. and N.A. de Ridder. 1991. *Analysis and Evaluation of Pumping Test Data*. 2nd Ed. Int. Inst. For Land Reclamation and Improvement. Wageningen. The Netherlands.

Project Name:	**BHP-B SEIS Field Investigations**	Date:	02-May-10
Client:	**BHP-B**	Time:	13:38

Well No. / Name: **RT09**

Depth to equilibrium water level (m RL)**:** 16.603 mPVC

Type of test:
Rising head ☐
Falling head ▤
(enter "3" against appropriate test type)

Type of test:
$L_w = H$ ▤
$L_w < H$ ☐
(enter "3" against solution constraint)

Depth to Water at Time '0': 16.52 (m)
$Y_0 =$ 0.083 (m)

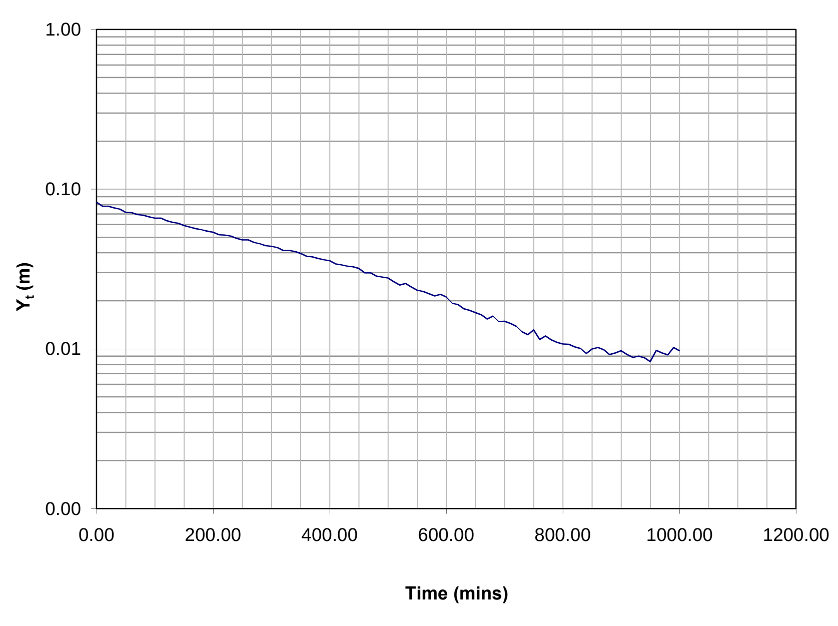
20

* Includes residual drawdown for falling head test

Data point	Elapsed time (mins)	Depth to water (m)	Drawdown * (Y_t)	
1	0.5	16.52	0.083	
20	10	16.52	0.078	*
40	20	16.52	0.078	*
60	30	16.53	0.076	*
80	40	16.53	0.075	*
100	50	16.53	0.072	*
120	60	16.53	0.071	*
140	70	16.53	0.070	*
160	80	16.53	0.069	*
180	90	16.54	0.067	*
200	100	16.54	0.066	*
220	110	16.54	0.066	*
240	120	16.54	0.064	*
260	130	16.54	0.062	*
280	140	16.54	0.061	*
300	150	16.54	0.059	*
320	160	16.55	0.058	*
340	170	16.55	0.057	*
360	180	16.55	0.056	*
380	190	16.55	0.055	*
400	200	16.55	0.054	*
420	210	16.55	0.052	*
440	220	16.55	0.052	*
460	230	16.55	0.051	*
480	240	16.55	0.049	*
500	250	16.55	0.048	*
520	260	16.55	0.048	*
540	270	16.56	0.046	*
560	280	16.56	0.046	*
580	290	16.56	0.044	*
600	300	16.56	0.044	*
620	310	16.56	0.043	*
640	320	16.56	0.041	*
660	330	16.56	0.041	*
680	340	16.56	0.041	*
700	350	16.56	0.040	*
720	360	16.56	0.038	*
740	370	16.57	0.038	*
760	380	16.57	0.037	*
780	390	16.57	0.036	*
800	400	16.57	0.036	*
820	410	16.57	0.034	*
840	420	16.57	0.034	*
860	430	16.57	0.033	*
880	440	16.57	0.033	*
900	450	16.57	0.032	*
920	460	16.57	0.030	*
940	470	16.57	0.030	*
960	480	16.57	0.029	*
980	490	16.57	0.028	*
1000	500	16.58	0.028	*
1020	510	16.58	0.026	*
1040	520	16.58	0.025	*
1060	530	16.58	0.026	*
1080	540	16.58	0.024	*
1100	550	16.58	0.023	*
1120	560	16.58	0.023	*
1140	570	16.58	0.022	*
1160	580	16.58	0.021	*
1180	590	16.58	0.022	*
1200	600	16.58	0.021	*
1220	610	16.58	0.019	*
1240	620	16.58	0.019	*
1260	630	16.59	0.018	*
1280	640	16.59	0.017	*
1300	650	16.59	0.017	*
1320	660	16.59	0.016	*
1340	670	16.59	0.015	*
1360	680	16.59	0.016	*
1380	690	16.59	0.015	*
1400	700	16.59	0.015	*
1420	710	16.59	0.014	*
1440	720	16.59	0.014	*
1460	730	16.59	0.013	*
1480	740	16.59	0.012	*
1500	750	16.59	0.013	*
1520	760	16.59	0.011	*
1540	770	16.59	0.012	*
1560	780	16.59	0.011	*
1580	790	16.59	0.011	*
1600	800	16.59	0.011	*
1620	810	16.59	0.011	*
1640	820	16.59	0.010	*
1660	830	16.59	0.010	*
1680	840	16.59	0.009	*
1700	850	16.59	0.010	*
1720	860	16.59	0.010	*
1740	870	16.59	0.010	*
1760	880	16.59	0.009	*
1780	890	16.59	0.009	*
1800	900	16.59	0.010	*
1820	910	16.59	0.009	*
1840	920	16.59	0.009	*
1860	930	16.59	0.009	*
1880	940	16.59	0.009	*
1900	950	16.59	0.008	*
1920	960	16.59	0.010	*
1940	970	16.59	0.009	*
1960	980	16.59	0.009	*
1980	990	16.59	0.010	*
2000	1000	16.59	0.010	*

Aquifer Test Solutions: **Slug Tests** **Bouwer Rice**

Project Name:	**BHP-B SEIS Field Investigations**	Date:	02-May-10
Client:	**BHP-B**	Time:	13:38
Well No. / Name:	**RT09**	**Depth to equilibrium water level** (m RL)**:**	16.603 mTOC
Type of test:	Rising head Falling head ☒	**Well Completion:**	Fully Penetrating ☒ Partially Penetrating



r_c =	casing radius	0.025
r_w =	radial distance between undisturbed aquifer and well centre	0.076
L_e =	length of intake	66
H =	saturated thickness of aquifer	54.397
L_w =	distance b/n water table and bottom of intake	54.397
R_e =	effective well radius	18.97
t =	time	450
Y_o =	initial drawdown	0.083
Y_t =	vertical distance between the water level in well at time t and equilibrium level	0.03
L_e/r_w =		868.4210526
A =	dimensionless co-efficient that is a function of L_e/r_w, and $L_w < H$	7
B =	dimensionless co-efficient that is a function of L_e/r_w, and $L_w < H$	2.75
C =	dimensionless co-efficient that is a function of L_e/r_w, and $L_w = H$	12

If $L_w < H$

$$\ln(R_e/r_w) = \{1.1 \,.\, [\ln(L_w/r_w)]^{-1} + A+B \,.\, \ln[(H-L_w)/r_w] \,.\, (L_e/r_w)^{-1}\}^{-1}$$

= **Lw = H** m

If $L_w = H$

$$\ln(R_e/r_w) = \{1.1 \,.\, [\ln(L_w/r_w)]^{-1} + C \,.\, (L_e/r_w)^{-1}\}^{-1}$$

= **5.52** m

Produced by: Alistair Walsh Date: 7/05/2010

Checked by: Kate Furness Date: 10/05/2010

$$K = [r_c^{2} \cdot \ln(R_e/r_w)]\, 2L^{-1} \,.\, t^{-1} \,.\, \ln(Y_o/Y_t)$$

= 5.91E-08 m/min

= **0.0001** m/d

Produced by: Alistair Walsh Date: 7/05/2010

Checked by: Kate Furness Date: 10/05/2010

Ref.

Bouwer H. 1989. *The Bouwer and Rice Slug Test - an Update*. Ground Water. Vol.27, No.3. May - June 1989.

Brown D.L. & T.N. Narasimhan. 1995. *An evaluation of the Bouwer and rice method of slug test analysis.* Water Resources Research. Vol. 31, No. 5, pp 1239-1246.

Kruseman G.P. and N.A. de Ridder. 1991. *Analysis and Evaluation of Pumping Test Data.* 2nd Ed. Int. Inst. For Land Reclamation and Improvement. Wageningen. The Netherlands.

Aquifer Test Solutions: Slug Tests Bouwer Rice

Project Name:	**BHP-B SEIS Field Investigations**	Date:	30-Apr-10
Client:	**BHP-B**	Time:	03:00

Well No. / Name: **RT07a**

Depth to equilibrium water level (m RL): 13.136 mPVC

Type of test:

Rising head		(enter "3" against appropriate test type)
Falling head	▤	

Type of test:

$L_w = H$		(enter "3" against solution constraint)
$L_w < H$	▤	

Depth to Water at Time '0': 13.07 (m)

$Y_0 =$ 0.066 (m)

5

* Includes residual drawdown for falling head test

Data point	Elapsed time (mins)	Depth to water (m)	Drawdown * (Y_t)	
1	0.5	13.07	0.063	
5	2.5	13.10	0.041	*
10	5	13.10	0.038	*
15	7.5	13.10	0.035	*
20	10	13.10	0.033	*
25	12.5	13.10	0.034	*
30	15	13.10	0.032	*
35	17.5	13.10	0.032	*
40	20	13.10	0.033	*
45	22.5	13.10	0.032	*
50	25	13.10	0.033	*
55	27.5	13.11	0.029	*
60	30	13.10	0.031	*
65	32.5	13.11	0.028	*
70	35	13.10	0.032	*
75	37.5	13.10	0.035	*
80	40	13.10	0.032	*
85	42.5	13.10	0.031	*
90	45	13.11	0.030	*
95	47.5	13.10	0.031	*
100	50	13.11	0.031	*
105	52.5	13.10	0.031	*
110	55	13.11	0.031	*
115	57.5	13.11	0.027	*
120	60	13.11	0.030	*
125	62.5	13.11	0.030	*
130	65	13.11	0.031	*
135	67.5	13.11	0.030	*
140	70	13.11	0.030	*
145	72.5	13.11	0.031	*
150	75	13.11	0.029	*
155	77.5	13.11	0.029	*
160	80	13.11	0.030	*
165	82.5	13.11	0.029	*
170	85	13.11	0.029	*
175	87.5	13.11	0.029	*
180	90	13.11	0.029	*
185	92.5	13.11	0.029	*
190	95	13.11	0.029	*
195	97.5	13.11	0.030	*
200	100	13.11	0.029	*

Aquifer Test Solutions: Slug Tests Bouwer Rice

Project Name: **BHP-B SEIS Field Investigations**
Client: **BHP-B**

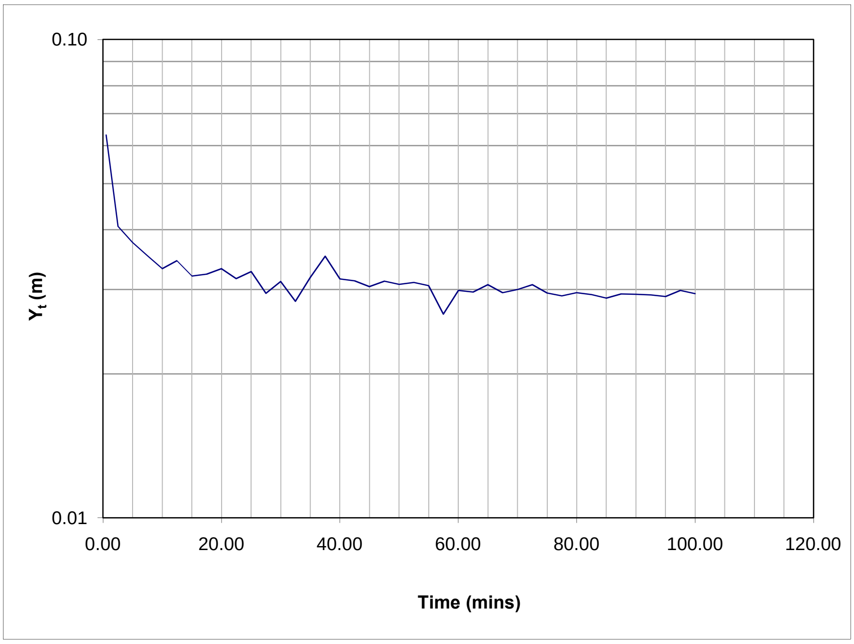
Date: 30-Apr-10
Time: 03:00

Well No. / Name: **RT07a**

Depth to equilibrium water level (m RL)**:** 13.136 mTOC

Type of test: Rising head / Falling head ▤

Well Completion: Fully Penetrating / Partially Penetrating ▤



r_c =	casing radius	0.025
r_w =	radial distance between undisturbed aquifer and well centre	0.076
L_e =	length of intake	111
H =	saturated thickness of aquifer	182
L_w =	distance b/n water table and bottom of intake	127.864
R_e =	effective well radius	29.15
t =	time	25
Y_o =	initial drawdown	0.066
Y_t =	vertical distance between the water level in well at time t and equilibrium level	0.033
L_e/r_w =		1460.526316
A =	dimensionless co-efficient that is a function of L_e/r_w, and L_w < H	9.5
B =	dimensionless co-efficient that is a function of L_e/r_w, and L_w < H	3
C =	dimensionless co-efficient that is a function of L_e/r_w, and L_w = H	12.75

If $L_w < H$

$$\ln(R_e/r_w) = \{1.1 \,.\, [\ln(L_w/r_w)]^{-1} + A+B \,.\, \ln[(H-L_w)/r_w] \,.\, (L_e/r_{w)}{}^{-1}\}^{-1}$$

= **5.95** m

If $L_w = H$

$$\ln(R_e/r_w) = \{1.1 \,.\, [\ln(L_w/r_w)]^{-1} + C \,.\, (L_e/r_{w)}{}^{-1}\}^{-1}$$

= **Lw < H** m

Produced by: Alistair Walsh Date: 7/05/2010

Checked by: Kate Furness Date: 10/05/2010

$$K = [r_c^{2\,\cdot}\ \ln(R_e/r_w)]\ 2L^{-1}\ .\ t^{-1}\ .\ \ln\ (Y_o/Y_t)$$

= 4.64E-07 m/min
= **0.001** m/d

Produced by: Alistair Walsh Date: 7/05/2010

Checked by: Kate Furness Date: 10/05/2010

Ref. Bouwer H. 1989. *The Bouwer and Rice Slug Test - an Update.* Ground Water. Vol.27, No.3. May - June 1989.
Brown D.L. & T.N. Narasimhan. 1995. *An evaluation of the Bouwer and rice method of slug test analysis.* Water Resources Research. Vol. 31, No. 5, pp 1239-1246.
Kruseman G.P. and N.A. de Ridder. 1991. *Analysis and Evaluation of Pumping Test Data.* 2nd Ed. Int. Inst. For Land Reclamation and Improvement. Wageningen. The Netherlands.

Aquifer Test Solutions: Slug Tests Bouwer Rice

Project Name: **BHP-B SEIS Field Investigations**
Client: **BHP-B**

Date: 01-May-10
Time: 10:00

Well No. / Name: **RT07b**

Depth to equilibrium water level (m RL)**:** 18.597 mPVC

Type of test:
Rising head ☐ (enter "3" against appropriate test type)
Falling head ▤

Type of test:
$L_w = H$ ▤ (enter "3" against solution constraint)
$L_w < H$ ☐

Depth to Water at Time '0': 17.83 (m)
$Y_0 =$ 0.767 (m)

200

* Includes residual drawdown for falling head test

Data point	Elapsed time (mins)	Depth to water (m)	Drawdown * (Y_t)	
1	0.05	17.83	0.770	
200	10	18.01	0.587	*
400	20	18.13	0.466	*
600	30	18.22	0.381	*
800	40	18.28	0.321	*
1000	50	18.32	0.275	*
1200	60	18.35	0.243	*
1400	70	18.38	0.218	*
1600	80	18.40	0.200	*
1800	90	18.41	0.185	*
2000	100	18.42	0.174	*
2200	110	18.43	0.167	*
2400	120	18.43	0.165	*
2600	130	18.43	0.164	*
2800	140	18.43	0.164	*
3000	150	18.43	0.164	*
3200	160	18.43	0.163	*
3400	170	18.43	0.163	*
3600	180	18.43	0.162	*
3800	190	18.44	0.162	*
4000	200	18.44	0.161	*
4200	210	18.44	0.161	*
4400	220	18.44	0.160	*
4600	230	18.44	0.160	*
4800	240	18.44	0.159	*
5000	250	18.44	0.158	*
5200	260	18.44	0.157	*
5400	270	18.44	0.157	*
5600	280	18.44	0.156	*
5800	290	18.44	0.156	*
6000	300	18.44	0.155	*
6200	310	18.44	0.154	*
6400	320	18.44	0.154	*
6600	330	18.44	0.153	*
6800	340	18.44	0.153	*
7000	350	18.44	0.152	*
7200	360	18.44	0.152	*
7400	370	18.45	0.152	*
7600	380	18.45	0.151	*
7800	390	18.45	0.150	*
8000	400	18.45	0.148	*
8200	410	18.45	0.145	*
8400	420	18.46	0.141	*
8600	430	18.46	0.137	*
8800	440	18.46	0.133	*
9000	450	18.47	0.128	*
9200	460	18.47	0.124	*
9400	470	18.48	0.119	*
9600	480	18.48	0.115	*
9800	490	18.49	0.111	*
10000	500	18.49	0.107	*
10200	510	18.49	0.103	*
10400	520	18.50	0.100	*
10600	530	18.50	0.096	*
10800	540	18.50	0.093	*
11000	550	18.51	0.091	*
11200	560	18.51	0.089	*
11400	570	18.51	0.088	*
11600	580	18.51	0.087	*
11800	590	18.51	0.087	*
12000	600	18.51	0.086	*

Aquifer Test Solutions: Slug Tests Bouwer Rice

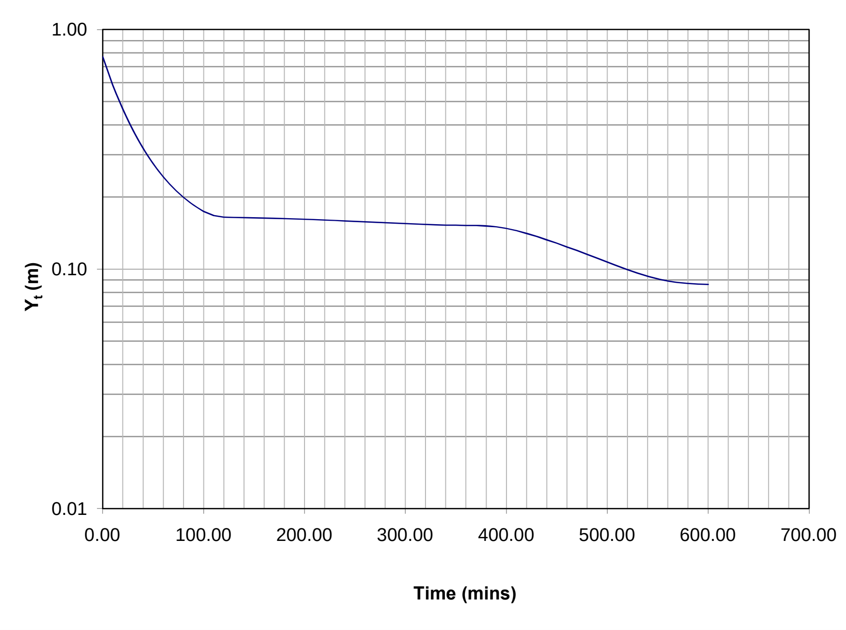
Project Name:	**BHP-B SEIS Field Investigations**	Date:	01-May-10
Client:	**BHP-B**	Time:	10:00

Well No. / Name: **RT07b**

Depth to equilibrium water level (m RL)**:** 18.597 mTOC

Type of test:
Rising head
Falling head ☒

Well Completion:
Fully Penetrating ☒
Partially Penetrating



r_c =	casing radius	0.025
r_w =	radial distance between undisturbed aquifer and well centre	0.076
L_e =	length of intake	32
H =	saturated thickness of aquifer	182
L_w =	distance b/n water table and bottom of intake	179.403
R_e =	effective well radius	32.12
t =	time	60
Y_o =	initial drawdown	0.767
Y_t =	vertical distance between the water level in well at time t and equilibrium level	0.24
L_e/r_w =		421.0526316
A =	dimensionless co-efficient that is a function of L_e/r_w, and L_w < H	8
B =	dimensionless co-efficient that is a function of L_e/r_w, and L_w < H	2
C =	dimensionless co-efficient that is a function of L_e/r_w, and L_w = H	10

If L_w < H

$$\ln(R_e/r_w) = \{1.1 . [\ln(L_w/r_w)]^{-1} + A+B . \ln[(H-L_w)/r_w] . (L_e/r_{w)}{}^{-1}\}^{-1}$$

= **Lw = H** m

If L_w = H

$$\ln(R_e/r_w) = \{1.1 . [\ln(L_w/r_w)]^{-1} + C . (L_e/r_{w)}{}^{-1}\}^{-1}$$

= **6.05** m

Produced by: Alistair Walsh Date: 7/05/2010

Checked by: Kate Furness Date: 10/05/2010

$$K = [r_c{}^{2} \cdot \ln(R_e/r_w)]\ 2L^{-1} \mathbf{.}\ t^{-1} \mathbf{.} \ln(Y_o/Y_t)$$

= 1.14E-06 m/min
= **0.002** m/d

Produced by: Alistair Walsh Date: 7/05/2010

Checked by: Kate Furness Date: 10/05/2010

Ref. Bouwer H. 1989. *The Bouwer and Rice Slug Test - an Update*. Ground Water. Vol.27, No.3. May - June 1989.
Brown D.L. & T.N. Narasimhan. 1995. *An evaluation of the Bouwer and rice method of slug test analysis.* Water Resources Research. Vol. 31, No. 5, pp 1239-1246.
Kruseman G.P. and N.A. de Ridder. 1991. *Analysis and Evaluation of Pumping Test Data*. 2nd Ed. Int. Inst. For Land Reclamation and Improvement. Wageningen. The Netherlands.

Aquifer Test Solutions: Slug Tests Bouwer Rice

Project Name:	**BHP-B SEIS Field Investigations**	Date:	02-May-10
Client:	**BHP-B**	Time:	12:25

Well No. / Name: **PT63**

Depth to equilibrium water level (m RL): 8.1 mPVC

Type of test:			
	Rising head		(enter "3" against appropriate test type)
	Falling head	▤	

Type of test:			
	$L_w = H$	▤	(enter "3" against solution constraint)
	$L_w < H$		

Depth to Water at Time '0': 7.91 (m)

$Y_0 =$ 0.19 (m)

Data point	Elapsed time (mins)	Depth to water (m)	Drawdown * (Y_t)
1	0.5	7.91	0.190
2	1	7.92	0.178
3	1.5	7.93	0.169
4	2	7.94	0.162
5	2.5	7.95	0.154
6	3	7.95	0.148
7	3.5	7.96	0.142
8	4	7.97	0.132
9	4.5	7.97	0.126
10	5	7.98	0.120
11	5.5	7.98	0.116
12	6	7.99	0.111
13	6.5	8.00	0.104
14	7	8.00	0.100
15	7.5	8.01	0.094
16	8	8.01	0.090
17	8.5	8.01	0.085
18	9	8.02	0.081
19	9.5	8.02	0.076
20	10	8.03	0.071
21	10.5	8.03	0.068
22	11	8.04	0.063
23	11.5	8.04	0.059
24	12	8.04	0.059
25	12.5	8.05	0.054
26	13	8.05	0.050
27	13.5	8.05	0.048
28	14	8.05	0.046
29	14.5	8.06	0.043
30	15	8.06	0.039
31	15.5	8.06	0.038
32	16	8.06	0.037
33	16.5	8.07	0.034
34	17	8.07	0.031
35	17.5	8.07	0.030
36	18	8.07	0.029
37	18.5	8.08	0.024
38	19	8.08	0.023
39	19.5	8.08	0.020
40	20	8.08	0.020
41	20.5	8.08	0.019
42	21	8.08	0.018
43	21.5	8.08	0.017
44	22	8.09	0.013
45	22.5	8.09	0.013
46	23	8.09	0.013
47	23.5	8.09	0.012
48	24	8.09	0.010
49	24.5	8.09	0.008
50	25	8.09	0.007
51	25.5	8.09	0.007
52	26	8.09	0.005
53	26.5	8.10	0.004
54	27	8.10	0.003
55	27.5	8.10	0.004
56	28	8.10	0.001
57	28.5	8.10	0.001
58	29	8.10	0.000

* Includes residual drawdown for falling head test

Aquifer Test Solutions: Slug Tests Bouwer Rice

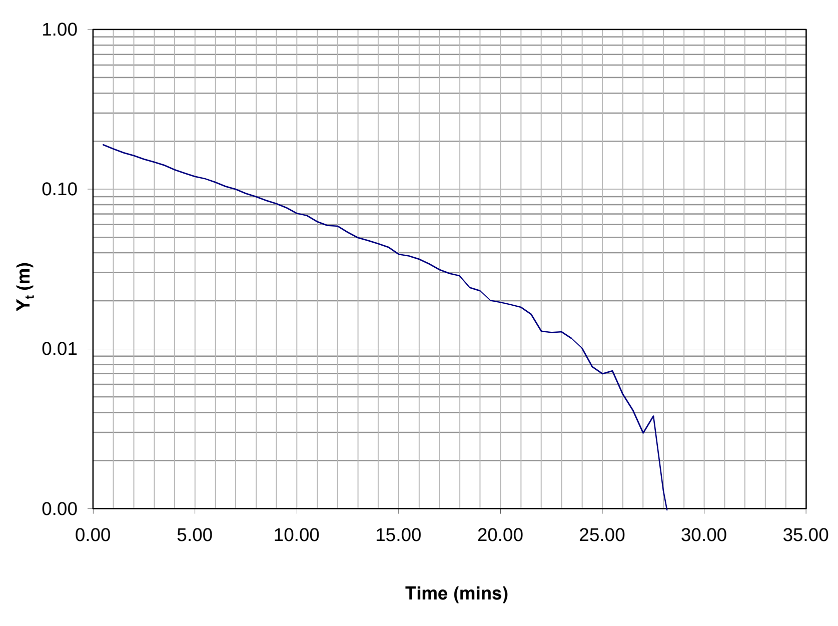
Project Name:	**BHP-B SEIS Field Investigations**	Date:	02-May-10
Client:	**BHP-B**	Time:	12:25

Well No. / Name: **PT63**

Depth to equilibrium water level (m RL)**:** 8.1 mTOC

Type of test:
Rising head
Falling head ☒

Well Completion:
Fully Penetrating ☒
Partially Penetrating



r_c =	casing radius	0.05
r_w =	radial distance between undisturbed aquifer and well centre	0.1015
L_e =	length of intake	24
H =	saturated thickness of aquifer	24
L_w =	distance b/n water table and bottom of intake	39.9
R_e =	effective well radius	10.44
t =	time	17
Y_o =	initial drawdown	0.19
Y_t =	vertical distance between the water level in well at time t and equilibrium level	0.03
L_e/r_w =		236.453202
A =	dimensionless co-efficient that is a function of L_e/r_w, and $L_w < H$	6.5
B =	dimensionless co-efficient that is a function of L_e/r_w, and $L_w < H$	1.25
C =	dimensionless co-efficient that is a function of L_e/r_w, and $L_w = H$	7.5

If $L_w < H$

$$\ln(R_e/r_w) = \{1.1 \cdot [\ln(L_w/r_w)]^{-1} + A+B \cdot \ln[(H-L_w)/r_w] \cdot (L_e/r_{w)}{}^{-1}\}^{-1}$$

= **Lw = H** m

If $L_w = H$

$$\ln(R_e/r_w) = \{1.1 \cdot [\ln(L_w/r_w)]^{-1} + C \cdot (L_e/r_{w)}{}^{-1}\}^{-1}$$

= **4.63** m

Produced by: Alistair Walsh Date: 6/05/2010

Checked by: Kate Furness Date: 10/05/2010

$$K = [r_c{}^{2} \cdot \ln(R_e/r_w)]\ 2L^{-1} \cdot t^{-1} \cdot \ln(Y_o/Y_t)$$

= 2.62E-05 m/min

= **0.038** m/d

Produced by: Alistair Walsh Date: 6/05/2010

Checked by: Kate Furness Date: 10/05/2010

Ref.
Bouwer H. 1989. *The Bouwer and Rice Slug Test - an Update*. Ground Water. Vol.27, No.3. May - June 1989.
Brown D.L. & T.N. Narasimhan. 1995. *An evaluation of the Bouwer and rice method of slug test analysis.* Water Resources Research. Vol. 31, No. 5, pp 1239-1246.
Kruseman G.P. and N.A. de Ridder. 1991. *Analysis and Evaluation of Pumping Test Data*. 2nd Ed. Int. Inst. For Land Reclamation and Improvement. Wageningen. The Netherlands.

Aquifer Test Solutions: Slug Tests Bouwer Rice

Project Name: **BHP-B SEIS Field Investigations**
Client: **BHP-B**

Date: 29-Apr-10
Time: 09:58

Well No. / Name: **RT41**

Depth to equilibrium water level (m RL)**:** 19.675 mPVC

Type of test:

Rising head		(enter "3" against appropriate test type)
Falling head	▤	

Type of test:

$L_w = H$	▤	(enter "3" against solution constraint)
$L_w < H$		

Depth to Water at Time '0': 19.4 (m)

$Y_0 =$ 0.275 (m)

Data point	Elapsed time (mins)	Depth to water (m)	Drawdown * (Y_t)
1	0.5	19.40	0.273
2	1	19.60	0.072
3	1.5	19.66	0.018
4	2	19.67	0.004
5	2.5	19.67	0.001
6	3	19.68	
7	3.5	19.68	
8	4	19.67	0.002
9	4.5	19.68	0.000

* Includes residual drawdown for falling head test

Aquifer Test Solutions: Slug Tests Bouwer Rice

Project Name: BHP-B SEIS Field Investigations
Client: BHP-B

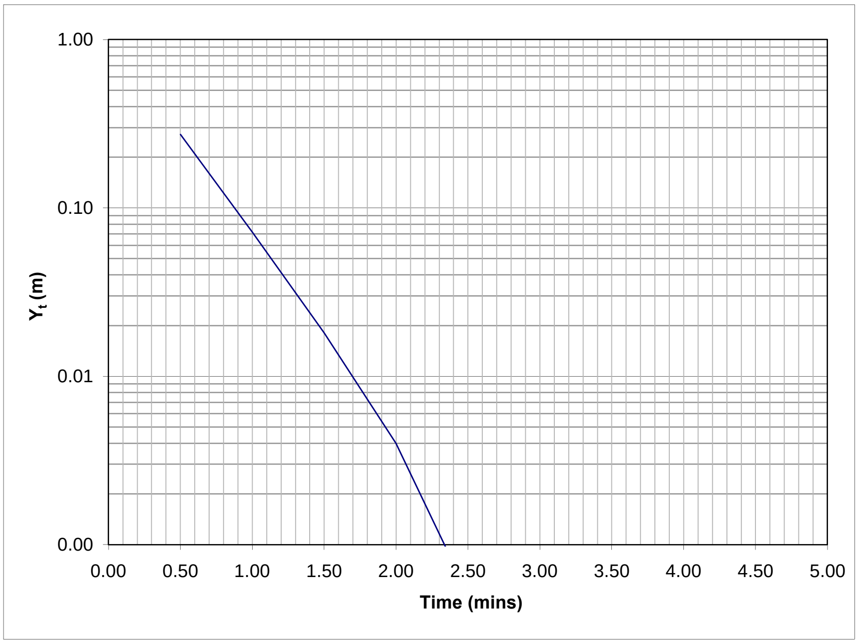
Date: 29-Apr-10
Time: 09:58

Well No. / Name: RT41

Depth to equilibrium water level (m RL)**:** 19.675 mTOC

Type of test: Rising head / Falling head ☒

Well Completion: Fully Penetrating ☒ / Partially Penetrating



r_c =	casing radius	0.05
r_w =	radial distance between undisturbed aquifer and well centre	0.1015
L_e =	length of intake	22
H =	saturated thickness of aquifer	22
L_w =	distance b/n water table and bottom of intake	82.325
R_e =	effective well radius	16.07
t =	time	1.2
Y_o =	initial drawdown	0.275
Y_t =	vertical distance between the water level in well at time t and equilibrium level	0.04
L_e/r_w =		216.7487685
A =	dimensionless co-efficient that is a function of L_e/r_w, and L_w < H	6.3
B =	dimensionless co-efficient that is a function of L_e/r_w, and L_w < H	1.2
C =	dimensionless co-efficient that is a function of L_e/r_w, and L_w = H	7.2

If L_w < H

$$\ln(R_e/r_w) = \{1.1 \,.\, [\ln(L_w/r_w)]^{-1} + A+B \,.\, \ln[(H-L_w)/r_w] \,.\, (L_e/r_{w)}^{-1}\}^{-1}$$

= **Lw = H** m

If L_w = H

$$\ln(R_e/r_w) = \{1.1 \,.\, [\ln(L_w/r_w)]^{-1} + C \,.\, (L_e/r_{w)}^{-1}\}^{-1}$$

= **5.06** m

Produced by: Alistair Walsh Date: 6/05/2010

Checked by: Kate Furness Date: 10/05/2010

$$K = [r_c^{2\,\cdot}\ \ln(R_e/r_w)]\ 2L^{-1} \,.\, t^{-1} \,.\, \ln(Y_o/Y_t)$$

= 4.62E-04 m/min

= **0.666** m/d

Produced by: Alistair Walsh Date: 6/05/2010

Checked by: Kate Furness Date: 10/05/2010

Ref. Bouwer H. 1989. *The Bouwer and Rice Slug Test - an Update.* Ground Water. Vol.27, No.3. May - June 1989.

Brown D.L. & T.N. Narasimhan. 1995. *An evaluation of the Bouwer and rice method of slug test analysis.* Water Resources Research. Vol. 31, No. 5, pp 1239-1246.

Kruseman G.P. and N.A. de Ridder. 1991. *Analysis and Evaluation of Pumping Test Data.* 2nd Ed. Int. Inst. For Land Reclamation and Improvement. Wageningen. The Netherlands.

Aquifer Test Solutions: Slug Tests Bouwer Rice

Project Name:	**BHP-B SEIS Field Investigations**	Date:	29-Apr-10
Client:	**BHP-B**	Time:	12:25

Well No. / Name: **RT42**

Depth to equilibrium water level (m RL)**:** 6.355 mPVC

Type of test:			
	Rising head		(enter "3" against appropriate test type)
	Falling head	▤	

Type of test:			
	$L_w = H$	▤	(enter "3" against solution constraint)
	$L_w < H$		

Depth to Water at Time '0': 5.91 (m)

$Y_0 =$ 0.445 (m)

20

* Includes residual drawdown for falling head test

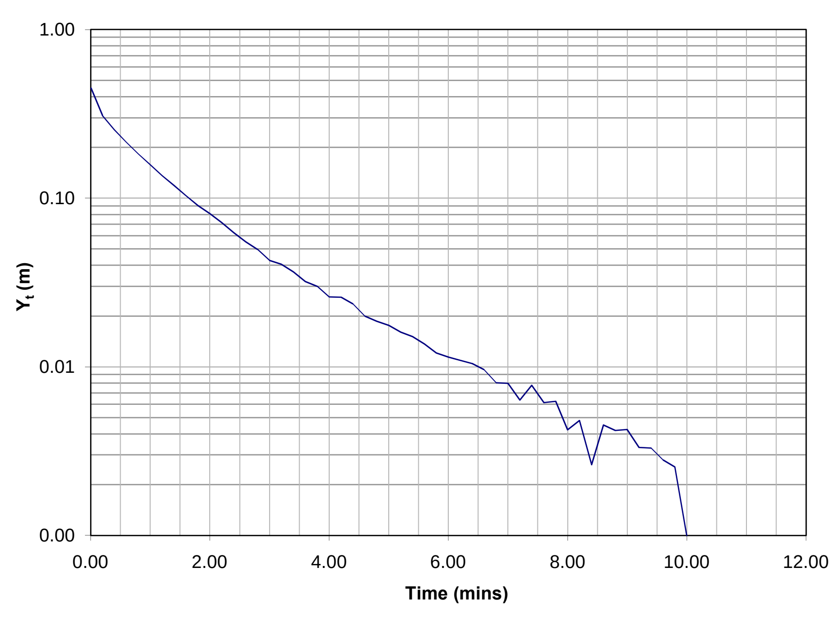
Data point	Elapsed time (mins)	Depth to water (m)	Drawdown * (Y_t)	
1	0.01	5.91	0.449	
20	0.2	6.05	0.309	*
40	0.4	6.10	0.255	*
60	0.6	6.14	0.215	*
80	0.8	6.17	0.183	*
100	1	6.20	0.157	*
120	1.2	6.22	0.136	*
140	1.4	6.24	0.119	*
160	1.6	6.25	0.103	*
180	1.8	6.26	0.090	*
200	2	6.27	0.081	*
220	2.2	6.28	0.072	*
240	2.4	6.29	0.063	*
260	2.6	6.300	0.055	*
280	2.8	6.305	0.050	*
300	3	6.312	0.043	*
320	3.2	6.314	0.041	*
340	3.4	6.318	0.037	*
360	3.6	6.323	0.032	*
380	3.8	6.325	0.030	*
400	4	6.329	0.026	*
420	4.2	6.329	0.026	*
440	4.4	6.331	0.024	*
460	4.6	6.335	0.020	*
480	4.8	6.336	0.019	*
500	5	6.337	0.018	*
520	5.2	6.339	0.016	*
540	5.4	6.340	0.015	*
560	5.6	6.341	0.014	*
580	5.8	6.343	0.012	*
600	6	6.344	0.011	*
620	6.2	6.344	0.011	*
640	6.4	6.345	0.010	*
660	6.6	6.345	0.010	*
680	6.8	6.347	0.008	*
700	7	6.347	0.008	*
720	7.2	6.349	0.006	*
740	7.4	6.347	0.008	*
760	7.6	6.349	0.006	*
780	7.8	6.349	0.006	*
800	8	6.351	0.004	*
820	8.2	6.350	0.005	*
840	8.4	6.352	0.003	*
860	8.6	6.350	0.005	*
880	8.8	6.351	0.004	*
900	9	6.351	0.004	*
920	9.2	6.352	0.003	*
940	9.4	6.352	0.003	*
960	9.6	6.352	0.003	*
980	9.8	6.352	0.003	*
1000	10	6.354	0.001	*

Project Name:	**BHP-B SEIS Field Investigations**	Date:	29-Apr-10
Client:	**BHP-B**	Time:	12:25

Well No. / Name: **RT42** **Depth to equilibrium water level** (m RL)**:** 6.355 mTOC

Type of test: Rising head / Falling head ☒

Well Completion: Fully Penetrating ☒ / Partially Penetrating



r_c =	casing radius	0.05
r_w =	radial distance between undisturbed aquifer and well centre	0.1015
L_e =	length of intake	6
H =	saturated thickness of aquifer	64
L_w =	distance b/n water table and bottom of intake	64
R_e =	effective well radius	9.62
t =	time	3.5
Y_o =	initial drawdown	0.445
Y_t =	vertical distance between the water level in well at time t and equilibrium level	0.035
L_e/r_w =		59.11330049
A =	dimensionless co-efficient that is a function of L_e/r_w, and L_w < H	3.3
B =	dimensionless co-efficient that is a function of L_e/r_w, and L_w < H	0.5
C =	dimensionless co-efficient that is a function of L_e/r_w, and L_w = H	2.9

If L_w < H

$$\ln(R_e/r_w) = \{1.1 \,.\, [\ln(L_w/r_w)]^{-1} + A+B \,.\, \ln[(H-L_w)/r_w] \,.\, (L_e/r_{w)}{}^{-1}\}^{-1}$$

= **Lw = H** m

If L_w = H

$$\ln(R_e/r_w) = \{1.1 \,.\, [\ln(L_w/r_w)]^{-1} + C \,.\, (L_e/r_{w)}{}^{-1}\}^{-1}$$

= **4.55** m

Produced by: Alistair Walsh Date: 6/05/2010

Checked by: Kate Furness Date: 10/05/2010

$$K = [r_c^{2\,\cdot}\ \ln(R_e/r_w)]\ 2L^{-1} \,.\, t^{-1} \,.\, \ln(Y_o/Y_t)$$

= 6.89E-04 m/min

= **0.99** m/d

Produced by: Alistair Walsh Date: 6/05/2010

Checked by: Kate Furness Date: 10/05/2010

Ref.
Bouwer H. 1989. *The Bouwer and Rice Slug Test - an Update*. Ground Water. Vol.27, No.3. May - June 1989.
Brown D.L. & T.N. Narasimhan. 1995. *An evaluation of the Bouwer and rice method of slug test analysis.* Water Resources Research. Vol. 31, No. 5, pp 1239-1246.
Kruseman G.P. and N.A. de Ridder. 1991. *Analysis and Evaluation of Pumping Test Data*. 2nd Ed. Int. Inst. For Land Reclamation and Improvement. Wageningen. The Netherlands.

Aquifer Test Solutions: Slug Tests Bouwer Rice

Project Name:	**BHP-B Supplementary EIS Field Investigations**	Date:	02-May-10
Client:	**BHP-B**	Time:	13:41

Well No. / Name: **PT62**

Depth to equilibrium water level (m RL)**:** 39.38 mTOC

Type of test:

Rising head		(enter "3" against appropriate test type)
Falling head	▤	

Type of test:

$L_w = H$		(enter "3" against solution constraint)
$L_w < H$	▤	

Depth to Water at Time '0': 39.05 (m)

$Y_0 =$ 0.336269895 (m)

Data point	Elapsed time (mins)	Depth to water (m)	Drawdown * (Y_t)
1	0.000	39.048	0.336
2	0.005	39.075	0.308
3	0.010	39.100	0.284
4	0.015	39.361	0.023
5	0.020	39.362	0.022
6	0.025	39.329	0.055
7	0.030	39.357	0.027
8	0.035	39.357	0.027
9	0.040	39.363	0.021
10	0.045	39.371	0.013
11	0.050	39.376	0.008
12	0.055	39.380	0.004
13	0.060	39.383	0.001
14	0.065	39.384	0.000

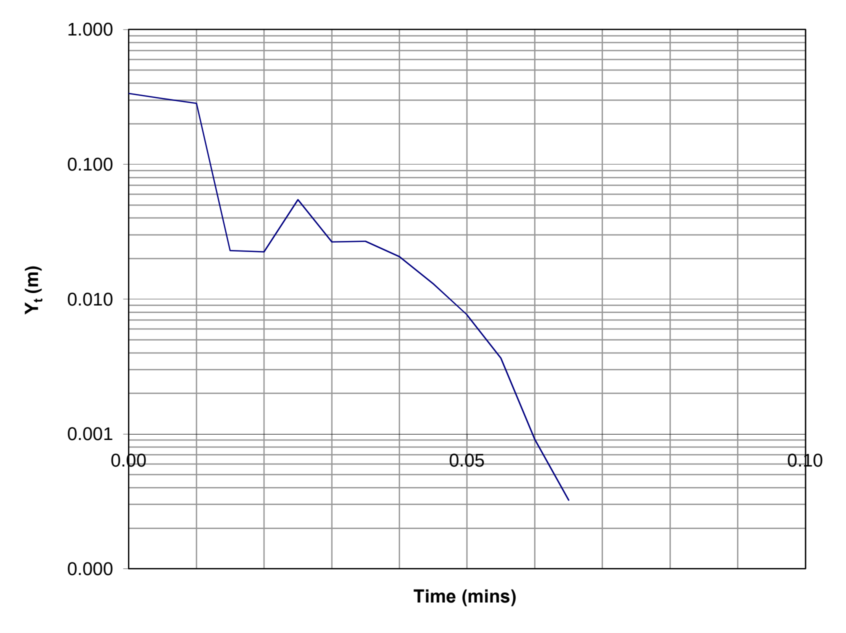
* Includes residual drawdown for falling head test

Aquifer Test Solutions: Slug Tests Bouwer Rice

Project Name: BHP-B Supplementary EIS Field Investigations Date: 02-May-10
Client: BHP-B Time: 13:41

Well No. / Name: PT62 **Depth to equilibrium water level** (m RL): 39.384 mTOC

Type of test: Rising head ☐ Falling head ☒ **Well Completion:** Fully Penetrating ☒ Partially Penetrating ☐



r_c =	casing radius	0.05
r_w =	radial distance between undisturbed aquifer and well centre	0.1015
L_e =	length of intake	19
H =	saturated thickness of aquifer	12
L_w =	distance b/n water table and bottom of intake	26.62
R_e =	effective well radius	7.91
t =	time	0.05
Y_o =	initial drawdown	0.336269895
Y_t =	vertical distance between the water level in well at time t and equilibrium level	0.006
L_e/r_w =		187.1921182
A =	dimensionless co-efficient that is a function of L_e/r_w, and L_w < H	5.7
B =	dimensionless co-efficient that is a function of L_e/r_w, and L_w < H	1
C =	dimensionless co-efficient that is a function of L_e/r_w, and L_w = H	6

If $L_w < H$

$$\ln(R_e/r_w) = \{1.1 . [\ln(L_w/r_w)]^{-1} + A{+}B . \ln[(H-L_w)/r_w] . (L_e/r_w)^{-1}\}^{-1}$$

= **Lw = H** m

If $L_w = H$

$$\ln(R_e/r_w) = \{1.1 . [\ln(L_w/r_w)]^{-1} + C . (L_e/r_w)^{-1}\}^{-1}$$

= **4.36** m

Produced by: Alistair Walsh Date: 10/05/2010

Checked by: Kate Furness Date: 10/05/2010

$$K = [r_c^{2} \cdot \ln(R_e/r_w)]\, 2L^{-1} \,.\, t^{-1} \,.\, \ln(Y_o/Y_t)$$

= 2.31E-02 m/min
= **33.230** m/d

Produced by: Alistair Walsh Date: 10/05/2010

Checked by: Kate Furness Date: 10/05/2010

Ref. Bouwer H. 1989. *The Bouwer and Rice Slug Test - an Update.* Ground Water. Vol.27, No.3. May - June 1989.
Brown D.L. & T.N. Narasimhan. 1995. *An evaluation of the Bouwer and rice method of slug test analysis.* Water Resources Research. Vol. 31, No. 5, pp 1239-1246.
Kruseman G.P. and N.A. de Ridder. 1991. *Analysis and Evaluation of Pumping Test Data.* 2nd Ed. Int. Inst. For Land Reclamation and Improvement. Wageningen. The Netherlands.

B.3 Hvorslev method

Hvorslev analysis of test conducted at well: RT02b

Data collected by: A. Walsh / T. McCarthy
Client: BHP Billiton
Test location: Borefield Rd
Date: 2/05/2010

SWL: 51.78 m
Slugged head (ho) 0.13 m

Hydrostratigraphic Unit Arcoona Qtz
Aquifer type: Fractured Rock(confined)

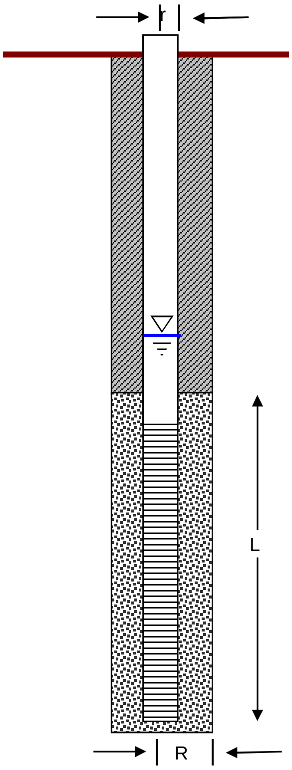
Well depth from RP 342 m
Length of well screen (L) 24 m
Casing radius (r) 0.025 m
Well radius (R) 0.1015 m

T_{37} (interpolated from graph) 1200 seconds

Indicate model that best represents tested well

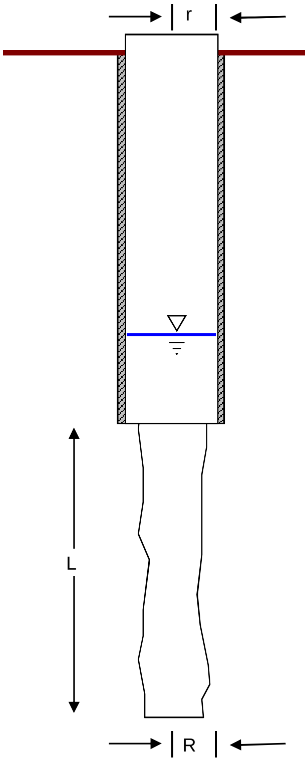
1. Constructed well [1]

☑



2. Open hole completion

☐



notes: 1. solution is unsuitable for cases where
- screen becomes dewatered (rising head test)
- water table straddles screen (rising or falling head test)

Solution:

$$K=\frac{r^2\ln(L/R)}{2LT_0}$$

$(L/R) > 8$
solution valid

$K=$ 5.93E-08 m/sec OR 0.0051 m/day

Hvorslev analysis of test conducted at well: RT02b

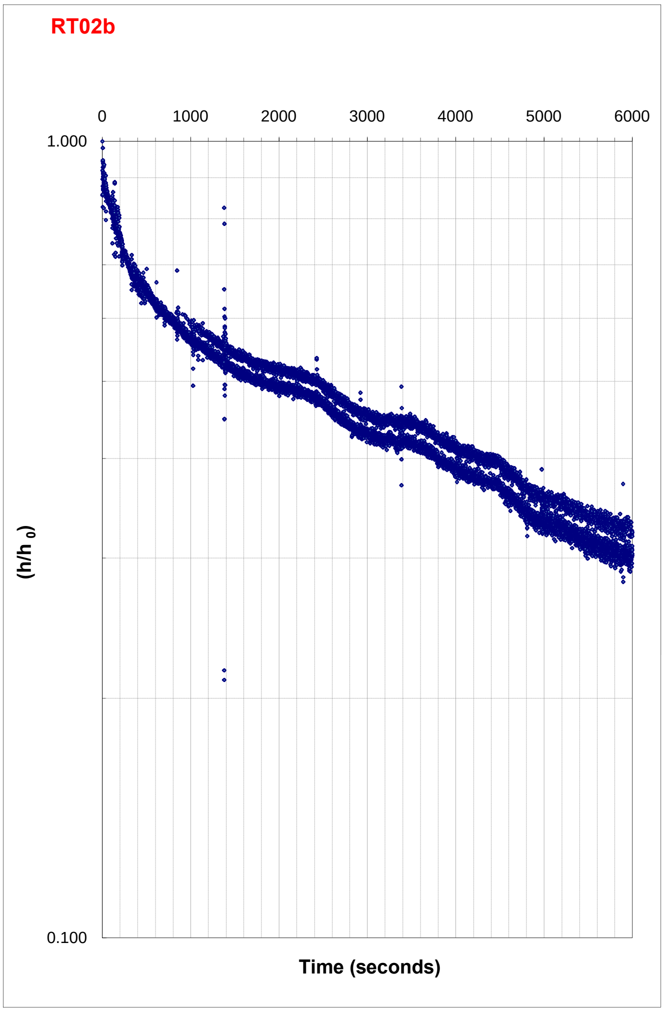
Date of test: 2/05/2010

SWL: 51.78 m
Slugged head (ho) 0.13 m

Data collected by: A. Walsh / T. McCarthy
Client: BHP Billiton
Test location: Borefield Rd

Aquifer type: Fractured Rock(confined)

T_{37} (interpolated from graph) 1200 seconds



Time (seconds)	Depth to water (m)	d in level (m)	h/h0
0.5	51.654	0.126	1.0000
1	51.651	0.129	1.0238
1.5	51.664	0.116	0.9192
2	51.672	0.108	0.8572
2.5	51.667	0.113	0.8962
3	51.651	0.129	1.0163
3.5	51.672	0.108	0.8553
4	51.675	0.105	0.8272
4.5	51.663	0.117	0.9274
5	51.656	0.124	0.9810
5.5	51.669	0.111	0.8785
6	51.672	0.108	0.8576
6.5	51.661	0.119	0.9435
7	51.660	0.120	0.9470
7.5	51.666	0.114	0.9027
8	51.670	0.110	0.8722
8.5	51.665	0.115	0.9099
9	51.661	0.119	0.9385
9.5	51.664	0.116	0.9132
10	51.670	0.110	0.8687
10.5	51.667	0.113	0.8955
11	51.663	0.117	0.9274
11.5	51.665	0.115	0.9053
12	51.670	0.110	0.8684
12.5	51.666	0.114	0.8983
13	51.662	0.118	0.9294
13.5	51.666	0.114	0.8983
14	51.669	0.111	0.8790
14.5	51.665	0.115	0.9112
15	51.662	0.118	0.9307
15.5	51.662	0.118	0.9347
16	51.676	0.104	0.8246
16.5	51.670	0.110	0.8674
17	51.667	0.113	0.8924
17.5	51.668	0.112	0.8834
18	51.668	0.112	0.8875
18.5	51.669	0.111	0.8762
19	51.668	0.112	0.8894
19.5	51.665	0.115	0.9122
20	51.667	0.113	0.8960
20.5	51.669	0.111	0.8759
21	51.665	0.115	0.9122
21.5	51.662	0.118	0.9347
22	51.668	0.112	0.8870
22.5	51.670	0.110	0.8669
23	51.665	0.115	0.9075
23.5	51.667	0.113	0.8965
24	51.667	0.113	0.8901
24.5	51.669	0.111	0.8757
25	51.668	0.112	0.8865
25.5	51.667	0.113	0.8939
26	51.667	0.113	0.8901
26.5	51.670	0.110	0.8669
27	51.669	0.111	0.8780
27.5	51.667	0.113	0.8970
28	51.667	0.113	0.8896
28.5	51.671	0.109	0.8643
29	51.669	0.111	0.8772
29.5	51.668	0.112	0.8849
30	51.668	0.112	0.8867
30.5	51.670	0.110	0.8733
31	51.669	0.111	0.8793
31.5	51.669	0.111	0.8797

Reduced by: Alistair Walsh
Date: 10/05/2010

Checked by: Kate Furness
Date: 10/05/2010

Hvorslev analysis of test conducted at well: RT05c

Data collected by: A. Walsh / T. McCarthy
Client: BHP Billiton
Test location: Mulgaria Station
Date: 30/04/2010

SWL: 18.67 m
Slugged head (ho) 0.85 m

Hydrostratigraphic Unit ABC Range Qtz / Brachina Formation
Aquifer type: fractured rock (confined)

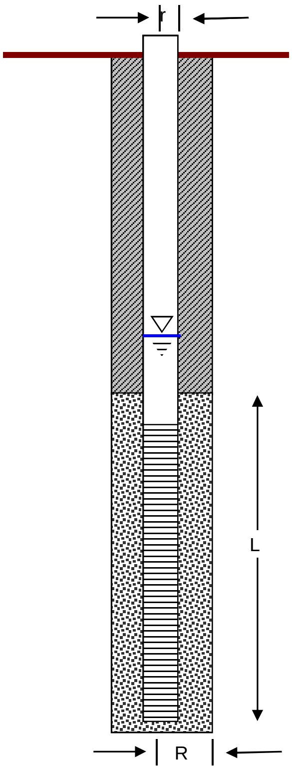
Well depth from RP 634 m
Length of well screen (L) 214 m
Casing radius (r) 0.025 m
Well radius (R) 0.1015 m

T_{37} (interpolated from graph) 2610 seconds

Indicate model that best represents tested well

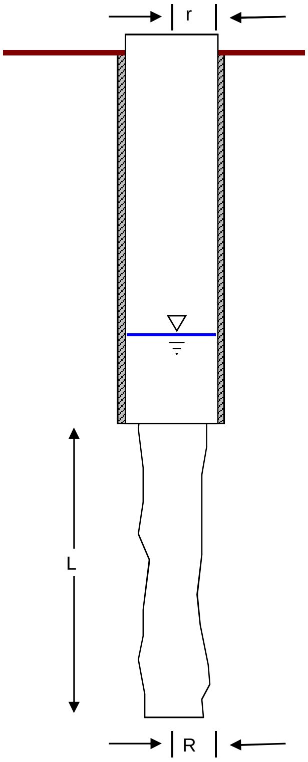
1. Constructed well [1]

☑



2. Open hole completion

☐



notes: 1. solution is unsuitable for cases where
- screen becomes dewatered (rising head test)
- water table straddles screen (rising or falling head test)

Solution:

$$K = \frac{r^2 \ln(L/R)}{2LT_0}$$

$(L/R) > 8$
solution valid

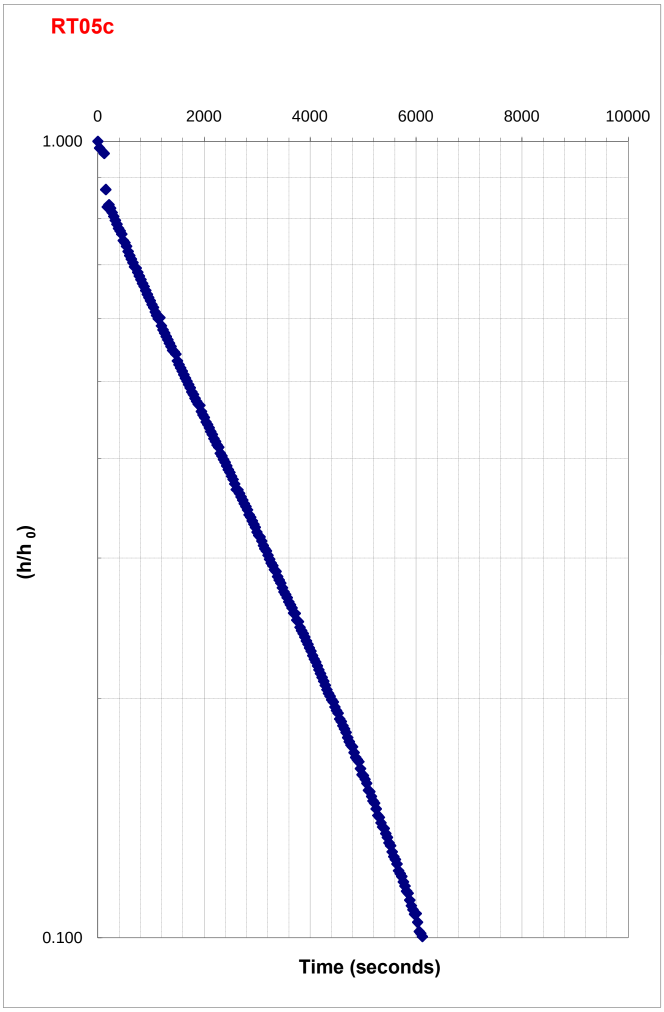
$K =$ 4.28E-09 m/sec *OR* 0.0004 m/day

Hvorslev analysis of test conducted at well: RT05c

Date of test: 30/04/2010

SWL: 18.67 m
Slugged head (ho) 0.85 m

Data collected by:	A Walsh
Client:	BHP Billiton
Test location:	Mulgaria Station
Aquifer type:	fractured rock (confined)
T_{37} (interpolated from graph)	2610 seconds



Reduced by: Kate Furness
Date: 10/5//2010

Checked by: Alistair Walsh
Date: 11/05/2010

Time (seconds)	Depth to water (m)	d in level (m)	h/h0
0	17.81	0.85	1.00
30	17.83	0.84	0.98
60	17.77	0.89	1.05
90	17.80	0.87	1.01
120	17.84	0.82	0.97
150	17.92	0.74	0.87
180	17.96	0.71	0.83
210	17.96	0.71	0.83
240	17.96	0.70	0.82
270	17.97	0.69	0.81
300	17.98	0.69	0.81
330	17.99	0.68	0.80
360	18.00	0.67	0.79
390	18.00	0.66	0.78
420	18.01	0.66	0.77
450	18.01	0.65	0.76
480	18.03	0.64	0.75
510	18.03	0.64	0.75
540	18.04	0.63	0.74
570	18.05	0.62	0.73
600	18.05	0.61	0.72
630	18.06	0.61	0.71
660	18.07	0.60	0.70
690	18.07	0.59	0.70
720	18.08	0.59	0.69
750	18.08	0.58	0.68
780	18.09	0.58	0.68
810	18.09	0.57	0.67
840	18.10	0.57	0.66
870	18.11	0.56	0.66
900	18.11	0.55	0.65
930	18.12	0.55	0.64
960	18.12	0.54	0.64
990	18.13	0.54	0.63
1020	18.13	0.53	0.62
1050	18.14	0.53	0.62
1080	18.15	0.52	0.61
1110	18.15	0.52	0.60
1140	18.16	0.51	0.60
1170	18.15	0.51	0.60
1200	18.17	0.50	0.59
1230	18.17	0.50	0.58
1260	18.18	0.49	0.57
1290	18.18	0.49	0.57
1320	18.19	0.48	0.56
1350	18.19	0.48	0.56
1380	18.20	0.47	0.55
1410	18.20	0.47	0.55
1440	18.20	0.46	0.54
1470	18.21	0.46	0.54
1500	18.21	0.45	0.53
1530	18.22	0.45	0.52
1560	18.22	0.44	0.52
1590	18.23	0.44	0.51
1620	18.23	0.43	0.51
1650	18.24	0.43	0.50
1680	18.24	0.43	0.50
1710	18.24	0.42	0.49
1740	18.25	0.42	0.49
1770	18.25	0.41	0.48
1800	18.26	0.41	0.48
1830	18.26	0.41	0.48
1860	18.26	0.40	0.47

Hvorslev analysis of test conducted at well: RT09

Data collected by:	A. Walsh / T. McCarthy
Client:	BHP Billiton
Test location:	Stuart Creek Station
Date:	2/05/2010

SWL:	16.59 m
Slugged head (ho)	0.07 m

Hydrostratigraphic Unit	Brachina Formation
Aquifer type:	Fractured Rock (confined)

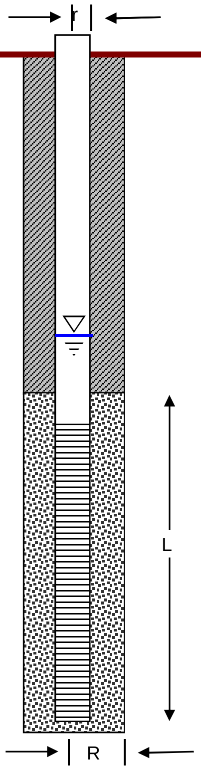
Well depth from RP	71 m
Length of well screen (L)	66 m
Casing radius (r)	0.025 m
Well radius (R)	0.076 m

T$_{37}$ (interpolated from graph) 21000 seconds

Indicate model that best represents tested well

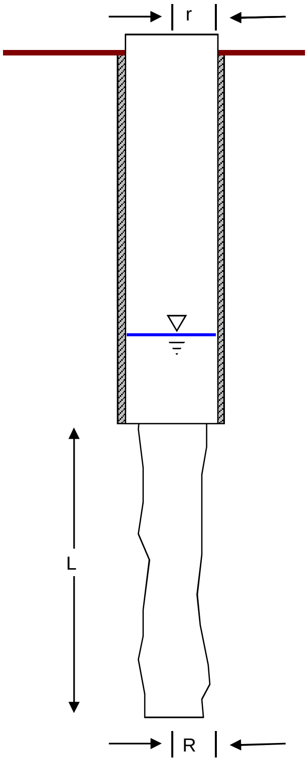
1. Constructed well [1]

☑



2. Open hole completion

☐



notes: 1. solution is unsuitable for cases where
- screen becomes dewatered (rising head test)
- water table straddles screen (rising or falling head test)

Solution:

$$K = \frac{r^2 \ln(L/R)}{2LT_0}$$

$(L / R) > 8$

solution valid

$K=$ 1.53E-09 m/sec OR 0.0001 m/day

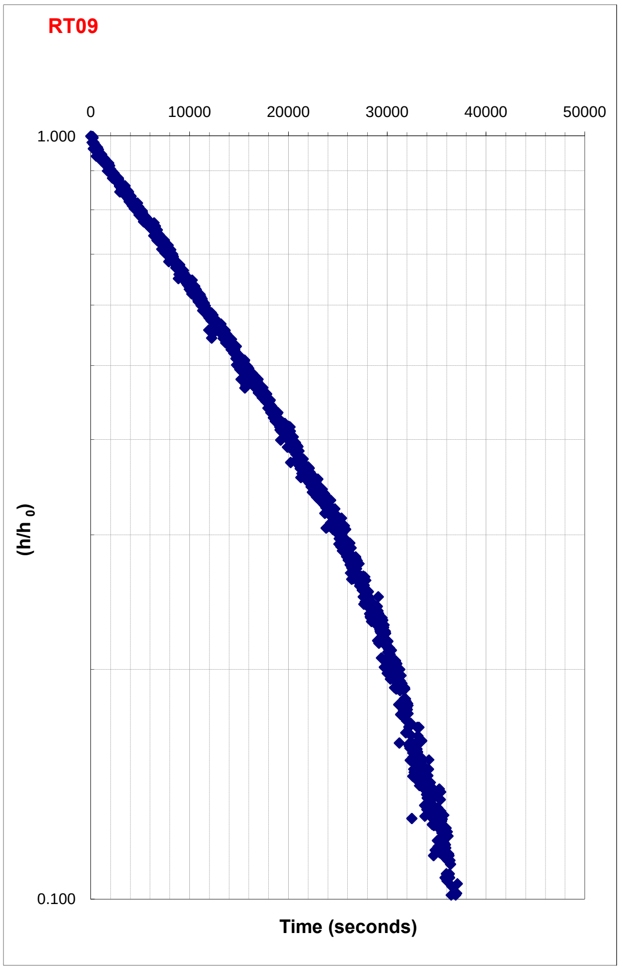
Hvorslev analysis of test conducted at well: RT09

Date of test: 2/05/2007

SWL: 16.59 m
Slugged head (ho) 0.07 m

Data collected by:	A. Walsh / T. McCarthy
Client:	BHP Billiton
Test location:	Stuart Creek Station
Aquifer type:	Fractured Rock (confined)
T_{37} (interpolated from graph)	21000 seconds

Time (seconds)	Depth to water (m)	d in level (m)	h/h0
0	16.520	0.070	1.0000
600	16.524	0.067	0.9542
1200	16.525	0.065	0.9310
1800	16.527	0.064	0.9084
2400	16.529	0.062	0.8840
3000	16.530	0.060	0.8581
3600	16.531	0.059	0.8453
4200	16.533	0.058	0.8226
4800	16.534	0.056	0.8063
5400	16.536	0.055	0.7829
6000	16.537	0.053	0.7590
6600	16.538	0.053	0.7542
7200	16.541	0.050	0.7108
7800	16.541	0.049	0.7026
8400	16.543	0.048	0.6843
9000	16.543	0.047	0.6781
9600	16.545	0.046	0.6516
10200	16.546	0.044	0.6350
10800	16.547	0.043	0.6190
11400	16.549	0.042	0.5973
12000	16.550	0.040	0.5778
12600	16.551	0.040	0.5671
13200	16.551	0.040	0.5671
13800	16.552	0.038	0.5466
14400	16.554	0.037	0.5267
15000	16.554	0.036	0.5158
15600	16.558	0.033	0.4676
16200	16.556	0.034	0.4893
16800	16.557	0.033	0.4768
17400	16.558	0.032	0.4607
18000	16.559	0.031	0.4467
18600	16.560	0.030	0.4342
19200	16.561	0.029	0.4199
19800	16.562	0.028	0.4065
20400	16.562	0.028	0.4026
21000	16.563	0.027	0.3916
21600	16.565	0.025	0.3593
22200	16.566	0.025	0.3564
22800	16.566	0.025	0.3509
23400	16.567	0.024	0.3372
24000	16.567	0.023	0.3292
24600	16.568	0.022	0.3189
25200	16.569	0.022	0.3075
25800	16.569	0.021	0.3051
26400	16.571	0.019	0.2718
27000	16.571	0.019	0.2751
27600	16.572	0.019	0.2651
28200	16.574	0.017	0.2407
28800	16.574	0.017	0.2381
29400	16.575	0.016	0.2283
30000	16.577	0.014	0.1976
30600	16.576	0.014	0.2021
31200	16.577	0.014	0.1954
31800	16.577	0.013	0.1884
32400	16.579	0.011	0.1639
33000	16.579	0.011	0.1586
33600	16.580	0.010	0.1482
34200	16.580	0.010	0.1479
34800	16.581	0.009	0.1288
35400	16.581	0.009	0.1304
36000	16.583	0.008	0.1079
36600	16.584	0.007	0.0980
37200	16.584	0.007	0.0945
37800	16.585	0.006	0.0804
38400	16.585	0.005	0.0714
39000	16.586	0.005	0.0702
39600	16.586	0.005	0.0647
40200	16.588	0.003	0.0394
40800	16.588	0.003	0.0425
41400	16.588	0.003	0.0380
42000	16.588	0.002	0.0323
42600	16.588	0.002	0.0315
43200	16.589	0.002	0.0262



Reduced by: Alistair Walsh
Date: 10/05/2010

Checked by: Kate Furness
Date: 10/05/2010

Hvorslev analysis of test conducted at well: RT07a

Data collected by: A. Walsh / T. McCarthy
Client: BHP Billiton
Test location: Mulgaria Station
Date: 30/04/2010

SWL: 13.11 m
Slugged head (ho) 0.04 m

Hydrostratigraphic Unit Amberoona Formation
Aquifer type: fractured rock (confined)

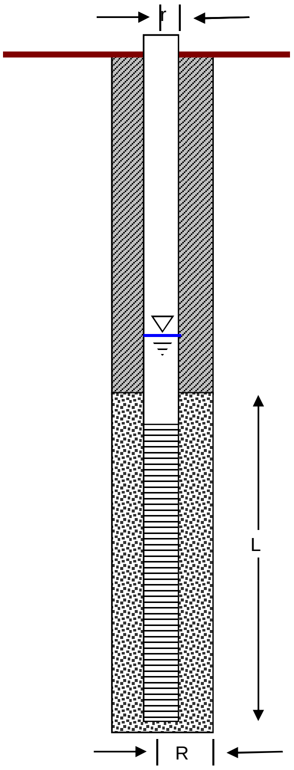
Well depth from RP 141 m
Length of well screen (L) 128 m
Casing radius (r) 0.025 m
Well radius (R) 0.076 m

T_{37} (interpolated from graph) 200 seconds

Indicate model that best represents tested well

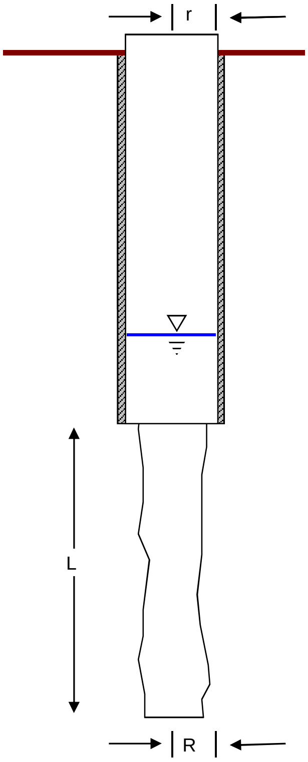
1. Constructed well [1]

☑



2. Open hole completion

☐



notes: 1. solution is unsuitable for cases where
- screen becomes dewatered (rising head test)
- water table straddles screen (rising or falling head test)

Solution:

$$K = \frac{r^2 \ln(L/R)}{2LT_0}$$

$(L/R) > 8$

solution valid

$K =$ 9.07E-08 m/sec OR 0.01 m/day

Prepared by Alistair Walsh,10 May 2010
Revision A

Hvorslev analysis of test conducted at well: RT07a

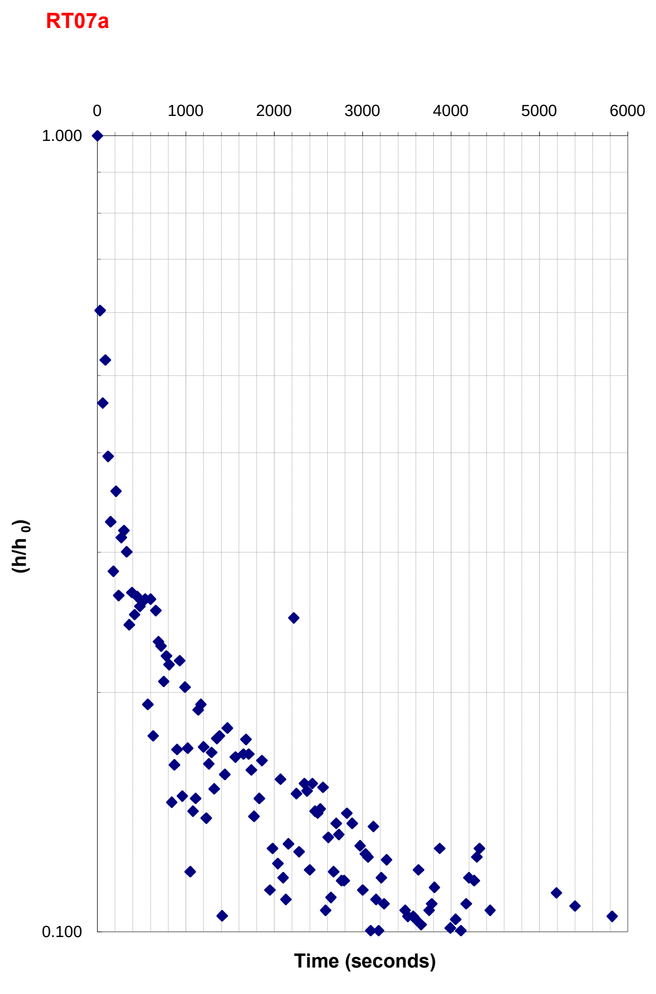
Date of test: 30/04/2010

SWL: 13.11 m
Slugged head (ho) 0.04 m

Data collected by: A Walsh
Client: BHP Billiton
Test location: Mulgaria Station

Aquifer type: fractured rock (confined)

T_{37} (interpolated from graph) 200 seconds



Time (seconds)	Depth to water (m)	d in level (m)	h/h0
0	13.07	0.04	1.00
30	13.09	0.02	0.60
60	13.09	0.02	0.46
90	13.09	0.02	0.52
120	13.10	0.01	0.40
150	13.10	0.01	0.33
180	13.10	0.01	0.28
210	13.10	0.01	0.36
240	13.10	0.01	0.26
270	13.10	0.01	0.31
300	13.10	0.01	0.32
330	13.10	0.01	0.30
360	13.10	0.01	0.24
390	13.10	0.01	0.27
420	13.10	0.01	0.25
450	13.10	0.01	0.26
480	13.10	0.01	0.26
510	13.10	0.01	0.26
540	13.10	0.01	0.26
570	13.10	0.01	0.19
600	13.10	0.01	0.26
630	13.10	0.01	0.18
660	13.10	0.01	0.25
690	13.10	0.01	0.23
720	13.10	0.01	0.23
750	13.10	0.01	0.21
780	13.10	0.01	0.22
810	13.10	0.01	0.22
840	13.10	0.01	0.15
870	13.10	0.01	0.16
900	13.10	0.01	0.17
930	13.10	0.01	0.22
960	13.10	0.01	0.15
990	13.10	0.01	0.20
1020	13.10	0.01	0.17
1050	13.11	0.00	0.12
1080	13.10	0.01	0.14
1110	13.10	0.01	0.15
1140	13.10	0.01	0.19
1170	13.10	0.01	0.19
1200	13.10	0.01	0.17
1230	13.10	0.01	0.14
1260	13.10	0.01	0.16
1290	13.10	0.01	0.17
1320	13.10	0.01	0.15
1350	13.10	0.01	0.17
1380	13.10	0.01	0.18
1410	13.11	0.00	0.10
1440	13.10	0.01	0.16
1470	13.10	0.01	0.18
1500	13.11	0.00	0.09
1530	13.11	0.00	0.09
1560	13.10	0.01	0.17
1590	13.11	0.00	0.07
1620	13.11	0.00	0.09
1650	13.10	0.01	0.17
1680	13.10	0.01	0.17
1710	13.10	0.01	0.17
1740	13.10	0.01	0.16
1770	13.10	0.01	0.14
1800	13.11	0.00	0.10
1830	13.10	0.01	0.15
1860	13.10	0.01	0.16

Reduced by: Kate Furness
Date: 10/5//2010

Checked by: Alistair Walsh
Date: 11/05/2010

Hvorslev analysis of test conducted at well: RT07b

Data collected by:	A. Walsh / T. McCarthy	**SWL:**	18.51 m
Client:	BHP Billiton	**Slugged head (ho)**	0.68 m
Test location:	Mulgaria Station		
Date:	1/05/2010		

Hydrostratigraphic Unit	Amberoona Formation
Aquifer type:	Fractured Rock(confined)

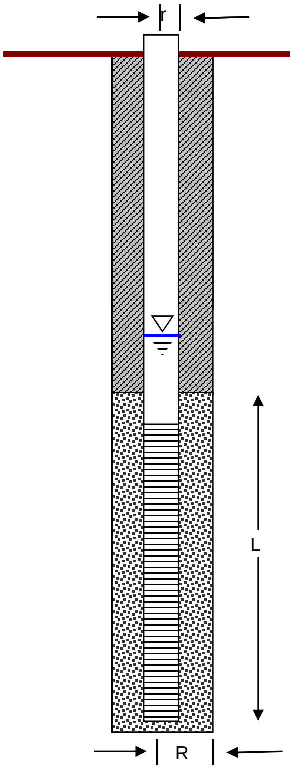
Well depth from RP	198 m
Length of well screen (L)	32 m
Casing radius (r)	0.025 m
Well radius (R)	0.076 m

T_{37} (interpolated from graph) 20000 seconds

Indicate model that best represents tested well

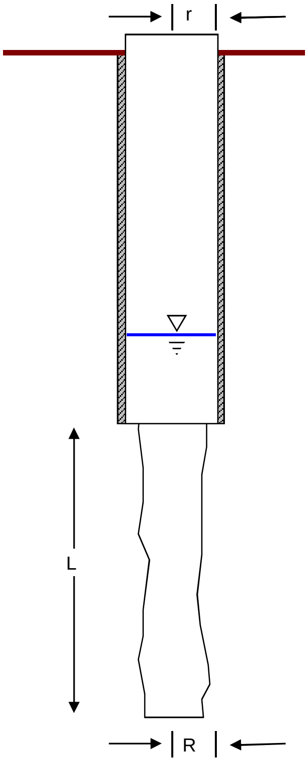
1. Constructed well [1]

☑



2. Open hole completion

☐



notes: 1. solution is unsuitable for cases where
- screen becomes dewatered (rising head test)
- water table straddles screen (rising or falling head test)

Solution:

$$K = \frac{r^2 \ln(L/R)}{2LT_0}$$

$(L / R) > 8$

solution valid

$K=$ 2.95E-09 m/sec *OR* 0.0003 m/day

Prepared by Alistair Walsh,10 May 2010
Revision A

Hvorslev analysis of test conducted at well: RT07b

Date of test: 1/05/2010

SWL: 18.51 m

Slugged head (ho) 0.68 m

Data collected by: A. Walsh / T. McCarthy

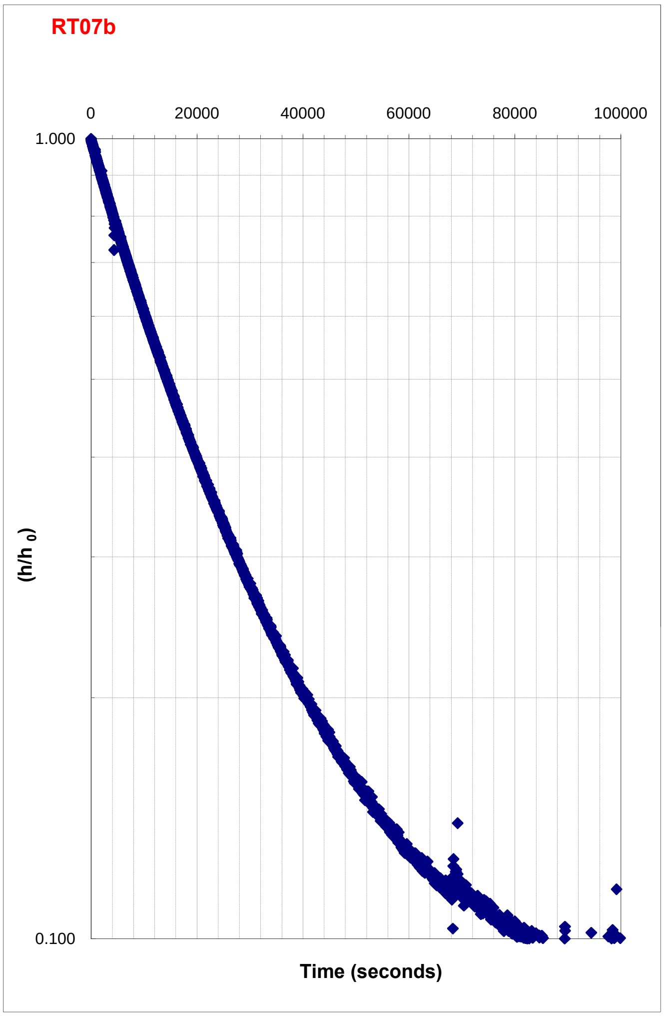
Client: BHP Billiton

Test location: Mulgaria Station

Aquifer type: Fractured Rock(confined)

T_{37} (interpolated from graph) 20000 seconds

Time (seconds)	Depth to water (m)	d in level (m)	h/h0
0	17.827	0.683	1.0000
6000	18.010	0.501	0.7331
12000	18.131	0.379	0.5548
18000	18.217	0.294	0.4298
24000	18.277	0.233	0.3414
30000	18.322	0.188	0.2751
36000	18.355	0.156	0.2280
42000	18.379	0.131	0.1921
48000	18.398	0.113	0.1648
54000	18.411	0.099	0.1452
60000	18.423	0.087	0.1273
66000	18.431	0.079	0.1160
72000	18.433	0.077	0.1126
78000	18.439	0.071	0.1045
84000	18.441	0.069	0.1016
90000	18.445	0.065	0.0951
96000	18.447	0.064	0.0930
102000	18.445	0.066	0.0961
108000	18.445	0.066	0.0963
114000	18.444	0.066	0.0966
120000	18.444	0.067	0.0978
126000	18.443	0.067	0.0982
132000	18.441	0.069	0.1013
138000	18.441	0.069	0.1015
144000	18.439	0.071	0.1046
150000	18.438	0.073	0.1062
156000	18.436	0.074	0.1083
162000	18.435	0.076	0.1109
168000	18.434	0.076	0.1115
174000	18.433	0.077	0.1133
180000	18.433	0.077	0.1128
186000	18.433	0.077	0.1129
192000	18.433	0.077	0.1128
198000	18.434	0.076	0.1118
204000	18.435	0.075	0.1099
210000	18.436	0.074	0.1084
216000	18.439	0.072	0.1048
222000	18.440	0.070	0.1029
228000	18.442	0.068	0.0994
234000	18.446	0.065	0.0948
240000	18.449	0.062	0.0904
246000	18.452	0.058	0.0853
252000	18.456	0.054	0.0796
258000	18.461	0.049	0.0724
264000	18.465	0.046	0.0670
270000	18.469	0.041	0.0606
276000	18.472	0.038	0.0554
282000	18.477	0.033	0.0484
288000	18.482	0.029	0.0422
294000	18.486	0.024	0.0351
300000	18.489	0.021	0.0312
306000	18.493	0.017	0.0249
312000	18.497	0.013	0.0193
318000	18.501	0.009	0.0137
324000	18.503	0.008	0.0111
330000	18.506	0.004	0.0062
336000	18.508	0.002	0.0035
342000	18.509	0.001	0.0013
348000	18.511	0.000	-0.0006
354000	18.510	0.000	-0.0002
360000	18.511	0.000	-0.0003



Reduced by: Alistair Walsh
Date: 10/05/2010

Checked by: Kate Furness
Date: 10/05/2010

Hvorslev analysis of test conducted at well: RT41

Data collected by: A. Walsh / T. McCarthy
Client: BHP Billiton
Test location: Borefield Rd
Date: 29/04/2010

SWL: 19.68 m
Slugged head (ho) 0.27 m

Hydrostratigraphic Unit Bulldog Shale
Aquifer type: Fractured Rock

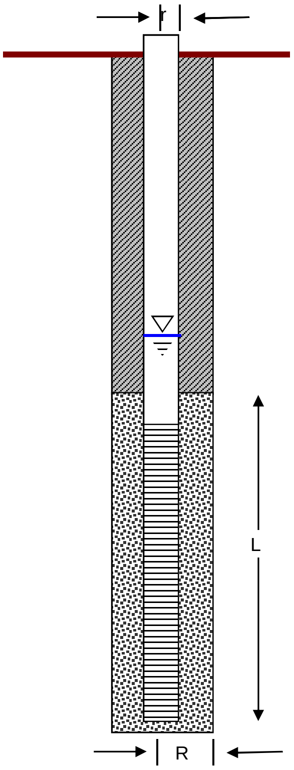
Well depth from RP 102 m
Length of well screen (L) 22 m
Casing radius (r) 0.05 m
Well radius (R) 0.1015 m

T_{37} (interpolated from graph) 20 seconds

Indicate model that best represents tested well

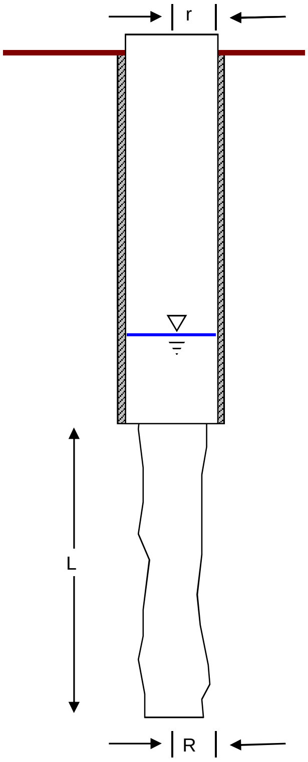
1. Constructed well [1]

☑



2. Open hole completion

☐



notes: 1. solution is unsuitable for cases where
- screen becomes dewatered (rising head test)
- water table straddles screen (rising or falling head test)

Solution:

$$K = \frac{r^2 \ln(L/R)}{2LT_0}$$

$(L / R) > 8$

solution valid

$K=$ 1.53E-05 m/sec *OR* 1.3202 m/day

Hvorslev analysis of test conducted at well: RT41

Date of test: 29/04/2010

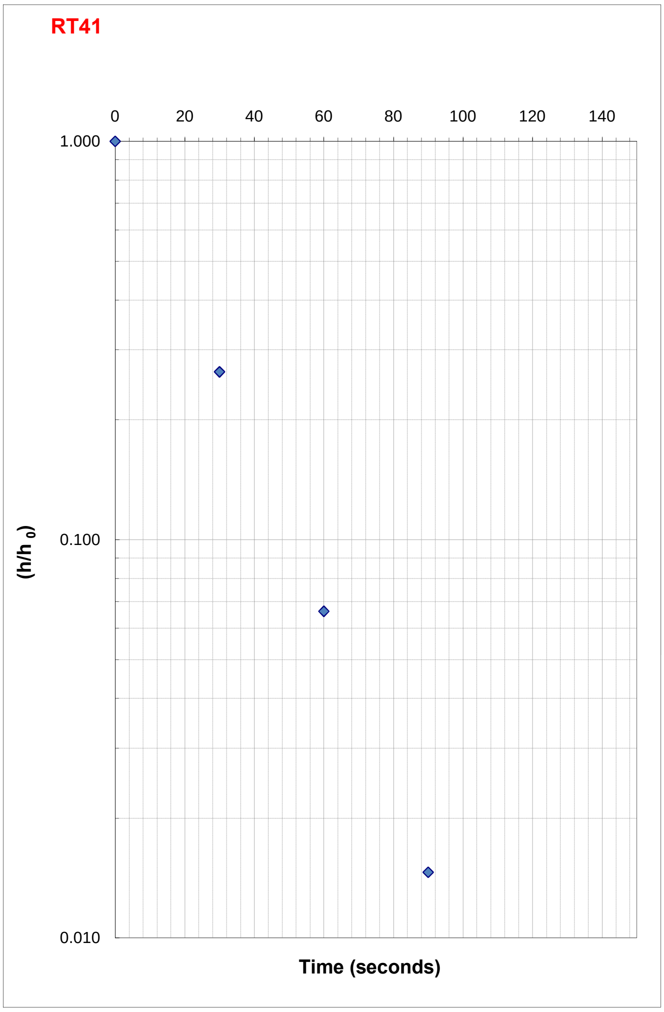
SWL: 19.68 m
Slugged head (ho) 0.27 m

Data collected by: A. Walsh / T. McCarthy
Client: BHP Billiton
Test location: Borefield Rd

Aquifer type: Fractured Rock

T_{37} (interpolated from graph) 20 seconds

Time (seconds)	Depth to water (m)	d in level (m)	h/h0
0	19.402	0.273	1.0000
30	19.603	0.072	0.2639
60	19.657	0.018	0.0661
90	19.671	0.004	0.0146
120	19.674	0.001	0.0019
150	19.677	-0.002	-0.0055
180	19.677	-0.002	-0.0056
210	19.673	0.002	0.0061
240	19.675	0.000	-0.0010



Reduced by: Alistair Walsh
Date: 10/05/2010

Checked by: Kate Furness
Date: 10/05/2010

Hvorslev analysis of test conducted at well: PT63

Data collected by:	A. Walsh / T. McCarthy	**SWL:**	8.10 m
Client:	BHP Billiton	**Slugged head (ho)**	0.19 m
Test location:	Stuart Creek Station		
Date:	2/05/2010		

Hydrostratigraphic Unit	Bulldog Shale
Aquifer type:	fractured rock (confined)

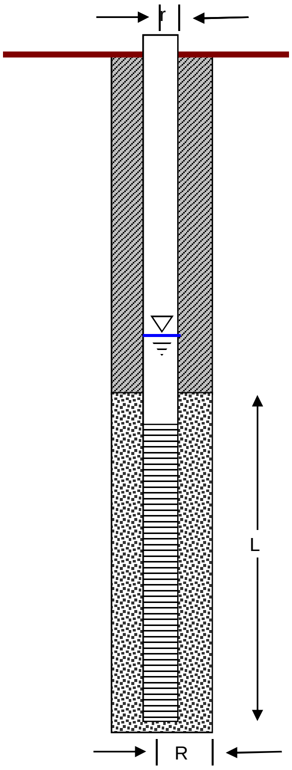
Well depth from RP	48 m
Length of well screen (L)	24 m
Casing radius (r)	0.05 m
Well radius (R)	0.1015 m

T_{37} (interpolated from graph) 570 seconds

Indicate model that best represents tested well

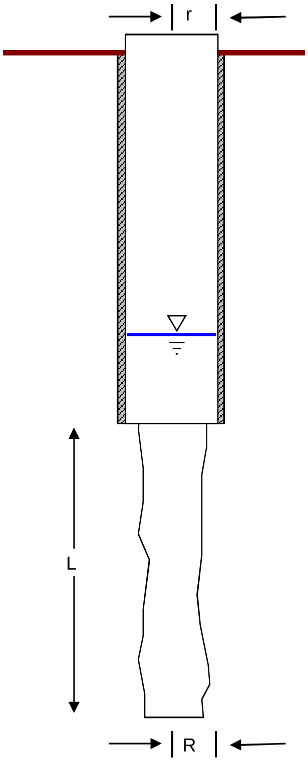
1. Constructed well [1]

☑



2. Open hole completion

☐



notes: 1. solution is unsuitable for cases where
- screen becomes dewatered (rising head test)
- water table straddles screen (rising or falling head test)

Solution:

$$K = \frac{r^2 \ln(L/R)}{2LT_0}$$

$(L/R) > 8$

solution valid

$K=$ 4.99E-07 m/sec *OR* 0.043 m/day

Hvorslev analysis of test conducted at well: PT63

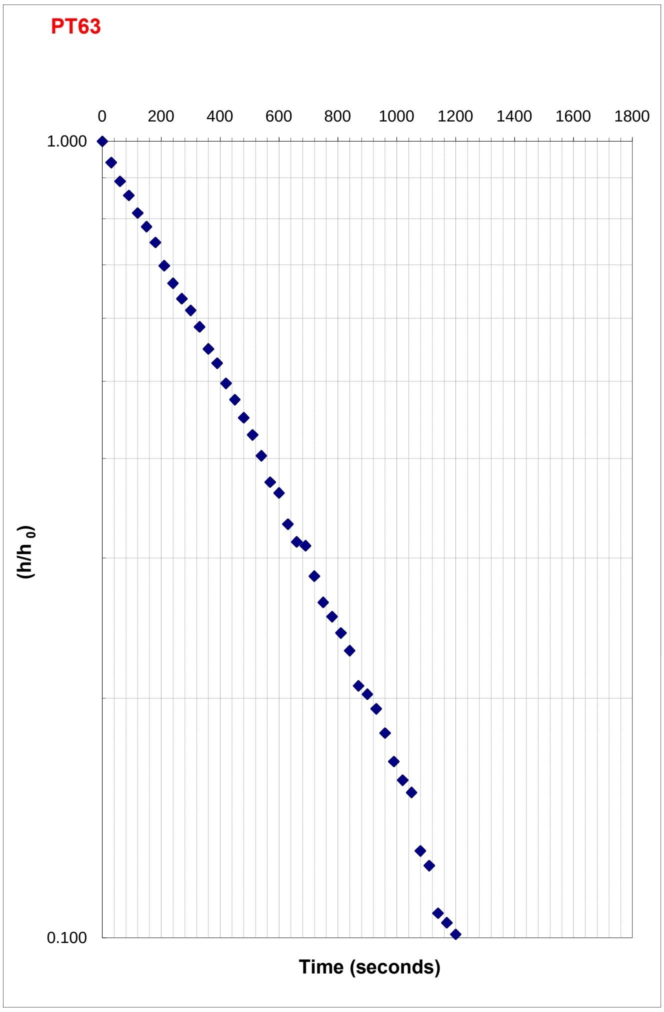
Date of test: 2/05/2010

SWL: 8.10 m
Slugged head (ho) 0.19 m

Data collected by: A Walsh / T McCarthy
Client: BHP Billiton
Test location: Stuart Creek Station

Aquifer type: fractured rock (confined)

T_{37} (interpolated from graph) 570 seconds



Time (seconds)	Depth to water (m)	d in level (m)	h/h0
0	7.91	0.19	1.00
30	7.92	0.18	0.94
60	7.93	0.17	0.89
90	7.94	0.16	0.86
120	7.95	0.15	0.81
150	7.95	0.15	0.78
180	7.96	0.14	0.75
210	7.97	0.13	0.70
240	7.97	0.13	0.66
270	7.98	0.12	0.63
300	7.98	0.12	0.61
330	7.99	0.11	0.58
360	8.00	0.10	0.55
390	8.00	0.10	0.53
420	8.01	0.09	0.50
450	8.01	0.09	0.47
480	8.01	0.09	0.45
510	8.02	0.08	0.43
540	8.02	0.08	0.40
570	8.03	0.07	0.37
600	8.03	0.07	0.36
630	8.04	0.06	0.33
660	8.04	0.06	0.31
690	8.04	0.06	0.31
720	8.05	0.05	0.28
750	8.05	0.05	0.26
780	8.05	0.05	0.25
810	8.05	0.05	0.24
840	8.06	0.04	0.23
870	8.06	0.04	0.21
900	8.06	0.04	0.20
930	8.06	0.04	0.19
960	8.07	0.03	0.18
990	8.07	0.03	0.17
1020	8.07	0.03	0.16
1050	8.07	0.03	0.15
1080	8.08	0.02	0.13
1110	8.08	0.02	0.12
1140	8.08	0.02	0.11
1170	8.08	0.02	0.10
1200	8.08	0.02	0.10
1230	8.08	0.02	0.10
1260	8.08	0.02	0.09
1290	8.09	0.01	0.07
1320	8.09	0.01	0.07
1350	8.09	0.01	0.07
1380	8.09	0.01	0.06
1410	8.09	0.01	0.05
1440	8.09	0.01	0.04
1470	8.09	0.01	0.04
1500	8.09	0.01	0.04
1530	8.09	0.01	0.03
1560	8.10	0.00	0.02
1590	8.10	0.00	0.02
1620	8.10	0.00	0.02
1650	8.10	0.00	0.01
1680	8.10	0.00	0.00
1710	8.10	0.00	0.00

Reduced by: Kate Furness
Date: 10/5//2010

Checked by: Alisair Walsh
Date: 11/05/2010

Hvorslev analysis of test conducted at well: RT42

Data collected by: A. Walsh / T. McCarthy
Client: BHP Billiton
Test location: Borefield Rd
Date: 29/04/2010

SWL: 6.36 m
Slugged head (ho) 0.46 m

Hydrostratigraphic Unit Bulldog Shale
Aquifer type: fractured rock (confined)

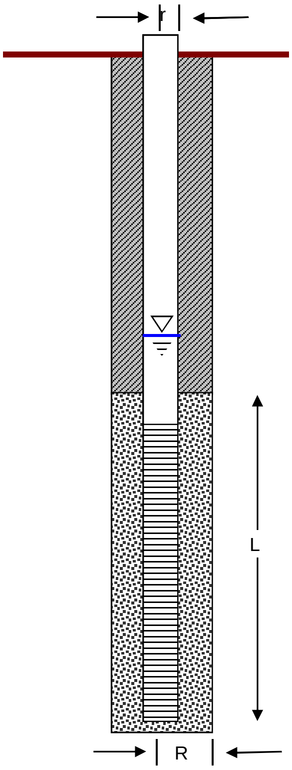
Well depth from RP 72 m
Length of well screen (L) 65 m
Casing radius (r) 0.05 m
Well radius (R) 0.1015 m

T_{37} (interpolated from graph) 90 seconds

Indicate model that best represents tested well

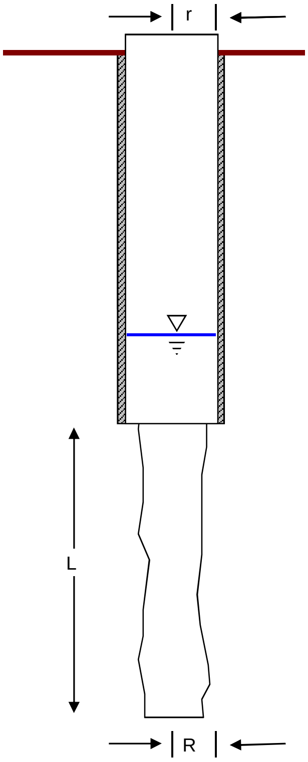
1. Constructed well [1]

☑



2. Open hole completion

☐



notes: 1. solution is unsuitable for cases where
- screen becomes dewatered (rising head test)
- water table straddles screen (rising or falling head test)

Solution:

$$K = \frac{r^2 \ln(L/R)}{2LT_0}$$

$(L/R) > 8$
solution valid

$K =$ 1.38E-06 m/sec *OR* 0.119 m/day

Hvorslev analysis of test conducted at well: RT42

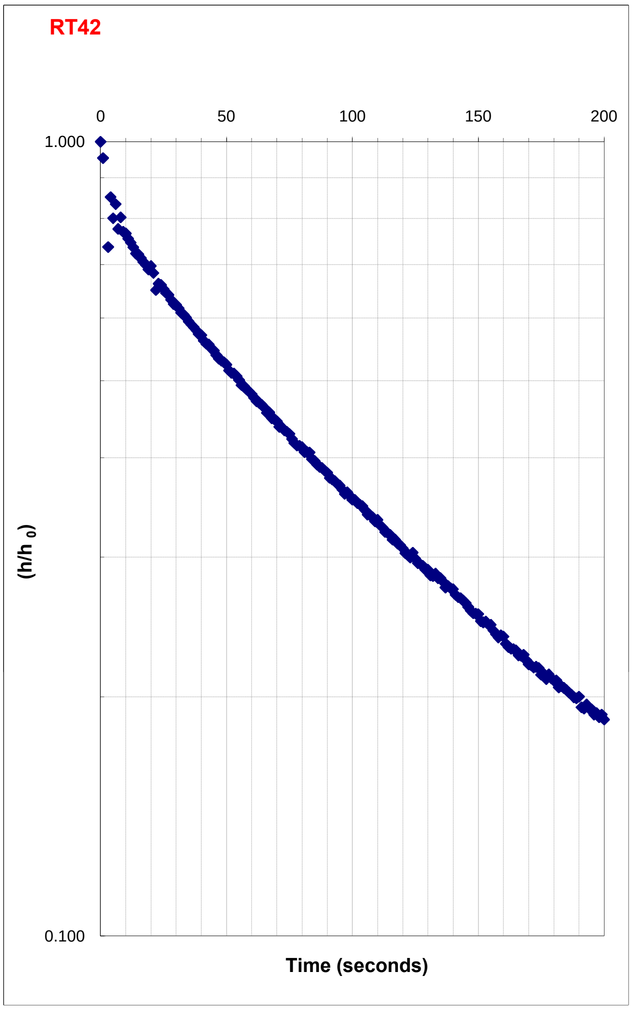
Date of test: 2/05/2010

SWL: 6.36 m
Slugged head (ho) 0.46 m

Data collected by: A Walsh, T McCarthy
Client: BHP Billiton
Test location: Borefield Rd

Aquifer type: fractured rock (confined)

T_{37} (interpolated from graph) 90 seconds



Time (seconds)	Depth to water (m)	d in level (m)	h/h0
0	5.91	0.46	1.00
20	6.04	0.32	0.70
40	6.10	0.26	0.57
60	6.14	0.22	0.48
80	6.17	0.19	0.41
100	6.20	0.16	0.35
120	6.22	0.14	0.31
140	6.24	0.12	0.27
160	6.25	0.11	0.24
180	6.27	0.10	0.21
200	6.28	0.09	0.19
220	6.29	0.07	0.16
240	6.29	0.07	0.15
260	6.298	0.06	0.14
280	6.305	0.06	0.12
300	6.310	0.05	0.11
320	6.314	0.05	0.10
340	6.322	0.04	0.09
360	6.325	0.04	0.08
380	6.325	0.04	0.08
400	6.327	0.03	0.07
420	6.331	0.03	0.07
440	6.332	0.03	0.06
460	6.335	0.03	0.06
480	6.337	0.02	0.05
500	6.338	0.02	0.05
520	6.339	0.02	0.05
540	6.340	0.02	0.04
560	6.342	0.02	0.04
580	6.342	0.02	0.04
600	6.343	0.02	0.04
620	6.344	0.02	0.04
640	6.346	0.01	0.03
660	6.346	0.01	0.03
680	6.350	0.01	0.02
700	6.347	0.01	0.03
720	6.347	0.01	0.03
740	6.347	0.01	0.03
760	6.352	0.01	0.02
780	6.349	0.01	0.02
800	6.352	0.01	0.02
820	6.350	0.01	0.02
840	6.352	0.01	0.02
860	6.350	0.01	0.02
880	6.351	0.01	0.02
900	6.350	0.01	0.02
920	6.352	0.01	0.02
940	6.351	0.01	0.02
960	6.352	0.01	0.02
980	6.353	0.01	0.02
1000	6.354	0.01	0.01

Reduced by: Alistair Walsh
Date: 10/05/2010

Checked by: Kate Furness
Date: 10/05/2010

Hvorslev analysis of test conducted at well: PT62

Data collected by: A. Walsh / T. McCarthy
Client: BHP Billiton
Test location: Stuart Creek Station
Date: 2/05/2010

SWL: 39.38 m
Slugged head (ho) 0.33 m

Hydrostratigraphic Unit Cadna-Owie
Aquifer type: Sedimentary (confined)

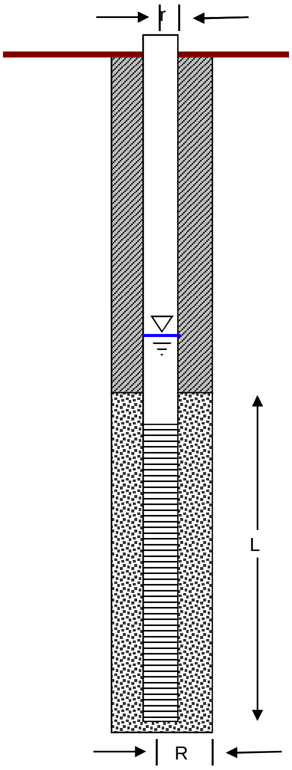
Well depth from RP 66 m
Length of well screen (L) 19 m
Casing radius (r) 0.05 m
Well radius (R) 0.1015 m

T_{37} (interpolated from graph) 1.25 seconds

Indicate model that best represents tested well

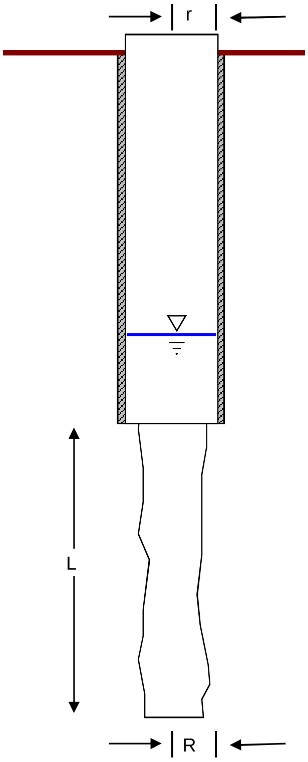
1. Constructed well [1]

☑



2. Open hole completion

☐



notes: 1. solution is unsuitable for cases where
- screen becomes dewatered (rising head test)
- water table straddles screen (rising or falling head test)

Solution:

$$K = \frac{r^2 \ln(L/R)}{2LT_0}$$

$(L / R) > 8$

solution valid

$K=$ 2.75E-04 m/sec OR 23.792 m/day

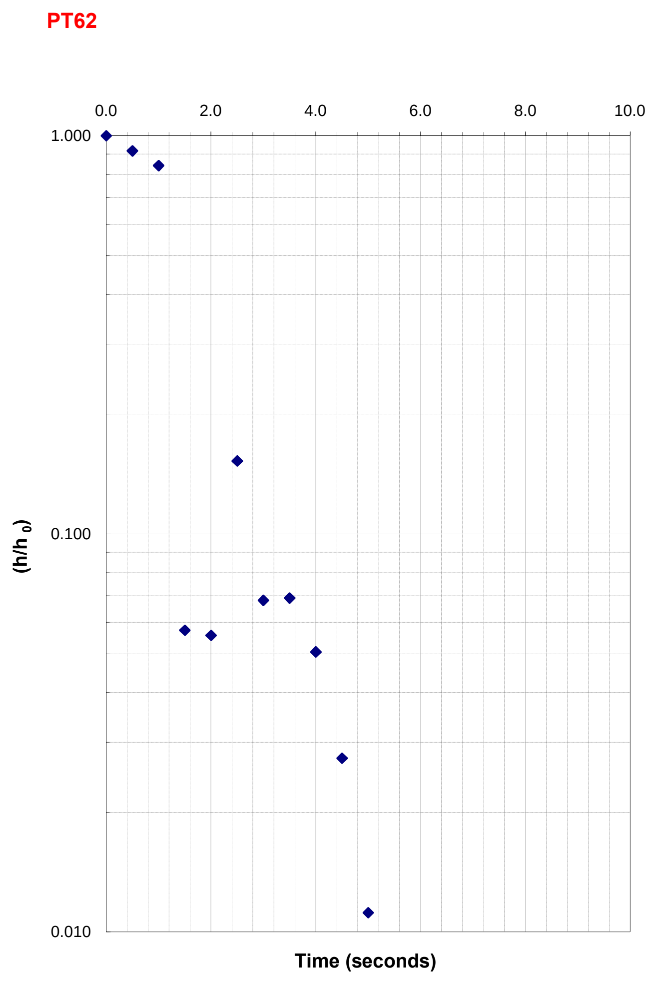
Hvorslev analysis of test conducted at well: PT62

Date of test: 2/05/2010

SWL: 39.38 m
Slugged head (ho) 0.33 m

Data collected by:	A. Walsh / T. McCarthy
Client:	BHP Billiton
Test location:	Stuart Creek Station
Aquifer type:	Sedimentary (confined)
T_{37} (interpolated from graph)	1.25 seconds

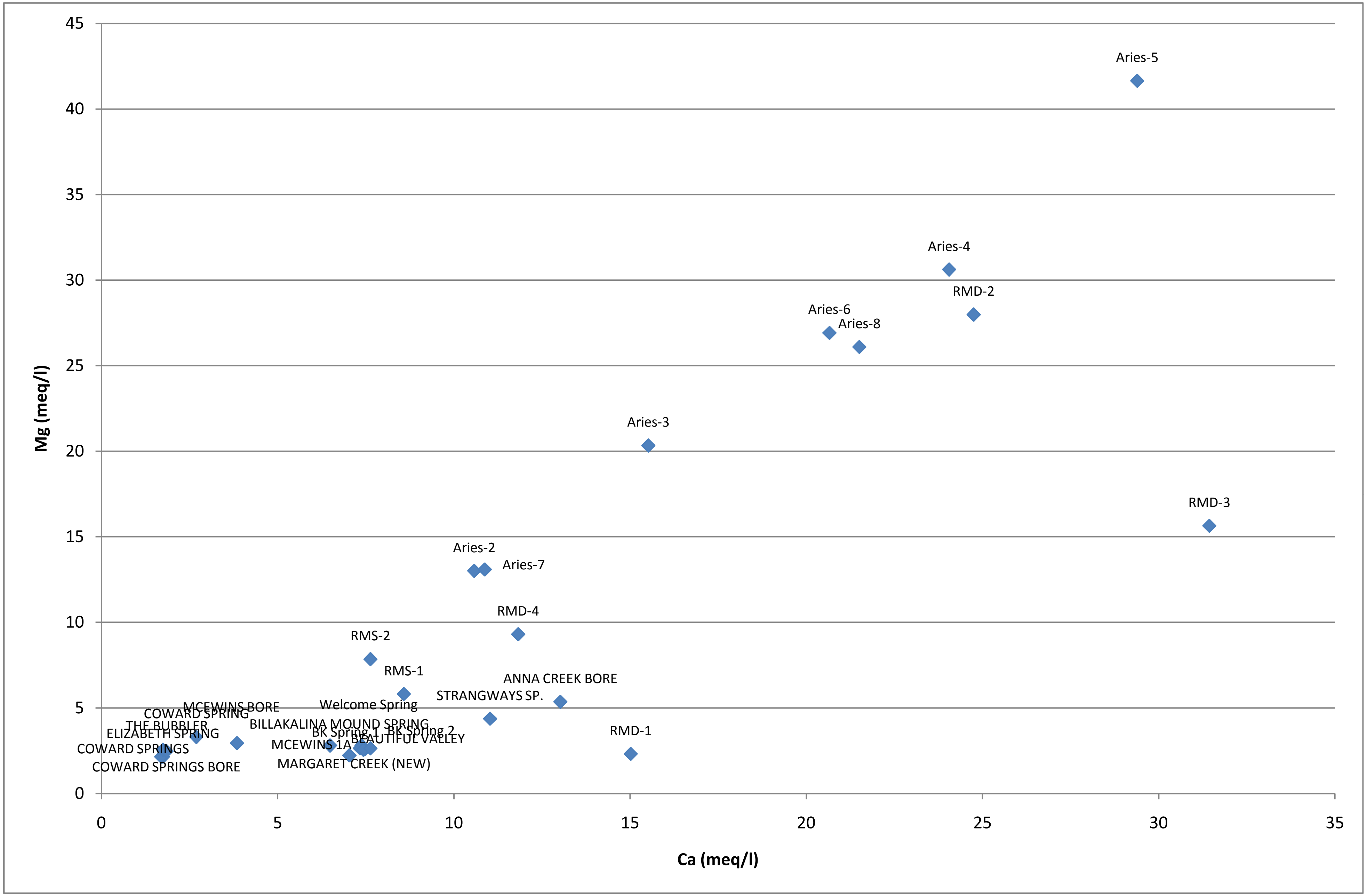
Time (seconds)	Depth to water (m)	d in level (m)	h/h0
0	39.048	0.332	1.0000
0.5	39.075	0.305	0.9163
1	39.100	0.280	0.8417
1.5	39.361	0.019	0.0573
2	39.362	0.018	0.0556
2.5	39.329	0.051	0.1524
3	39.357	0.023	0.0681
3.5	39.357	0.023	0.0690
4	39.363	0.017	0.0505
4.5	39.371	0.009	0.0273
5	39.376	0.004	0.0112

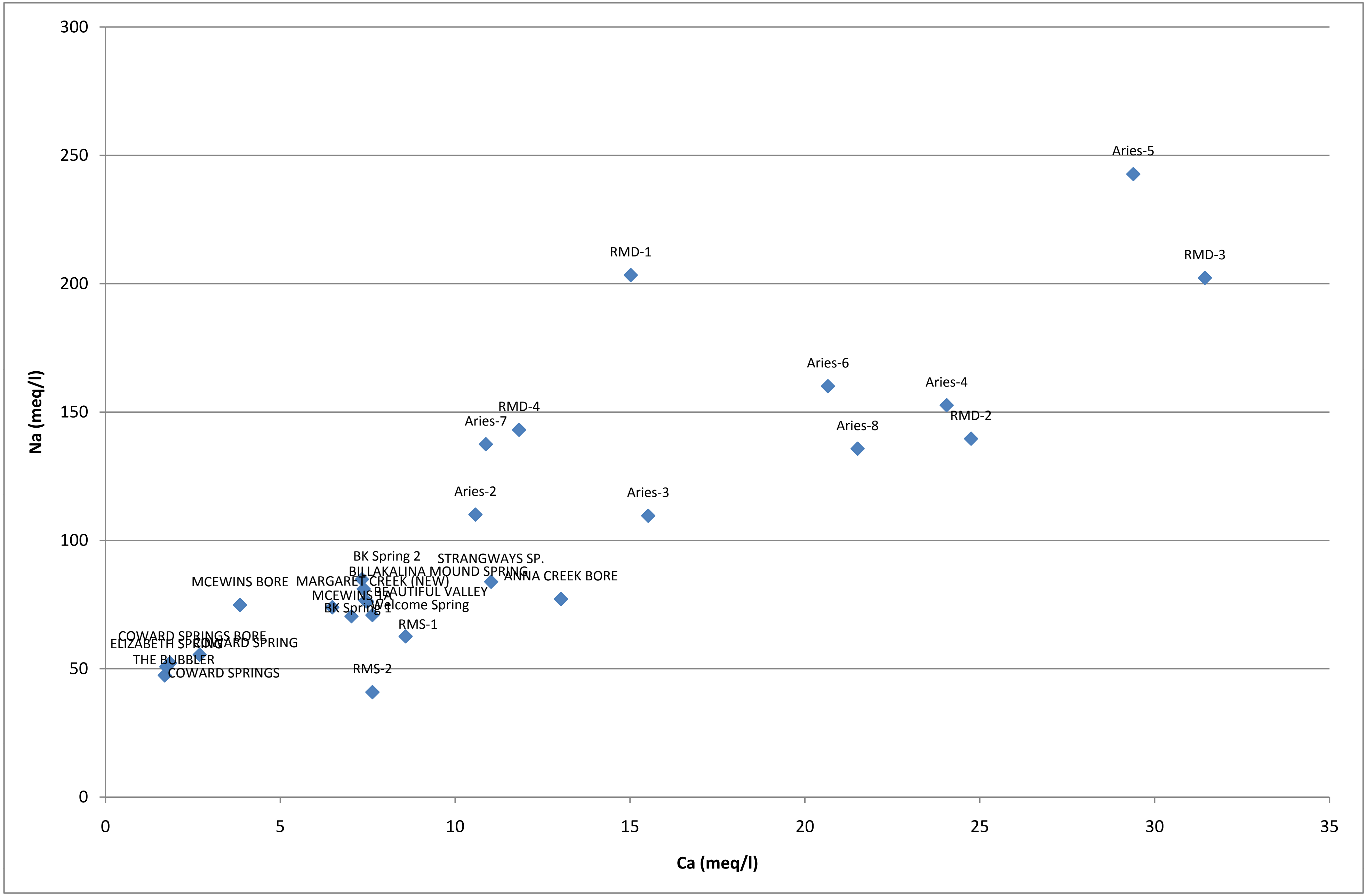


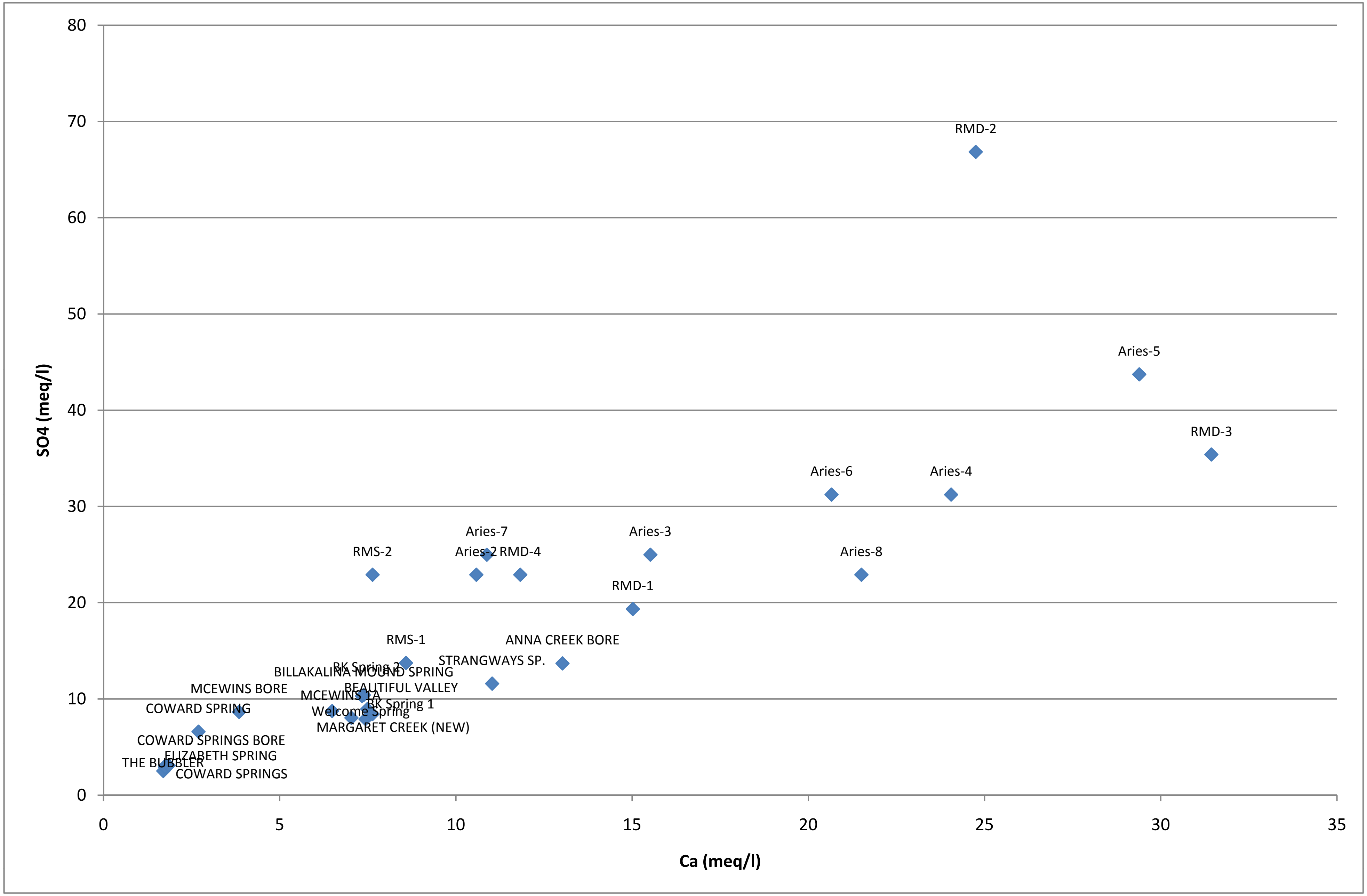
Reduced by: Alistair Walsh
Date: 10/05/2010

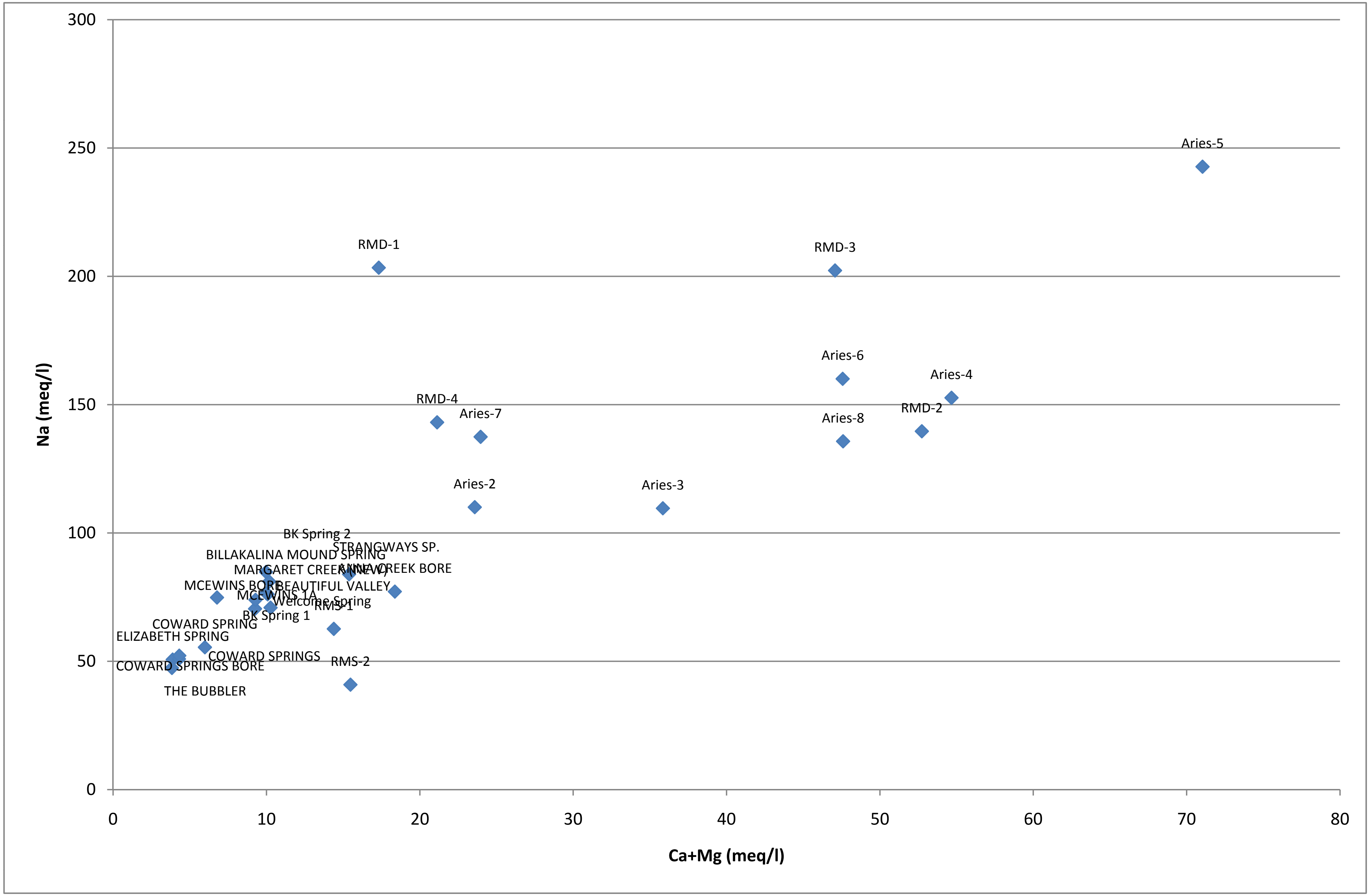
Checked by: Kate Furness
Date: 10/05/2010

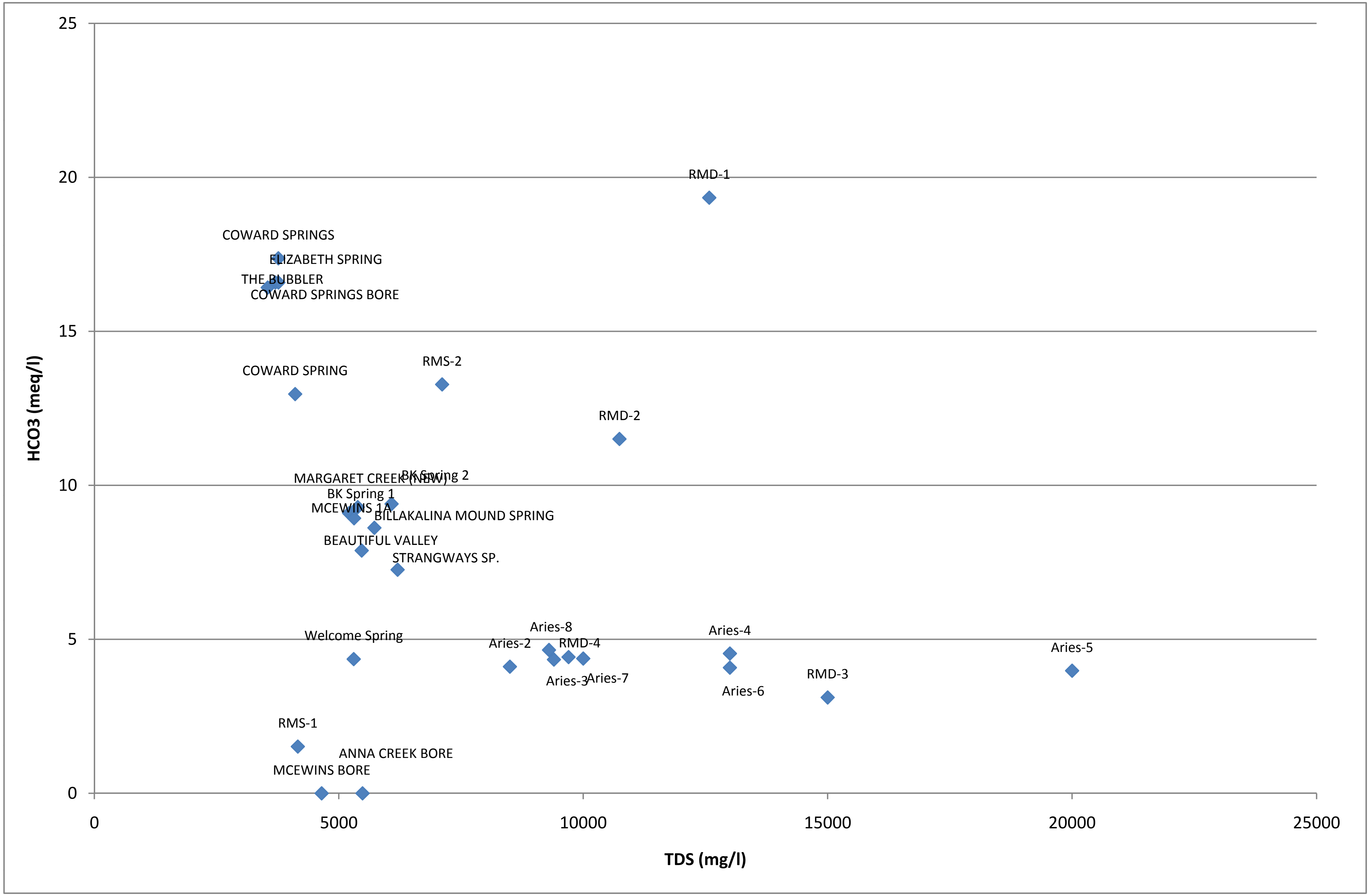
Attachment C
Major ion & isotope water chemistry

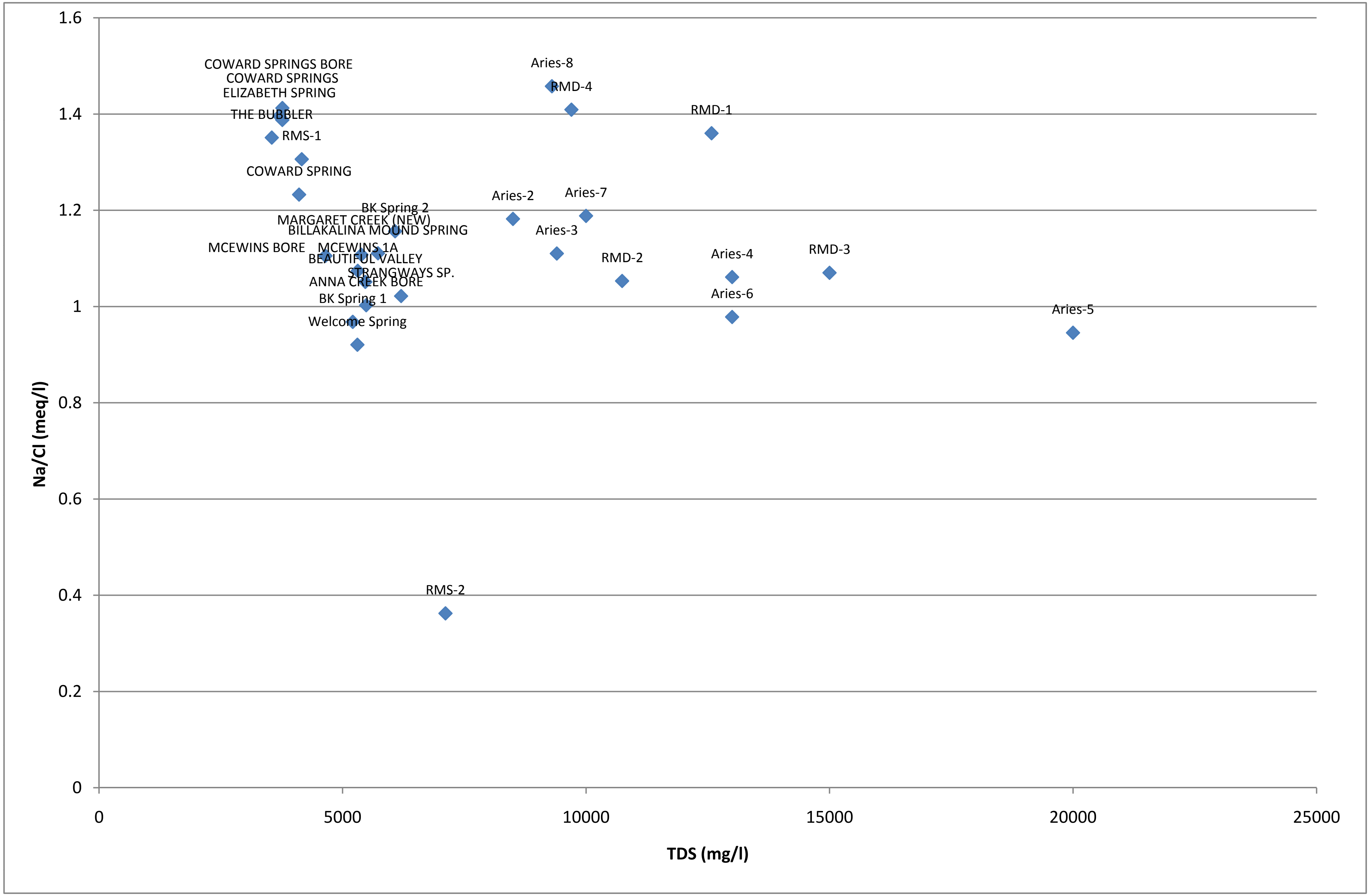

Aries-5
Aries-4
RMD-2
Aries-6
Aries-8
Aries-3
RMD-3
Aries-2
Aries-7
RMD-4
RMS-2
RMS-1
ANNA CREEK BORE
STRANGWAYS SP.
Welcome Spring
MCEWINS BORE
COWARD SPRING
THE BUBBLER
ELIZABETH SPRING
BILLAKALINA MOUND SPRING
BK Spring 1
BK Spring 2
BEAUTIFUL VALLEY
MCEWINS 1A
COWARD SPRINGS
COWARD SPRINGS BORE
MARGARET CREEK (NEW)
RMD-1
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
Mg (meq/l)
Ca (meq/l)

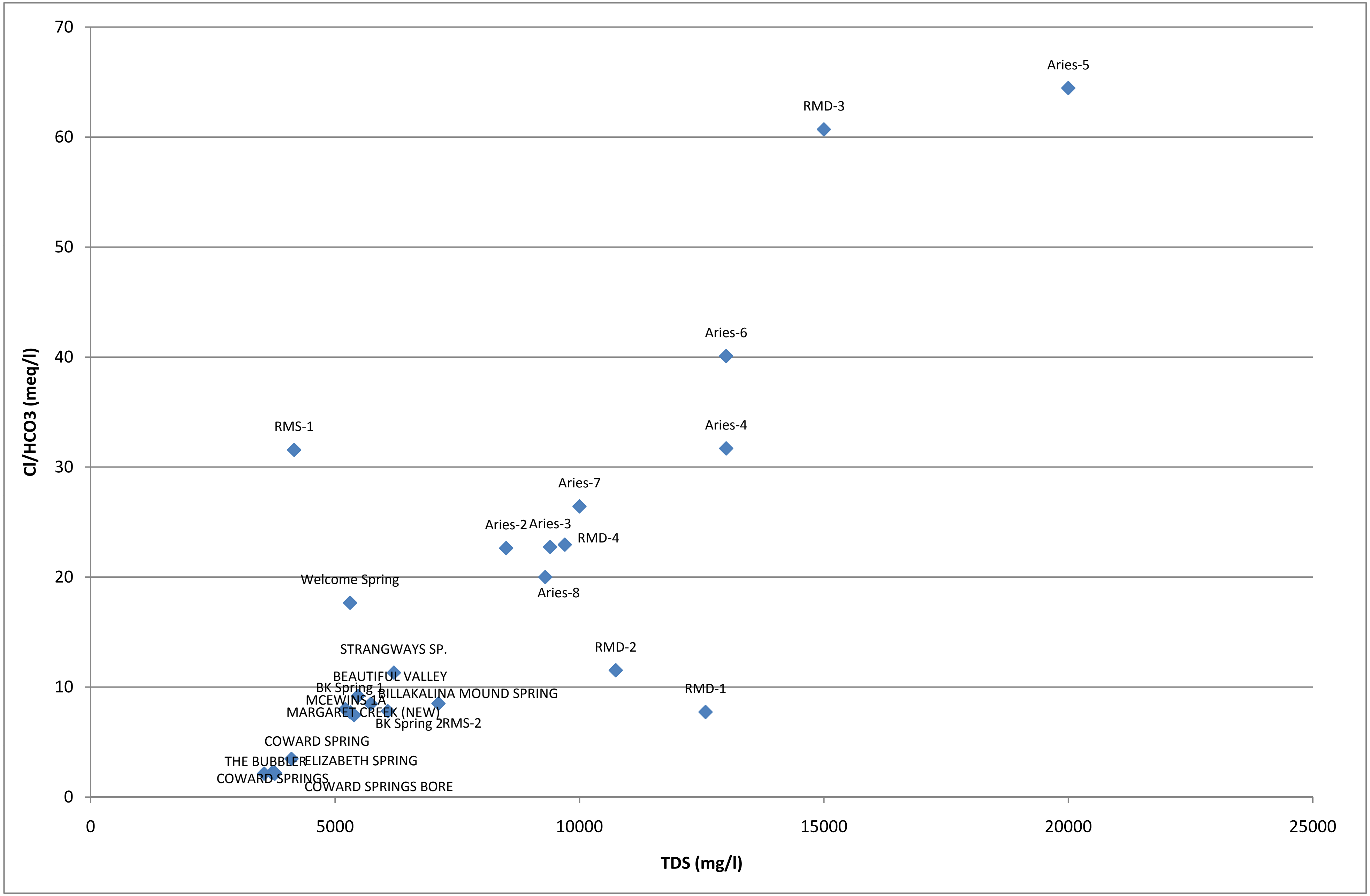

Na (meq/l)
300
250
200
150
100
50
0
Ca (meq/l)
0
5
10
15
20
25
30
35
Aries-5
RMD-1
RMD-3
Aries-6
Aries-4
RMD-2
Aries-8
RMD-4
Aries-7
Aries-2
Aries-3
BK Spring 2
STRANGWAYS SP.
BILLAKALINA MOUND SPRING
ANNA CREEK BORE
MCEWINS BORE
MARGARET CREEK (NEW)
MCEWINS 1A
BEAUTIFUL VALLEY
BK Spring 1
Welcome Spring
RMS-1
COWARD SPRINGS BORE
ELIZABETH SPRING
COWARD SPRING
THE BUBBLER
COWARD SPRINGS
RMS-2

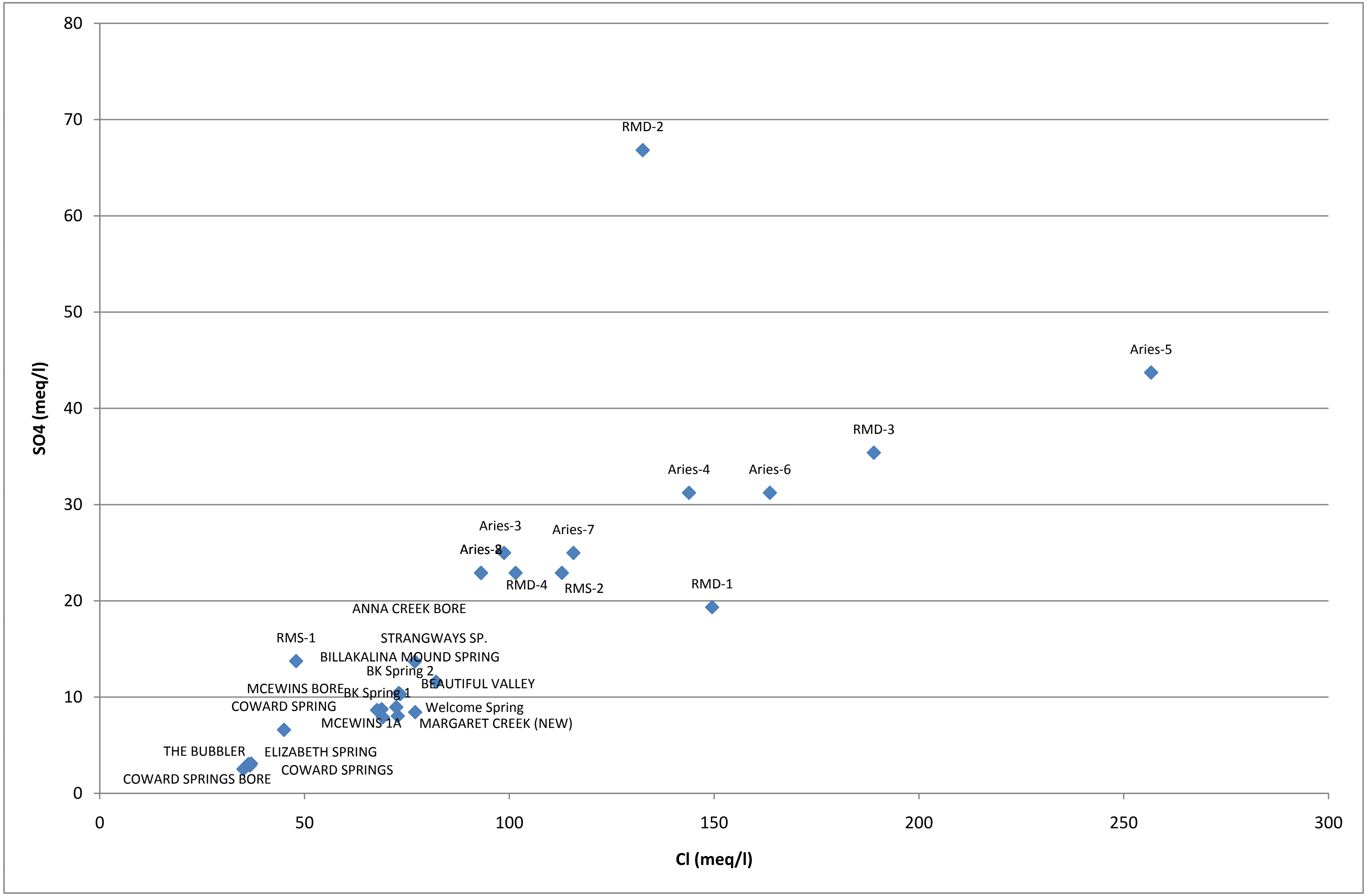

RMD-2
Aries-5
RMD-3
Aries-6
Aries-4
Aries-7
Aries-3
RMS-2
Aries-2
RMD-4
Aries-8
RMD-1
RMS-1
ANNA CREEK BORE
STRANGWAYS SP.
BK Spring 2
BILLAKALINA MOUND SPRING
MCEWINS BORE
BEAUTIFUL VALLEY
MCEWINS 1A
COWARD SPRING
BK Spring 1
Welcome Spring
MARGARET CREEK (NEW)
COWARD SPRINGS BORE
ELIZABETH SPRING
THE BUBBLER
COWARD SPRINGS
SO4 (meq/l)
0
10
20
30
40
50
60
70
80
Ca (meq/l)
0
5
10
15
20
25
30
35

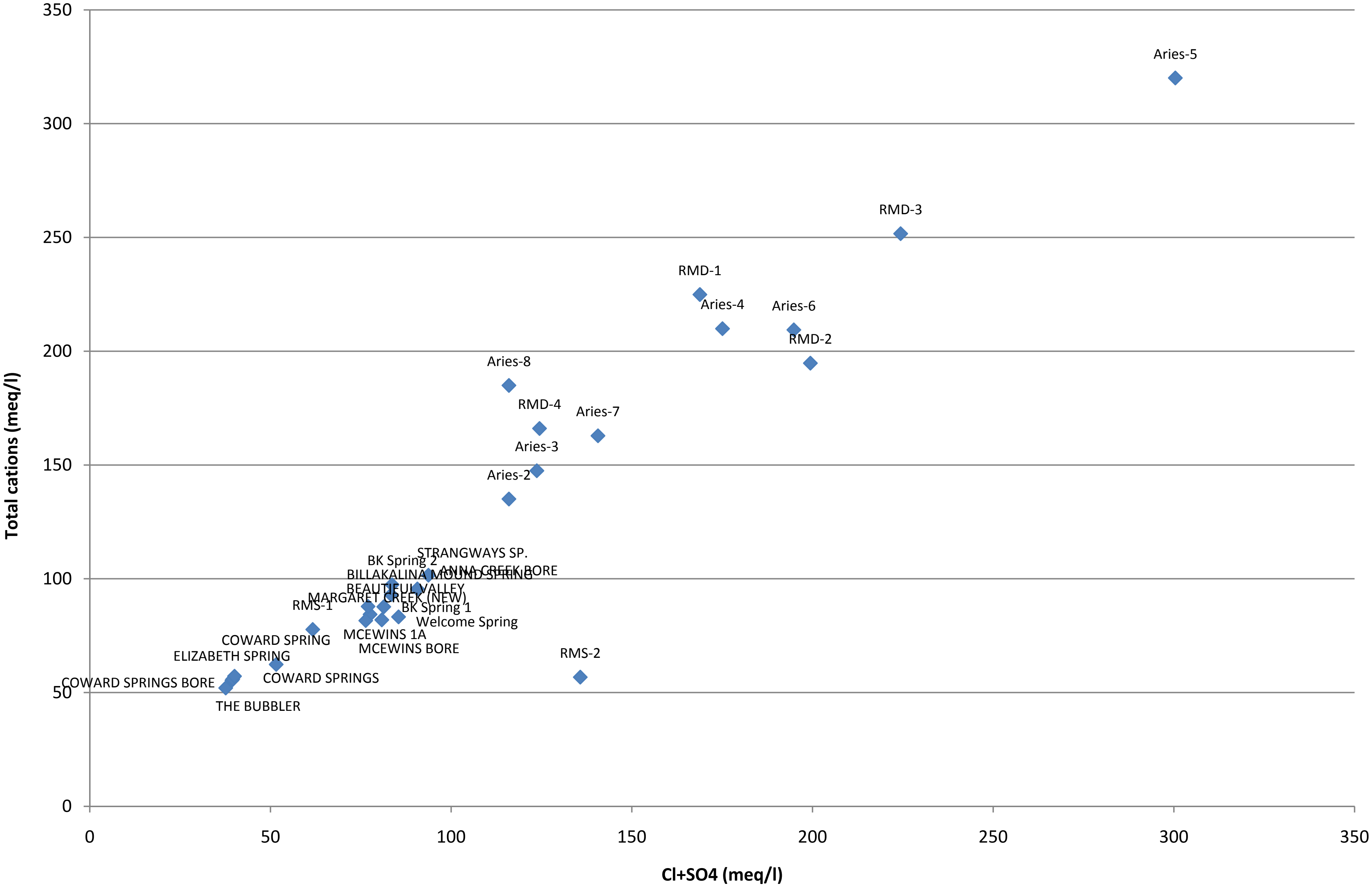

Na (meq/l)
300
250
200
150
100
50
0
Ca+Mg (meq/l)
0
10
20
30
40
50
60
70
80
Aries-5
RMD-1
RMD-3
Aries-6
Aries-4
RMD-4
Aries-7
RMD-2
Aries-8
Aries-2
Aries-3
BK Spring 2
STRANGWAYS SP.
BILLAKALINA MOUND SPRING
MARGARET CREEK (NEW)
ANNA CREEK BORE
MCEWINS BORE
BEAUTIFUL VALLEY
MCEWINS 1A
Welcome Spring
RMS-1
BK Spring 1
COWARD SPRING
ELIZABETH SPRING
COWARD SPRINGS
COWARD SPRINGS BORE
RMS-2
THE BUBBLER

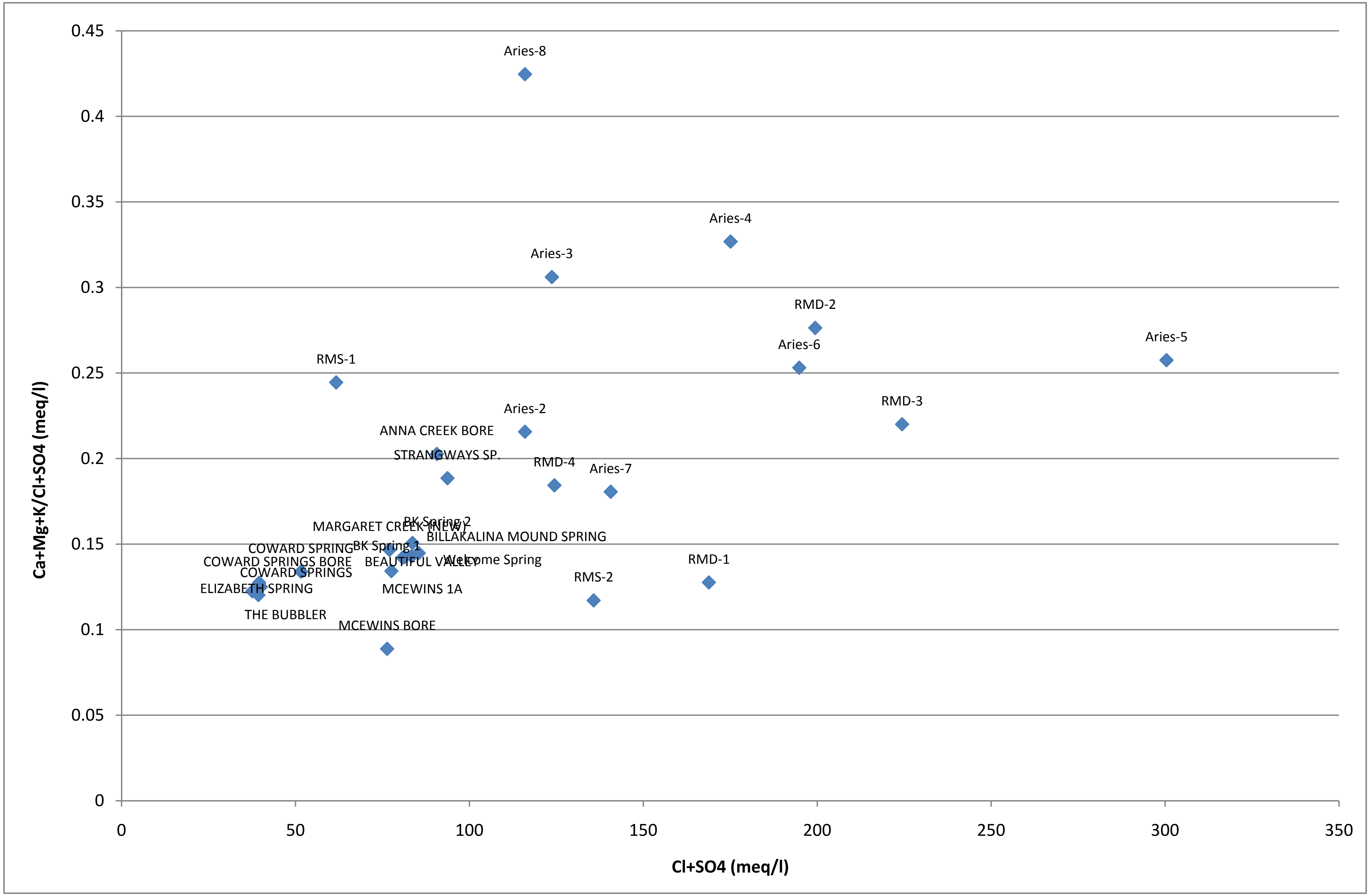

25
20
15
10
5
0
HCO3 (meq/l)
0
5000
10000
15000
20000
25000
TDS (mg/l)
RMD-1
COWARD SPRINGS
ELIZABETH SPRING
THE BUBBLER
COWARD SPRINGS BORE
COWARD SPRING
RMS-2
RMD-2
MARGARET CREEK (NEW)
BK Spring 2
BK Spring 1
MCEWINS 1A
BILLAKALINA MOUND SPRING
BEAUTIFUL VALLEY
STRANGWAYS SP.
Welcome Spring
Aries-8
Aries-2
RMD-4
Aries-3
Aries-7
Aries-4
Aries-6
RMD-3
Aries-5
RMS-1
ANNA CREEK BORE
MCEWINS BORE

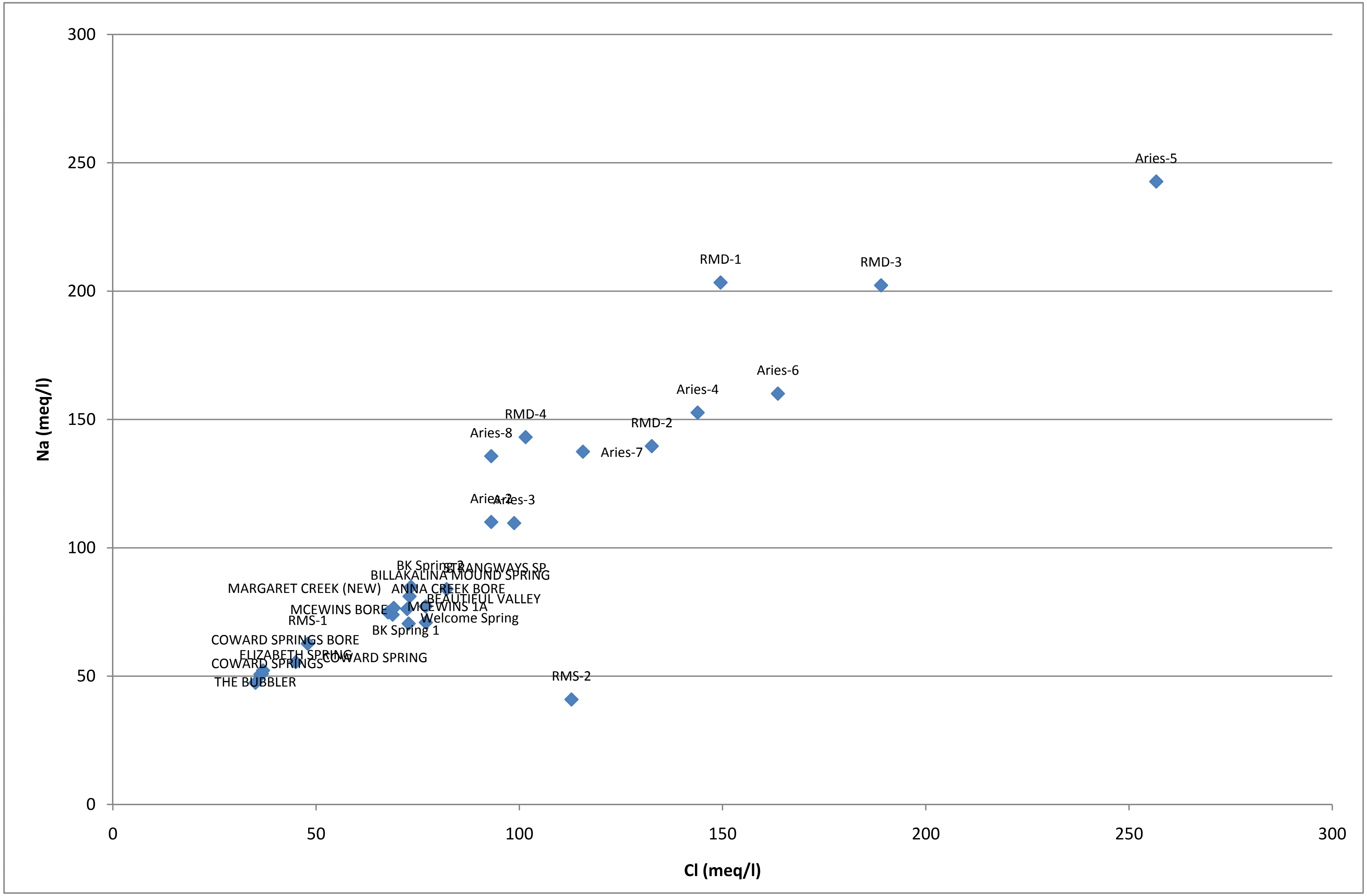

1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Na/Cl (meq/l)
0
5000
10000
15000
20000
25000
TDS (mg/l)
COWARD SPRINGS BORE
COWARD SPRINGS
ELIZABETH SPRING
THE BUBBLER
RMS-1
COWARD SPRING
BK Spring 2
MARGARET CREEK (NEW)
BILLAKALINA MOUND SPRING
MCEWINS BORE
MCEWINS 1A
BEAUTIFUL VALLEY
STRANGWAYS SP.
ANNA CREEK BORE
BK Spring 1
Welcome Spring
RMS-2
Aries-8
RMD-4
RMD-1
Aries-2
Aries-7
Aries-3
RMD-2
Aries-4
RMD-3
Aries-6
Aries-5

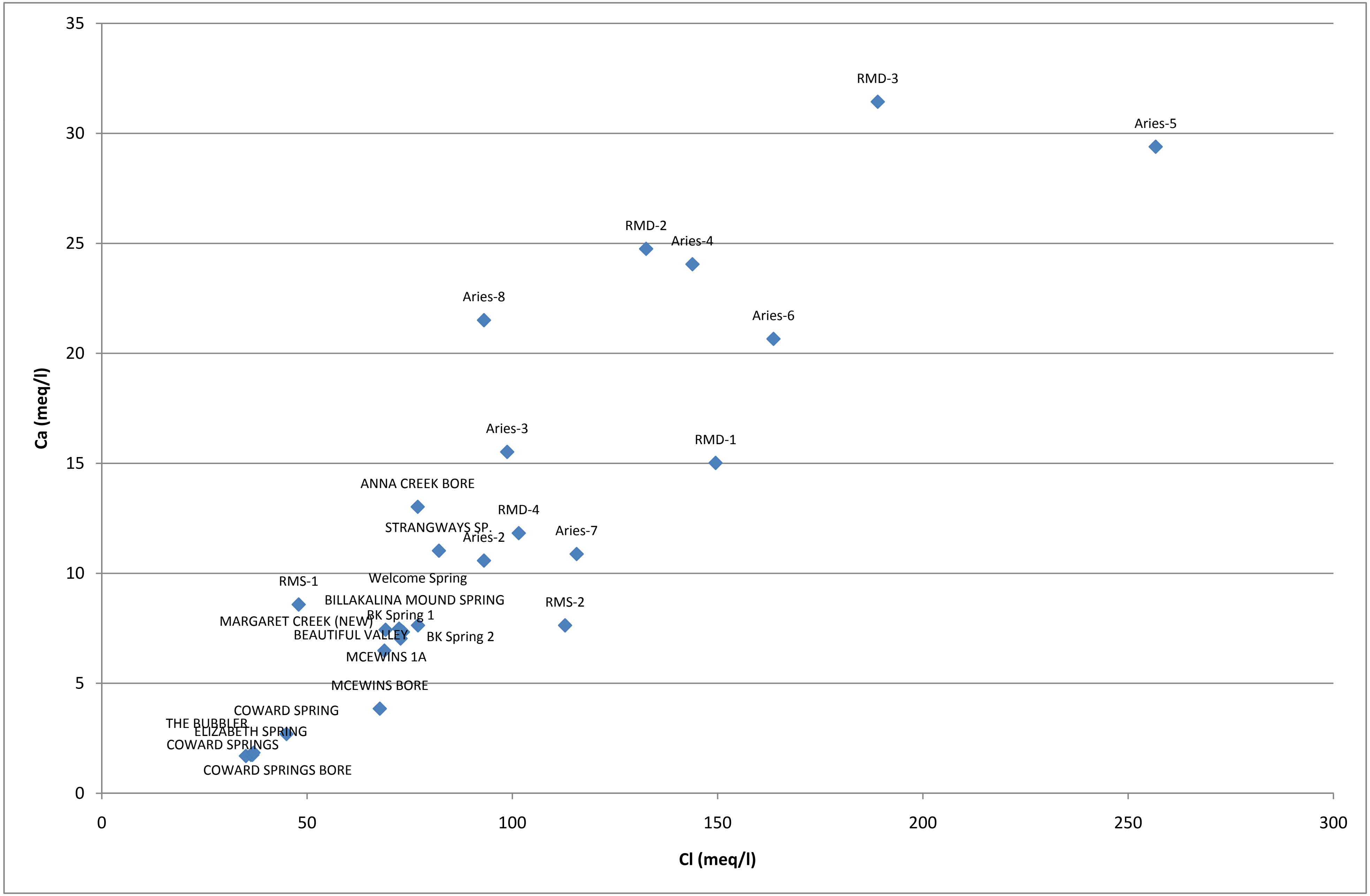

Cl/HCO3 (meq/l)
70
60
50
40
30
20
10
0
Aries-5
RMD-3
Aries-6
RMS-1
Aries-4
Aries-7
Aries-2
Aries-3
RMD-4
Welcome Spring
Aries-8
STRANGWAYS SP.
RMD-2
BEAUTIFUL VALLEY
BK Spring 1
BILLAKALINA MOUND SPRING
RMD-1
MCEWINS 1A
MARGARET CREEK (NEW)
BK Spring 2
RMS-2
COWARD SPRING
THE BUBBLER
ELIZABETH SPRING
COWARD SPRINGS
COWARD SPRINGS BORE
0
5000
10000
15000
20000
25000
TDS (mg/l)


SO4 (meq/l)
Cl (meq/l)
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
RMD-2
Aries-5
RMD-3
Aries-4
Aries-6
Aries-3
Aries-7
Aries-8
RMD-4
RMS-2
RMD-1
ANNA CREEK BORE
RMS-1
STRANGWAYS SP.
BILLAKALINA MOUND SPRING
BK Spring 2
MCEWINS BORE
BK Spring 1
BEAUTIFUL VALLEY
COWARD SPRING
Welcome Spring
MCEWINS 1A
MARGARET CREEK (NEW)
THE BUBBLER
ELIZABETH SPRING
COWARD SPRINGS
COWARD SPRINGS BORE

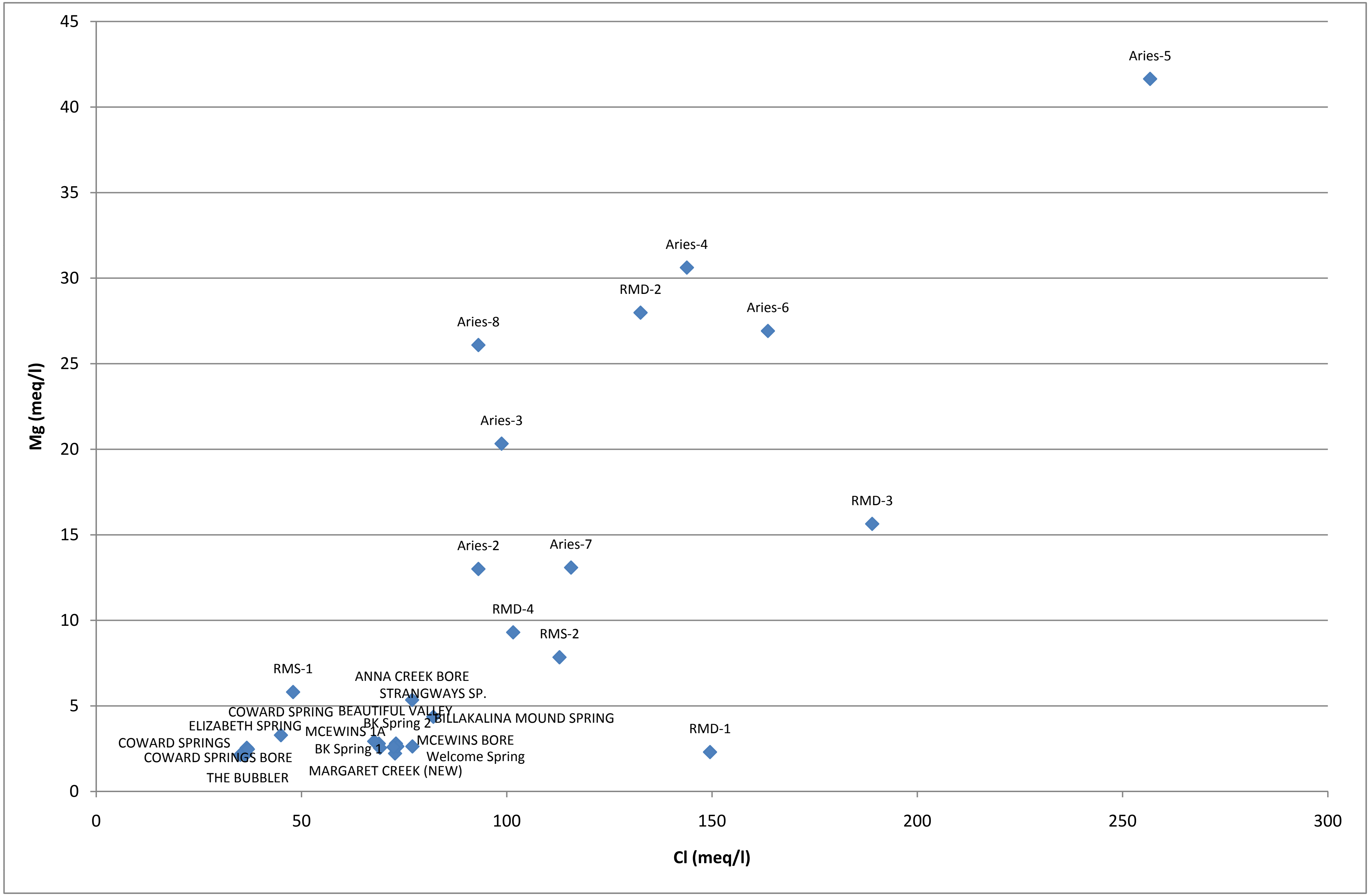

Total cations (meq/l)
Cl+SO4 (meq/l)
0
50
100
150
200
250
300
350
0
50
100
150
200
250
300
350
Aries-5
RMD-3
RMD-1
Aries-4
Aries-6
RMD-2
Aries-8
RMD-4
Aries-7
Aries-3
Aries-2
STRANGWAYS SP.
BK Spring 2
ANNA CREEK BORE
BILLAKALINA MOUND SPRING
BEAUTIFUL VALLEY
MARGARET CREEK (NEW)
RMS-1
BK Spring 1
Welcome Spring
MCEWINS 1A
MCEWINS BORE
COWARD SPRING
ELIZABETH SPRING
COWARD SPRINGS BORE
COWARD SPRINGS
THE BUBBLER
RMS-2

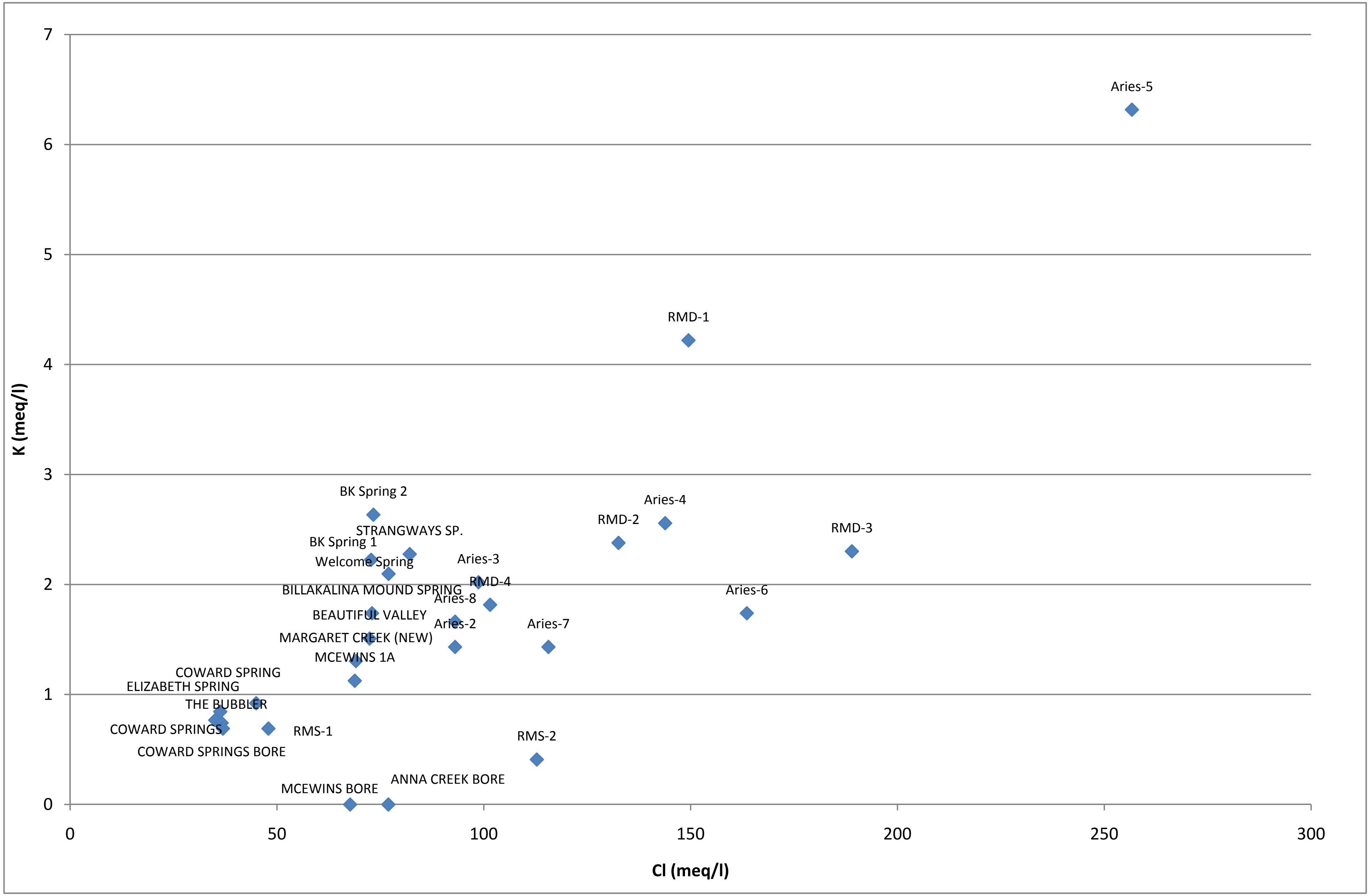

Ca+Mg+K/Cl+SO4 (meq/l)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
50
100
150
200
250
300
350
Cl+SO4 (meq/l)
Aries-8
Aries-4
Aries-3
RMD-2
Aries-6
Aries-5
RMS-1
RMD-3
Aries-2
ANNA CREEK BORE
STRANGWAYS SP.
RMD-4
Aries-7
MARGARET CREEK (NEW)
BK Spring 2
BILLAKALINA MOUND SPRING
COWARD SPRING
BK Spring 1
COWARD SPRINGS BORE
BEAUTIFUL VALLEY
Welcome Spring
COWARD SPRINGS
RMD-1
RMS-2
ELIZABETH SPRING
MCEWINS 1A
THE BUBBLER
MCEWINS BORE

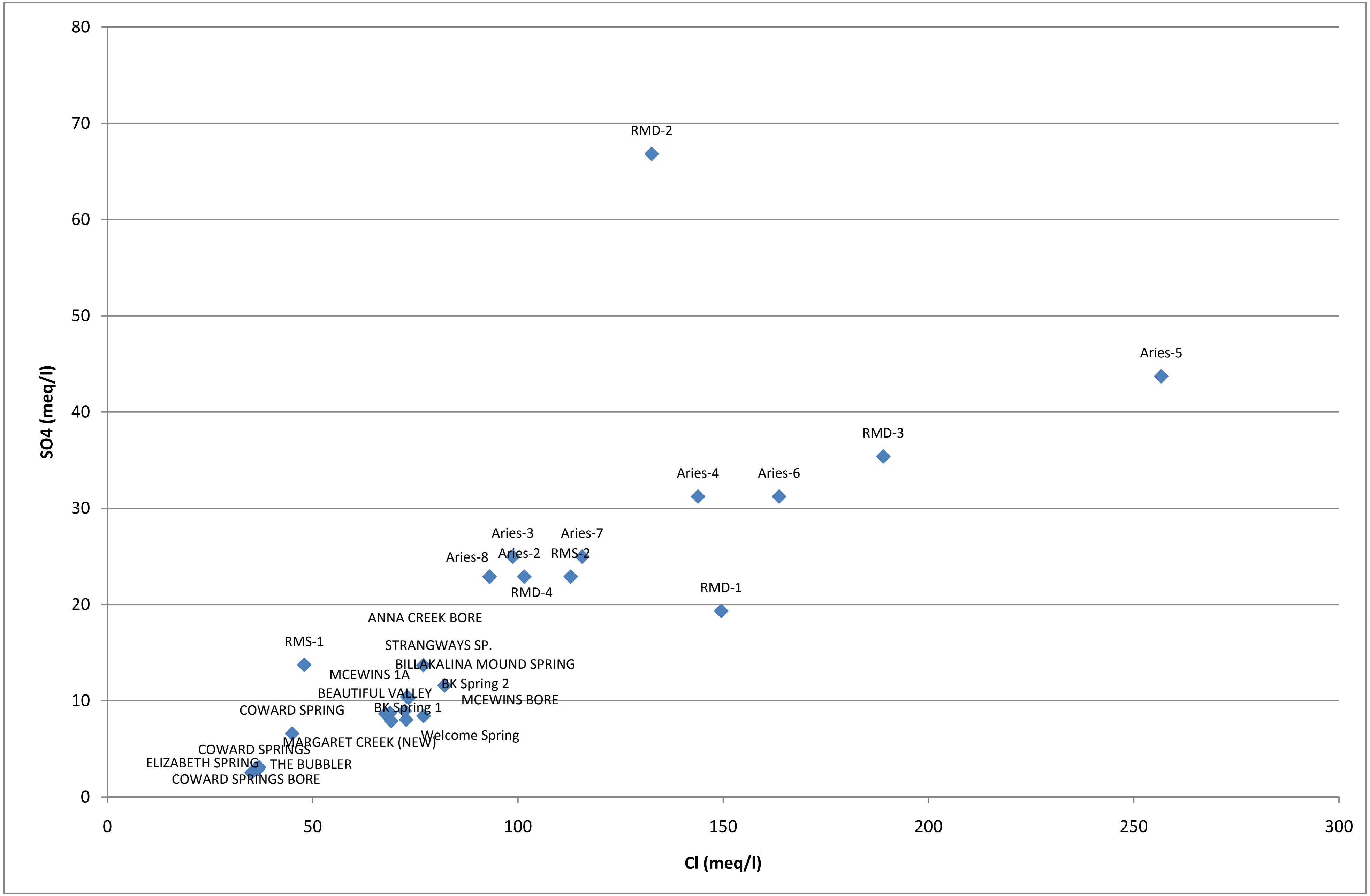

Na (meq/l)
Cl (meq/l)
0
50
100
150
200
250
300
0
50
100
150
200
250
300
Aries-5
RMD-1
RMD-3
Aries-6
Aries-4
RMD-4
RMD-2
Aries-8
Aries-7
Aries-2
Aries-3
BK Spring 2
STRANGWAYS SP
BILLAKALINA MOUND SPRING
MARGARET CREEK (NEW)
ANNA CREEK BORE
BEAUTIFUL VALLEY
MCEWINS BORE
MCEWINS 1A
Welcome Spring
RMS-1
BK Spring 1
COWARD SPRINGS BORE
ELIZABETH SPRING
COWARD SPRING
COWARD SPRINGS
THE BUBBLER
RMS-2

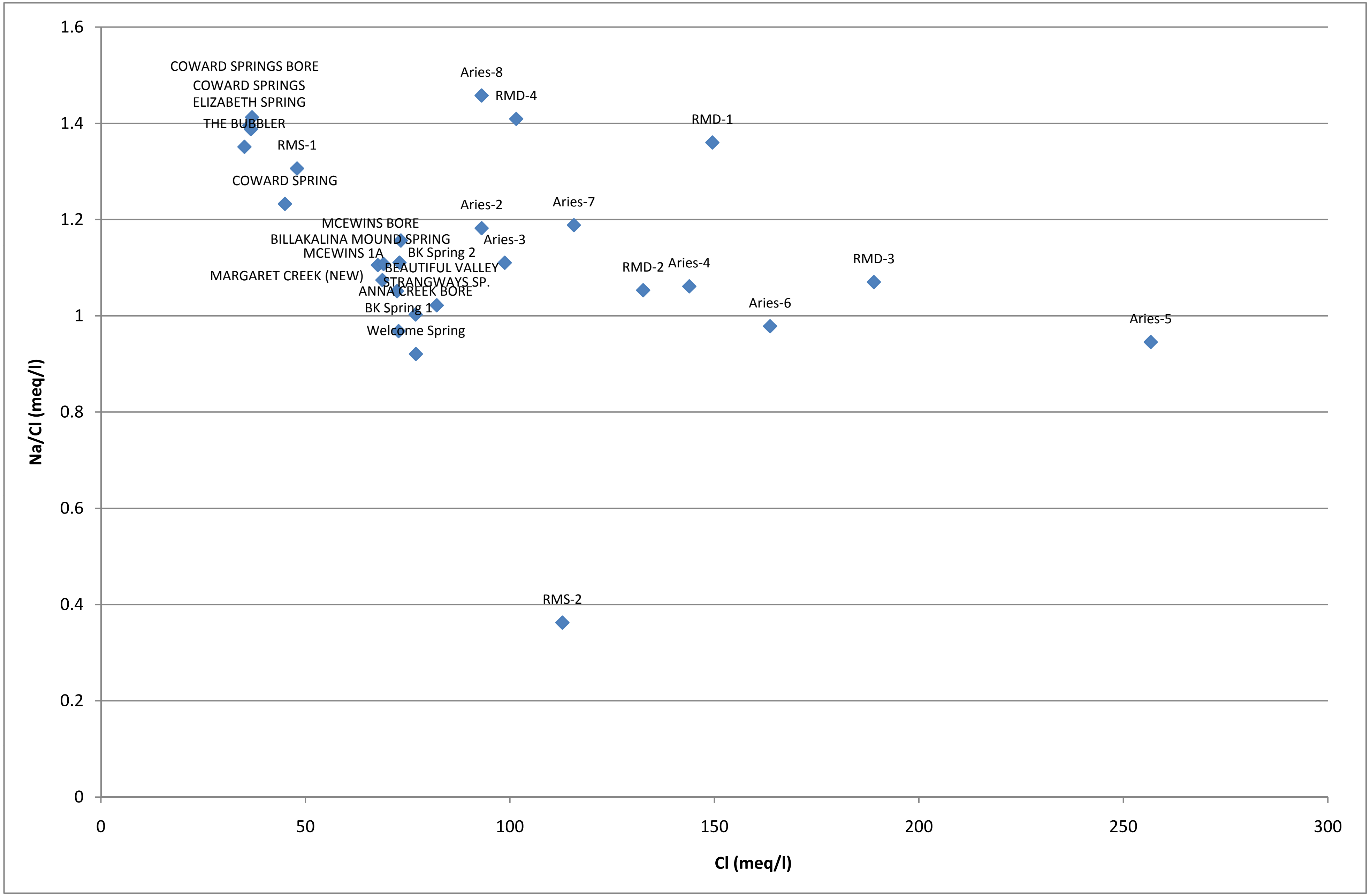


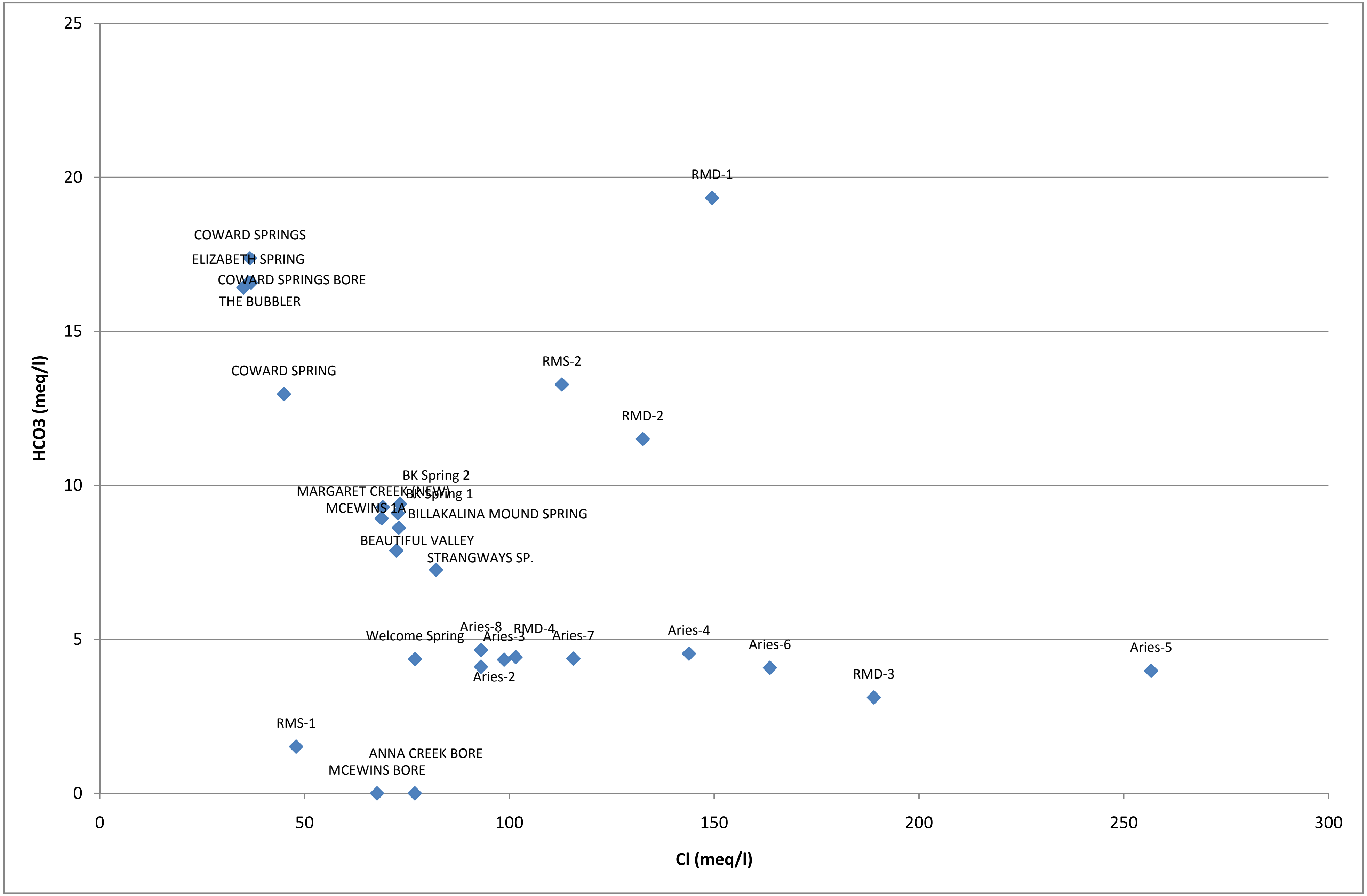
35
30
25
20
15
10
5
0
Ca (meq/l)
RMD-3
Aries-5
RMD-2
Aries-4
Aries-8
Aries-6
Aries-3
RMD-1
ANNA CREEK BORE
RMD-4
STRANGWAYS SP.
Aries-2
Aries-7
RMS-1
Welcome Spring
BILLAKALINA MOUND SPRING
RMS-2
MARGARET CREEK (NEW)
BK Spring 1
BEAUTIFUL VALLEY
BK Spring 2
MCEWINS 1A
MCEWINS BORE
COWARD SPRING
THE BUBBLER
ELIZABETH SPRING
COWARD SPRINGS
COWARD SPRINGS BORE
0
50
100
150
200
250
300
Cl (meq/l)

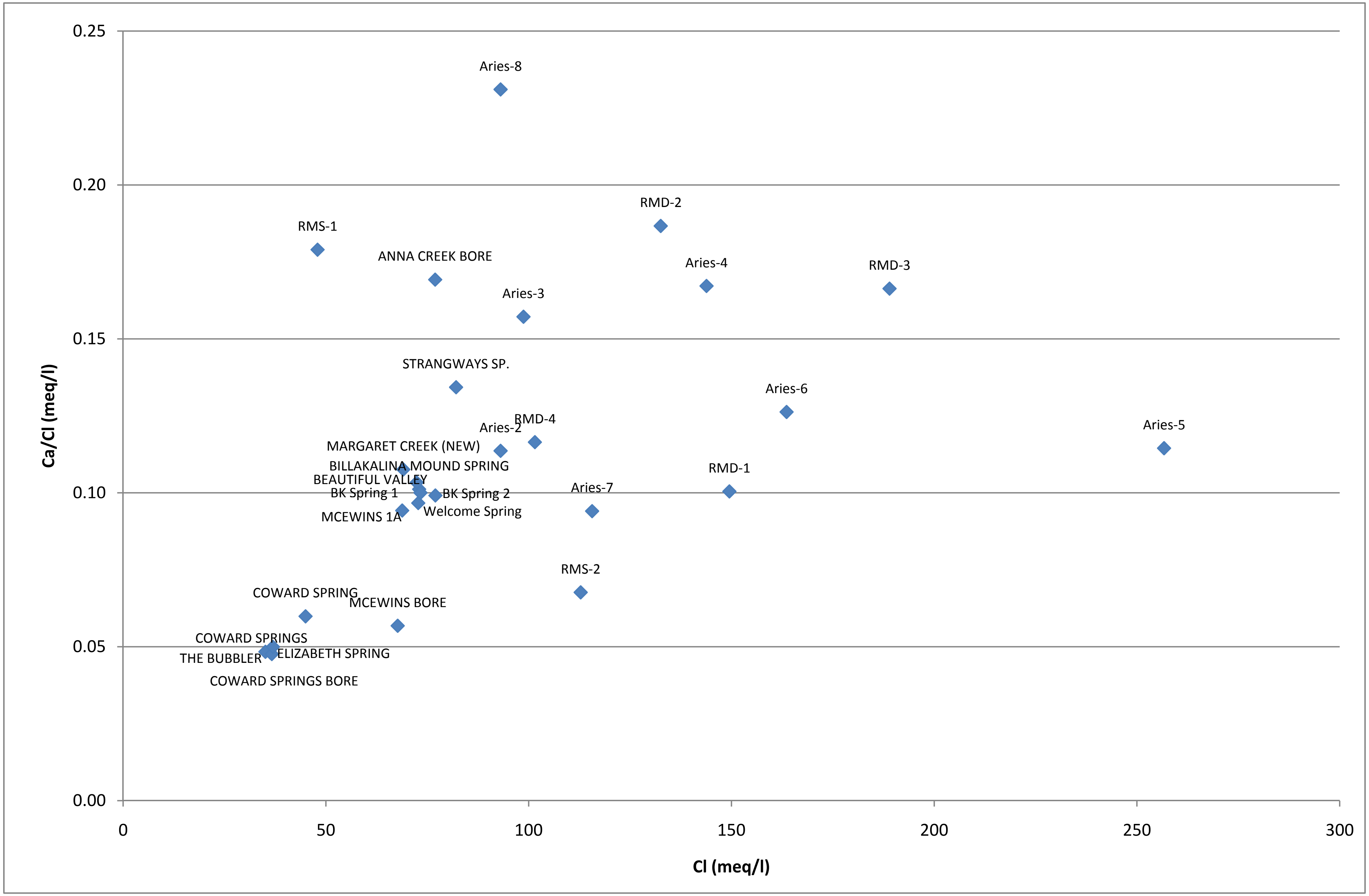

Mg (meq/l)
45
40
35
30
25
20
15
10
5
0
0
50
100
150
200
250
300
Cl (meq/l)
Aries-5
Aries-4
RMD-2
Aries-6
Aries-8
Aries-3
RMD-3
Aries-2
Aries-7
RMD-4
RMS-2
RMS-1
ANNA CREEK BORE
STRANGWAYS SP.
COWARD SPRING
BEAUTIFUL VALLEY
BILLAKALINA MOUND SPRING
ELIZABETH SPRING
BK Spring 2
MCEWINS 1A
RMD-1
COWARD SPRINGS
MCEWINS BORE
BK Spring 1
COWARD SPRINGS BORE
Welcome Spring
MARGARET CREEK (NEW)
THE BUBBLER

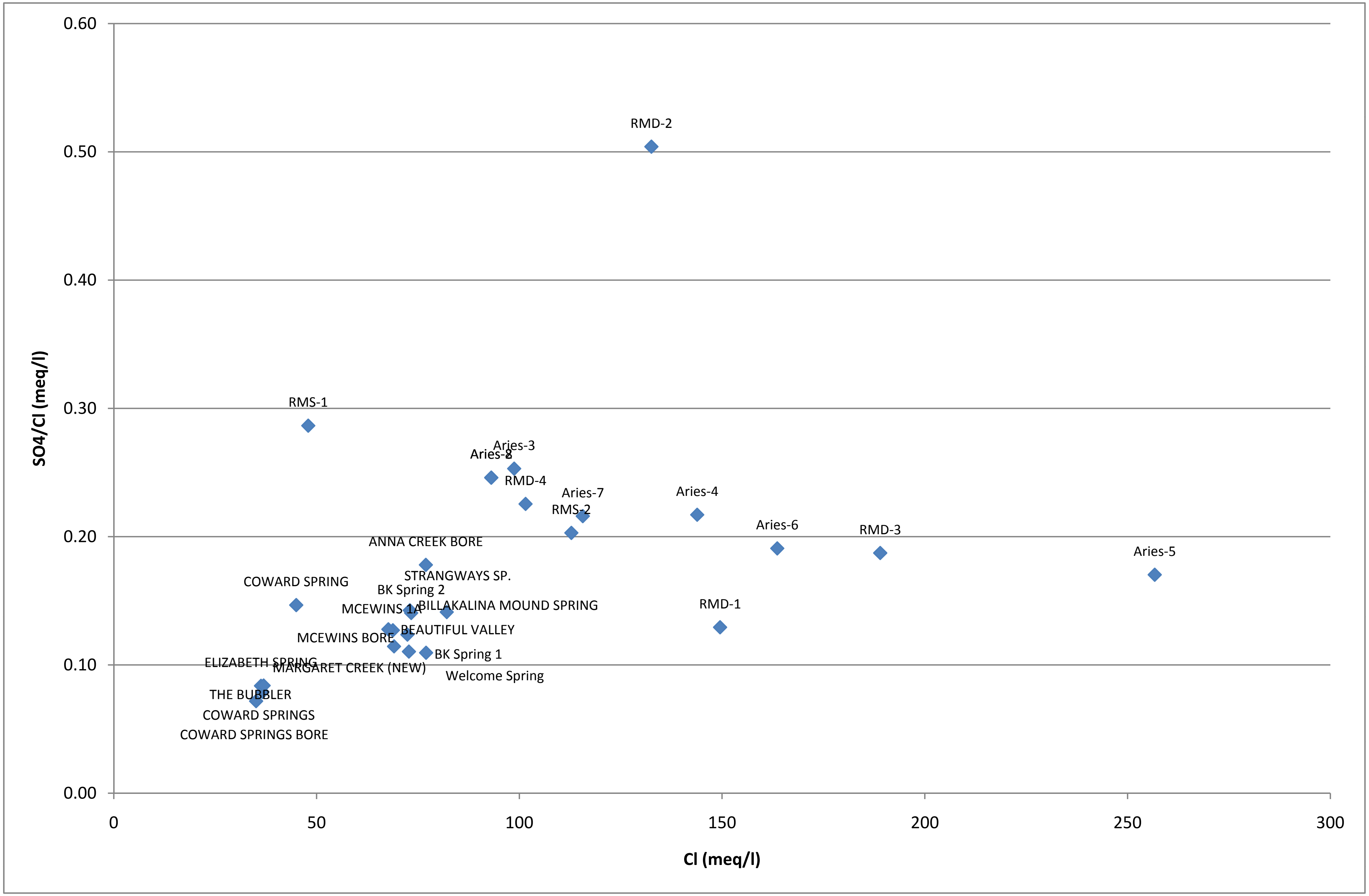

K (meq/l)
Cl (meq/l)
0
1
2
3
4
5
6
7
0
50
100
150
200
250
300
Aries-5
RMD-1
BK Spring 2
STRANGWAYS SP.
BK Spring 1
Welcome Spring
Aries-3
RMD-4
BILLAKALINA MOUND SPRING
Aries-8
BEAUTIFUL VALLEY
Aries-2
MARGARET CREEK (NEW)
MCEWINS 1A
COWARD SPRING
ELIZABETH SPRING
THE BUBBLER
COWARD SPRINGS
RMS-1
COWARD SPRINGS BORE
MCEWINS BORE
ANNA CREEK BORE
RMS-2
Aries-7
RMD-2
Aries-4
RMD-3
Aries-6


SO4 (meq/l)
80
70
60
50
40
30
20
10
0
Cl (meq/l)
0
50
100
150
200
250
300
RMD-2
Aries-5
RMD-3
Aries-4
Aries-6
Aries-3
Aries-7
Aries-8
Aries-2
RMS-2
RMD-4
RMD-1
ANNA CREEK BORE
RMS-1
STRANGWAYS SP.
BILLAKALINA MOUND SPRING
MCEWINS 1A
BK Spring 2
BEAUTIFUL VALLEY
MCEWINS BORE
COWARD SPRING
BK Spring 1
Welcome Spring
MARGARET CREEK (NEW)
COWARD SPRINGS
ELIZABETH SPRING
THE BUBBLER
COWARD SPRINGS BORE


Na/Cl (meq/l)
Cl (meq/l)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
COWARD SPRINGS BORE
COWARD SPRINGS
ELIZABETH SPRING
THE BUBBLER
RMS-1
COWARD SPRING
Aries-8
RMD-4
RMD-1
Aries-2
Aries-7
MCEWINS BORE
BILLAKALINA MOUND SPRING
Aries-3
MCEWINS 1A
BK Spring 2
MARGARET CREEK (NEW)
BEAUTIFUL VALLEY
STRANGWAYS SP.
ANNA CREEK BORE
RMD-2
Aries-4
RMD-3
BK Spring 1
Aries-6
Welcome Spring
Aries-5
RMS-2


HCO3 (meq/l)
Cl (meq/l)
0
5
10
15
20
25
0
50
100
150
200
250
300
RMD-1
COWARD SPRINGS
ELIZABETH SPRING
COWARD SPRINGS BORE
THE BUBBLER
COWARD SPRING
RMS-2
RMD-2
BK Spring 2
MARGARET CREEK (NEW)
BK Spring 1
MCEWINS 1A
BILLAKALINA MOUND SPRING
BEAUTIFUL VALLEY
STRANGWAYS SP.
Aries-8
Welcome Spring
Aries-3
RMD-4
Aries-7
Aries-4
Aries-6
Aries-5
Aries-2
RMD-3
RMS-1
ANNA CREEK BORE
MCEWINS BORE


Aries-8
RMD-2
RMS-1
ANNA CREEK BORE
Aries-4
RMD-3
Aries-3
STRANGWAYS SP.
Aries-6
Aries-2
RMD-4
Aries-5
MARGARET CREEK (NEW)
BILLAKALINA MOUND SPRING
RMD-1
BEAUTIFUL VALLEY
BK Spring 1
BK Spring 2
Aries-7
Welcome Spring
MCEWINS 1A
RMS-2
COWARD SPRING
MCEWINS BORE
COWARD SPRINGS
THE BUBBLER
ELIZABETH SPRING
COWARD SPRINGS BORE
Ca/Cl (meq/l)
0.25
0.20
0.15
0.10
0.05
0.00
0
50
100
150
200
250
300
Cl (meq/l)



RMD-2
RMS-1
Aries-3
Aries-8
RMD-4
Aries-7
RMS-2
Aries-4
Aries-6
RMD-3
Aries-5
ANNA CREEK BORE
STRANGWAYS SP.
COWARD SPRING
BK Spring 2
MCEWINS 1A
BILLAKALINA MOUND SPRING
RMD-1
BEAUTIFUL VALLEY
MCEWINS BORE
BK Spring 1
ELIZABETH SPRING
MARGARET CREEK (NEW)
Welcome Spring
THE BUBBLER
COWARD SPRINGS
COWARD SPRINGS BORE
SO4/Cl (meq/l)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
50
100
150
200
250
300
Cl (meq/l)

Table C.1 ^{36}Cl groundwater concentrations for regional aquifers

Aquifer system	Sample location	Cl (mg/L)	^{36}Cl:Cl ($\times10^{-15}$)	^{36}Cl atoms/L ($\times10^{6}$)
artesian Eromanga (GAB)	Various [1]	6,300	7.5	0.55
non-artesian Eromanga	Stock well (Millers Creek) [2]	2,000	94	3.19
Arckaringa Basin	Deep Boorthanna (Aries AB) [2]	6,020	39	3.99
Arckaringa Basin	Shallow Boorthanna (Virgo 9) [2]	23,000	7	2.74
Stuart Shelf	Tent Hill Aquifer (TPW4) [3]	32,000	28	15.22
Stuart Shelf	Andamooka Limestone Aquifer (MAR4) [3]	22,500	39	14.91
Adelaide Geosyncline	Adelaide Geosyncline (RT9a) [3]	17,500	53	15.76
Adelaide Geosyncline (Amberoona Formation)	Adelaide Geosyncline (RT7a) [3]	31,900	34	18.42
Stuart Shelf / Adelaide Geosyncline	Yarra Wurta Springs [3]	30,500	35	18.13

Notes:
1. Pers. comm, Rein Habermahl, Oct. 2007
2. OZ Minerals 2009
3. SKM/REM 2008

Attachment D
Total suspended solids analytical data

Table D.1 Reported TSS values for wells sampled multiple times

Sample	Drilled		Airlifted		Bailed		Pumped	
ID	TSS (mg/L)	Depth	TSS (mg/L)	Depth	TSS (mg/L)	Depth	TSS (mg/L)	Depth
MXTB-07a	810	106m (€a)	13	98-104m (€a)	10	98-104m (€a)		
MXTB-07b	11	186m (€a)	4	166-172m (€a)	12	166-172m (€a)		
MXTB-10a	221	130m (€a)	12	136-142m (€a)	10	136-142m (€a)		
MXTB-10b	478	264m (€a)			30	240-246m (€a)		
MXTB-13A	1560	100m (€a)	**18**	90-96m (€a)				
MXTB-13B	145	192m (€a)	**10**	158-164m (€a)				
MAR3			445	228m (€a)			**318**	88-228m (€a)
MAR4			90	186m (€a)			**107**	84-186m (€a)
TPW-1			97	216m (Pwc)			**258**	178-216m (Pwc)
RT-2a	77	25-295m (€a/Pws)	**52**	113.5-119.5m (€a)				
PT-6	2070	208m (Pwc)	**74**	200-206m (Pwc)				
PT-5a			4740	Open Hole Airlift 70-268.3m (Pws/Pwc)				
PT-5a			**90**	Constructed Airlift 250-262m (Pwc)				

Notes: €a ; Andamooka Limestone Pws; Arcoona Quartzite
Pwc; Corraberra Sandstone

- **Table D.2 TSS concentrations and sampled aquifers**

Sample ID	Date Sampled	Sampling Method	Depth/Construction	TSS (mg/L)	Geology
LR-10	23/07/2007	Airlifted	Screened interval	98	€a
MAR2	19/02/2008	Airlifted	Open Hole	310	€a
MAR2	7/12/2007	Airlifted	Drilled depth	379	€a
MAR2-10a	6/12/2007	Airlifted	Screened interval	134	€a
MAR2-10b	6/12/2007	Airlifted	Screened interval	563	€a
MAR2-50	5/12/2007	Airlifted	Screened interval	90	€a
MAR2-50b	5/12/2007	Airlifted	Screened interval	704	€a
MAR3	23/01/2008	Airlifted	Open Hole	445	€a
MAR3	5/02/2008	Pumped	Open Hole	318	€a
MAR3-20	22/01/2008	Airlifted	Screened interval	614	€a
MAR4	12/12/2007	Airlifted	Open Hole	90	€a
MAR4	27/01/2008	Pumped	Open Hole	107	€a
MXBT-10b	1/11/2008	Airlifted	Screened interval	16	€a
MXTB-07	4/11/2008	Drilled	Open Hole	810	€a
MXTB-07	4/11/2008	Drilled	Open Hole	11	€a
MXTB-07a	9/11/2008	Airlifted	Screened interval	13	€a
MXTB-07a	15/11/2008	Bailing	Screened interval	10	€a
MXTB-07b	9/11/2008	Airlifted	Screened interval	4	€a
MXTB-07b	15/11/2008	Bailing	Screened interval	12	€a
MXTB-09a	20/11/2008	Bailing	Screened interval	15	€a
MXTB-09b	20/11/2008	Bailing	Screened interval	14	€a
MXTB-10	27/10/2008	Drilled	Open Hole	221	€a
MXTB-10	27/10/2008	Drilled	Open Hole	478	€a
MXTB-10a	1/11/2008	Airlifted	Screened interval	12	€a
MXTB-10a	9/11/2008	Bailing	Screened interval	10	€a
MXTB-10b	9/11/2008	Bailing	Screened interval	30	€a
MXTB-11b	8/12/2008	Bailing	Screened interval	115	€a
MXTB-12a	30/11/2008	Bailing	Screened interval	40	€a
MXTB-12b	30/11/2008	Bailing	Screened interval	38	€a
MXTB-13	17/10/2008	Drilled	Open Hole	1560	€a
MXTB-13	18/10/2008	Drilled	Open Hole	145	€a
MXTB-13A	24/10/2008	Bailing	Screened interval	18	€a
MXTB-13B	24/10/2008	Bailing	Screened interval	10	€a
MXTB-14a	16/10/2008	Bailing	Screened interval	30	€a
MXTB-14b	16/10/2008	Bailing	Screened interval	31	€a

Table D.2 TSS concentrations and sampled aquifers (cont.)

Sample ID	Date Sampled	Sampling Method	Depth/Construction	TSS (mg/L)	Geology
PT-1	15/04/2007	Airlifted	Screened interval	198	Pwc
PT-12	21/04/2007	Airlifted	Open hole	206	Pws/Pwc
PT-12	23/04/2007	Airlifted	Screened interval	5	Pwc
PT-17	25/02/2007	Airlifted	Screened interval	72	Pwc
PT-18	13/02/2007	Airlifted	Screened interval	61	Pwc
PT-2	14/04/2007	Airlifted	Screened interval	40	Pws
PT-24a	14/03/2007	Airlifted	Screened interval	10	€a
PT-24b	29/03/2007	Airlifted	Screened interval	36	Pwc
PT-3/4b	13/04/2007	Airlifted	Screened interval	112	Pws
PT-40	7/02/2008	Airlifted	Screened interval	4690	€a
PT-42	28/02/2008	Airlifted	Open Hole	170	€a
PT-44	22/02/2008	Airlifted	Open Hole	108	€a
PT-45	18/02/2008	Airlifted	Open Hole	136	€a
PT-48	5/03/2008	Airlifted	Open Hole	526	€a
PT-51	16/03/2008	Airlifted	Open Hole	144	€a
PT-5a	9/12/2006	Airlifted	Open Hole	4740	Pws/Pwc
PT-5a	12/12/2006	Airlifted	Screened interval	90	Pwc
PT-5d	29/01/2007	Airlifted	Screened interval	108	Pwc
PT-6	14/01/2007	Drilled	Screened interval	2070	Pws
PT-6	15/01/2007	Airlifted	Screened interval	74	Pwc
PT-60	11/03/2008	Airlifted	Open Hole	60	€a
PT-61	15/02/2008	Airlifted	Open Hole	66	€a
PT-66	31/01/2008	Airlifted	Open Hole	420	€a
PT-7	27/03/2007	Airlifted	Screened interval	48	Pwc
PT-9	6/02/2007	Airlifted	Screened interval	55	Pwc
RT-1	24/07/2007	Airlifted	Screened interval	200	Pwc
RT-2	29/06/2007	Airlifted	Screened interval	52	€a
RT-2a	11/12/2006	Drilled	Open Hole	77	€a/Pws
RT-2b	12/07/2007	Airlifted	Screened interval	596	Pws (red)
RT-4a	22/08/2007	Airlifted	Screened interval	200	€a
RT-4b	22/08/2007	Airlifted	Screened interval	536	Pwx
RT-5a	7/08/2007	Airlifted	Screened interval	160	€a
RT-5b	9/08/2007	Airlifted	Screened interval	458	€a (lower)
RT-5c	9/08/2007	Airlifted	Screened interval	1150	Pwa
RT-7a	24/08/2007	Airlifted	Screened interval	608	Pfa (upper)
RT-7b	24/08/2007	Airlifted	Screened interval	296	Pfa (lower)
RT-9	11/01/2007	Airlifted	Screened interval	3160	Pwr
TPW-1	8/02/2007	Airlifted	Screened interval	97	Pwc
TPW-1	11/04/2007	Pumped	Screened interval	258	Pwc
TPW-2	17/04/2007	Pumped	Screened interval	64	Pwc
TPW-3	24/04/2007	Pumped	Screened interval	36	Pwc