TECHNICAL REPORT

SOUTH AUSTRALIA–VICTORIA BORDER ZONE GROUNDWATER INVESTIGATION:

RESULTS OF THE PUMPING TEST PROGRAM

2011/23

Government of South Australia
Department for Water

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FOREWORD

South Australia's Department for Water leads the management of our most valuable resource—water.

Water is fundamental to our health, our way of life and our environment. It underpins growth in population and our economy—and these are critical to South Australia's future prosperity.

High quality science and monitoring of our State's natural water resources is central to the work that we do. This will ensure we have a better understanding of our surface and groundwater resources so that there is sustainable allocation of water between communities, industry and the environment.

Department for Water scientific and technical staff continue to expand their knowledge of our water resources through undertaking investigations, technical reviews and resource modelling.

Scott Ashby
CHIEF EXECUTIVE
DEPARTMENT FOR WATER

ACKNOWLEDGEMENTS

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Australian Government

National Water Commission

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SUMMARY

Groundwater is the major water resource along the Victorian–South Australian border and is used for irrigation, industrial, stock and town water supplies. Groundwater flows through two major regional systems; an upper unconfined Tertiary Limestone Aquifer (TLA) and a deeper Tertiary Confined Sand Aquifer (TCSA). The Tertiary Confined Sand Aquifer is known as the Dilwyn Formation in the Otway Basin and the Renmark Group in the Murray Basin. The Tertiary Limestone Aquifer is generally known as the Gambier Limestone in the Otway Basin and the Murray Group Limestone in the Murray Basin. In some parts of the study area it also comprises the Pleistocene aeolianites of the Bridgewater Formation.

Extensive faulting occurs through the south east of South Australia and across the border between South Australia and Victoria. Although faulting has a significant impact on lateral flow in both unconfined and confined aquifers, its impact on vertical flow had not been determined. Vertical flow between the Tertiary Limestone Aquifer (TLA) and the Tertiary Confined Sand Aquifer is likely to be significant however this is not well understood.

The National Water Commission provided funding for a joint interstate study into this relationship between the TLA and the TCSA. This investigation was a cooperative venture between the Department for Water (DFW) in South Australia and the Department of Sustainability and Environment (DSE) in Victoria.

In total eight sites were aquifer tested across the two states, however this report details the results at the four South Australian locations. Testing to determine the degree of hydraulic connectivity between the two aquifer systems was the major objective. At each location, observation wells had been constructed into each of the aquifer sub units. Generally the completions were in either a limestone or sandstone unit, the transitional sub unit of the Mepunga Formation and the TCSA clay aquitard and sand aquifer.

The results of the aquifer test data for sites SA1, SA2, SA3 and SA4 indicate that the confined aquifer at these sites can be leaky. The vertical hydraulic conductivities for the aquitard at sites SA1, SA2, SA3 and SA4 were 2.7x10-3 m/d, 4.36x10-2 m/d, 3.13x10-4 m/d and 2.87x10-3 respectively.

The results also indicate the presence of a boundary within the TCSA at site SA1, which could be due to a zone of lower permeability.

The TCSA observation well at site SA2 showed a different response to pumping of the production well from those seen at sites SA1, SA3 and SA4. The drawdown data at this site showed an early steady decline followed by a slower rate of declining for a longer period of time. After this gently-sloping trend, the decline continued with steeper rates.

The Noordburgum effect (which resulted in a rise in the water level in the upper aquitard and the un-pumped wells during the pumping of the production well) was noticed in the observation wells monitoring the unconfined (TLA) observation well at site SA1 and the aquitard observation wells at sites SA3 and SA4 and is a response to the mechanical stress which propagates faster than the hydraulic drawdown in these units.

The analysis of the pumping test data from site SA4 indicates the importance of recording the response of the water level during the early time in a pumping test, which can affect the interpretation and the results of the analysis.

1. INTRODUCTION

The National Water Commission provided funding for a joint interstate study into the relationship between Tertiary Limestone Aquifer (TLA) and the Tertiary Confined Sand Aquifer (TCSA). This investigation was a cooperative venture between the Department for Water (DFW) in South Australia and the Department of Sustainability and Environment (DSE) in Victoria. Results of the program have been reported to the Border Groundwater Agreement Review Committee (BGARC).

The investigation area covers Zones 1A, 1B and parts of 2A and 2B of the Designated Area between South Australia and Victoria (Fig. 1). The study area contains thin unconfined aquifer sediments which overlay a relatively thick (about 300 m) extensive confined sand aquifer. In 2000, DFW carried out an investigation to examine the hydraulic relationship between the two aquifers and estimated recharge rates of the confined aquifer (Brown et al., 2001). The study inferred that recharge to the TCSA is occurring via preferential flow paths (fractures, faults or sinkholes), however the rate of vertical recharge could not quantified.

Land use, along with climate variability, has produced declines in the potentiometric heads in both aquifers. Hydrographs for the TCSA aquifer indicate quick response times to changes in the unconfined TLA aquifer water levels, leading to a suggestion that in certain areas, either direct interconnection maybe occurring, or significant aquifer hydrostatic loading and unloading is the cause of these changes.

The project was instigated to study this possible interaction by examining the different hydrostratigraphy, water chemistries and properties of the confined clay aquitard. The TLA and TCSA aquifers are separated by generally low permeability aquitard. The thickness of the aquitard varies from about two meters to more than ten meters and also varies in composition from fine gritty silty clay to lignitic clay.

Investigation sites were either located close to mapped Tertiary fault alignments as defined from seismic data, or removed from the faulting zones to ascertain any differences in aquifer properties. Site SA2 was drilled directly into an unconfined aquifer groundwater depression which has been associated with confined aquifer recharge.

This report details the results of aquifer tests conducted at the four South Australian sites drilled as part of the project. Sinclair Knight Merz (SKM) has reported the conclusions for the four Victorian sites.

At each South Australian investigation site the following well completions existed:

- TCSA production well
- TCSA observation well
- TCSA aquitard observation well
- Mepunga Formation observation well
- TLA observation well
- At sites SA3 and SA 4, observation wells existed in nested piezometers and gave an ability to monitor the hydrostratigraphy in greater detail.

The aquifer properties were obtained using two aquifer test interpretive packages. These were:

- Clarke's Groundwater Programs
- Aquifer Test Pro 4.2 (Schlumberger).

The aquifer testing consisted of a three-stage step test to obtain a well equation. This was used to determine a pumping rate for the three-day constant rate discharge test (followed by one day recovery). The intention of the constant-rate discharge test was to stress the TCSA and observe if leakage occurred from any of the overlying hydrostratigraphic units.

Understanding the degree of inter-connection between the two aquifers may have implications for resource management.

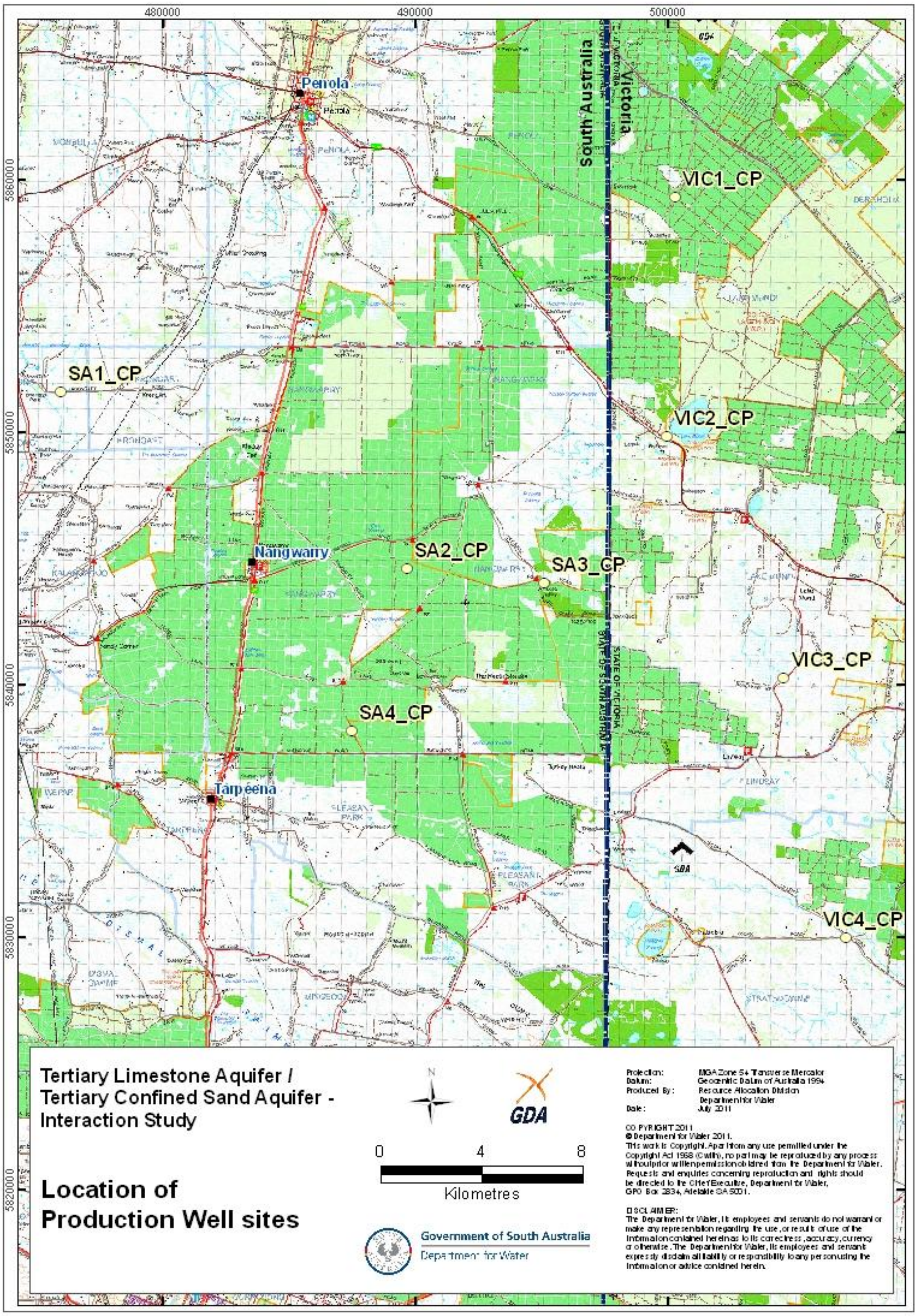


Figure 1 **The location of study sites within the investigation area. Sites SA1, SA2, SA3 and SA4 are in South Australia and VIC1, VIC2, VIC and VIC4 in Victoria**

2. METHODOLOGY

2.1. *AQUIFER TESTING PROCEDURES*

For each of the sites the same testing procedure was undertaken:

- Installation of the pump in the well and trialling of different production rates while recording the water levels. Three rates were selected for the step test to allow the determination of a well equation.
- The following day, a three part step drawdown test was conducted and after completion the results were used for determination of the well equation. A production rate was set for the 72 hour constant rate discharge test. The step test was conducted so that the aquifer could be stressed, but without the pumping level dropping close to the pump intake depth.
- Next morning, the 72 hour constant rate discharge test commenced. After 72 hours, the pump was switched off and aquifer recovery was monitored for a further 24 hours.

The pump was then removed from the well and moved to the next site.

2.2. *WATER LEVEL RECORDING*

The water level recording at each site occurred in two different ways.

- Manual water levels were taken in the TCSA production and observation wells along with other monitoring wells on the site. At sites SA3 and SA4, additional observation wells were monitored.
- Vented data loggers were installed in the observation wells recording a water level every 10 minutes over the 72 hours. A logger was only installed in the production well after cessation of pumping as using a Variable Speed Drive motor connected to the pump, can potentially affect the accuracy of the readings.

These data were processed and used in the analysis and interpretation.

2.3. *BAROMETRIC CORRECTION*

The barometric pressure was recorded at each site for the duration of the aquifer testing. The manually recorded water level data were corrected for barometric pressure and was added to these data logger records at all sites.

2.4. *WELL PERFORMANCE TEST*

A step test was conducted prior to the constant rate pumping test at the SA1, SA2, SA3 and SA4 sites. The information collected from the step test was used to develop the well equation, which relates drawdown to discharge rate and time. The well equation allows for the prediction of the hydraulic performance of the production well and also designing a suitable pumping rate for the long-term constant rate pumping test.

3. RESULTS

3.1. *SITE SA1*

This is the most westerly investigation site in the programme. The wells were located on the southern edge of Krongart Road and positioned in a line from West to East. Figure 2 shows the location and the spatial distribution of the TCSA production well and the observation wells at site SA1.

The summary of the main hydrogeological units at site SA1 is presented in Table 1. Appendix A provides a detailed description of the lithology.

Table 1 Hydrogeological units of site SA1

Depth (m) From	to	Lithologic Description	Thickness (m)
0	1	OVERBURDEN	1
1	6	BRIDGEWATER FORMATION	5
6	15	GAMBIER LIMESTONE	9
15	23	MEPUNGA FORMATION	8
23	30	TCSA – Clay Unit 1	7
30	33	TCSA – Sand Aquifer 1	3
33	34	TCSA – Clay Unit 2	1
34	45	TCSA – Sand Aquifer 2	11
45	51	TCSA – Clay Unit 3	6

The configuration of the production and observation wells at site SA1 is presented in Figure 3. The wells constructed at this site are:

- TCSA production well
- TCSA observation well located 50 metres east of the production well
- Aquitard observation well located 10 metres from the production well
- Mepunga Formation observation well located 5 metres from the production well
- TLA observation well located 5 metres from the production well but to the west.

3.1.1. WATER QUALITY

During the aquifer test, water parameters such as pH, salinity as EC (µS/cm) and temperature were recorded from an inline unit using a TPS 90FL multi-meter data logger. The salinity fluctuated between 770 µS/cm and 788 µS/cm during the course of the test and pH ranged between 7.08 and 7.0 (Appendix B).

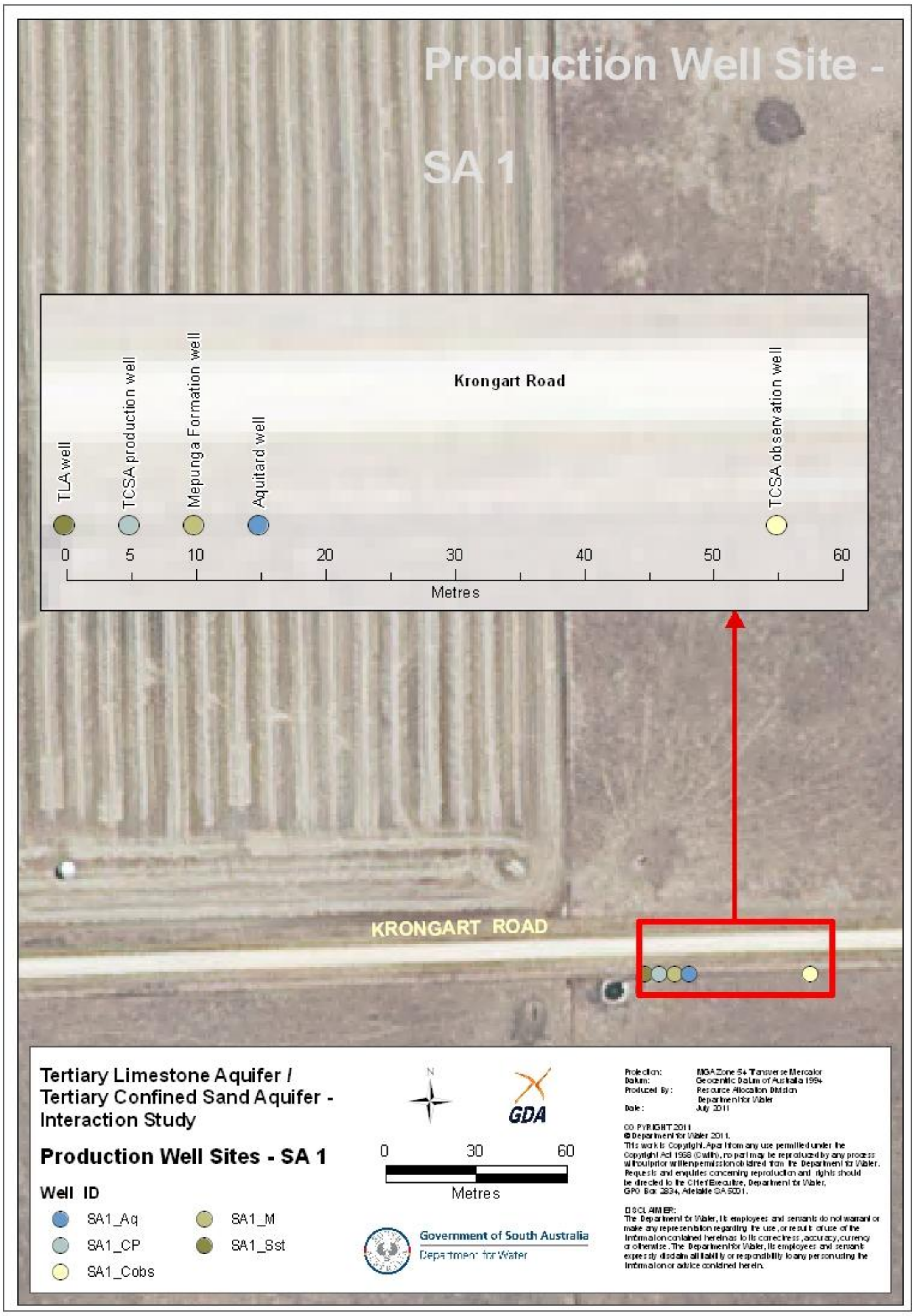


Figure 2 **Map showing the spatial distribution of the TCSA production well and the observations wells at site SA1**

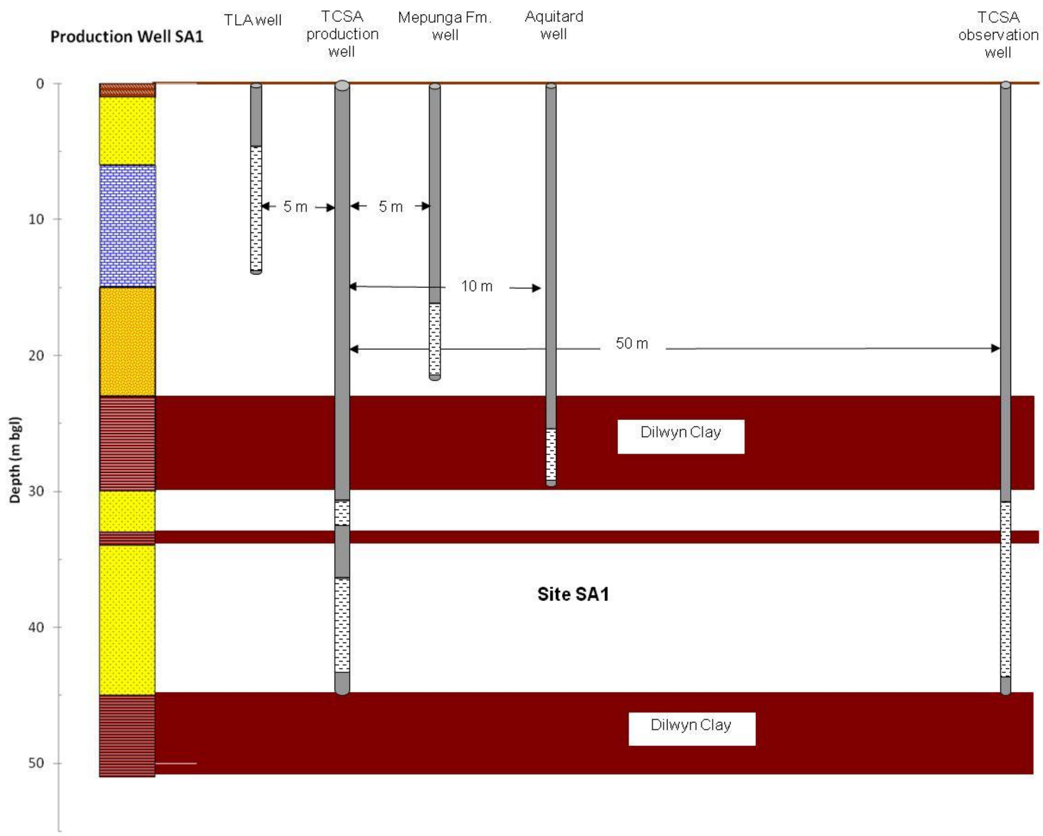


Figure 3 **Schematic cross-section of the lithological units and well configuration at site SA1**

3.1.2. CONSTANT RATE DISCHARGE TEST

The main objective of the constant-rate discharge test was to determine the TCSA hydraulic properties and to assess the response of the aquitard and the upper units to pumping stress.

The test commenced at 10:00 am on 17 June 2011 ran for three days, followed by a one day recovery test. The discharge rate was 30 L/s. Water levels were monitored manually and loggers were installed in the observation wells completed in the TCSA, aquitard, Mepunga Formation and TLA units. Setting the frequency of data logger water level recordings to 10 minute intervals may have compromised the analysis and interpretation of the test data due to the missing of the early time data (0 to 10 min) which may be crucial for the assessment of the aquifer at the early stages. However some adjustment was made by adding the readings from early manual data to the logger records.

Aquifer Test ProV4.2 software (Schlumberger) was used to analyse the constant rate discharge test data.

The observed rise in water level in the TLA observation well during the pumping phase indicates a Noordbergum effect (Kim & Parizek, 1997), in which the response to mechanical stress due to the mechanical propagation (deformation) of the pumping stress is faster than the hydraulic propagation (drawdown) from the pumped aquifer into the adjacent un-pumped aquifer.

The water level response in the Mepunga Formation and the TCSA aquitard had an observed decline in water level after 600 minutes of pumping (Fig. 4).

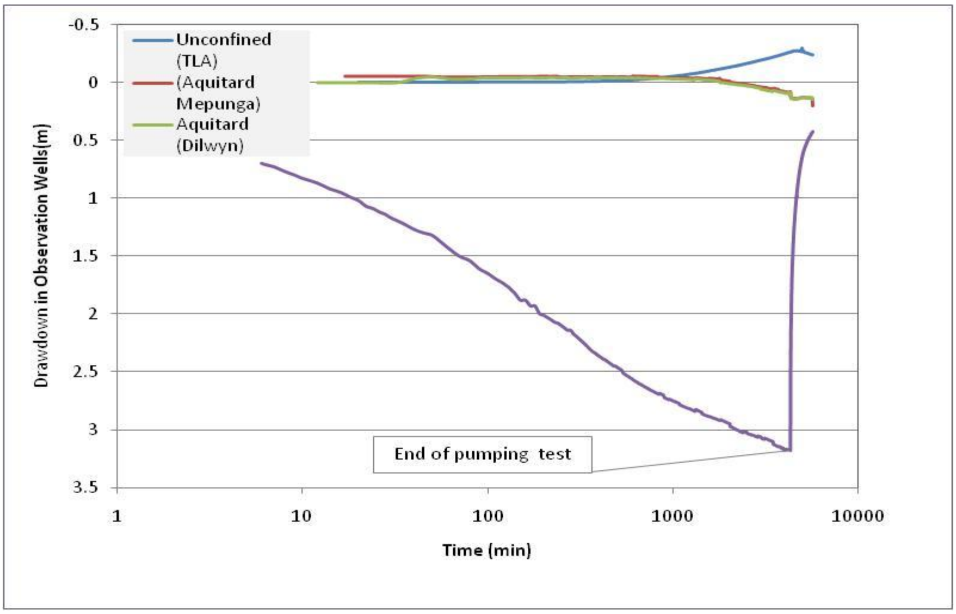


Figure 4 **Drawdown in observation wells during pumping at sites SA1**

The time drawdown response in the TCSA observation well is shown in Figure 5. These data show a steady decline throughout the test. However the rate of drawdown changes after about 100 minutes. This change in the rate of water level decline may suggest a barrier boundary was intersected. The rate of the observed drawdown slowed down after about 700 minutes, which may indicate leakage is occurring from the aquitard unit.

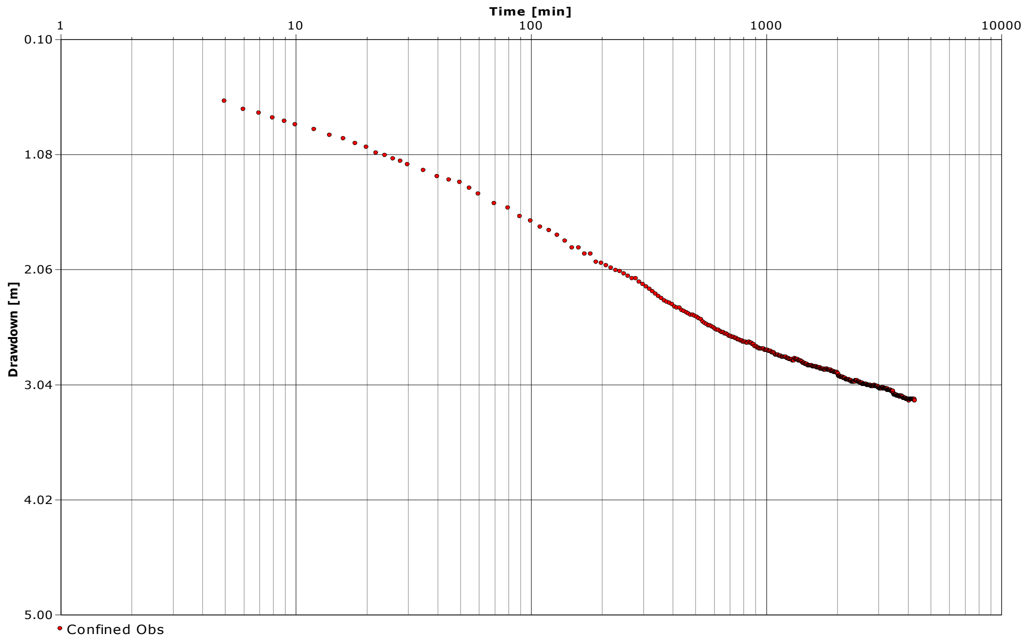


Figure 5 **Log Time vs drawdown plot of water level drawdown data obtained from the TCSA observation well at site SA1**

Theis Solution

Figure 6 shows the match between the Theis-type curve and the observed drawdown data from the TCSA observation well. The graph shows a reasonable match between the type curve and the observed data, with most falling on the type curve. The Theis solution resulted in a transmissivity of 496 m^2/d and storage coefficient of 5.30x10^{-4} for the TCSA.

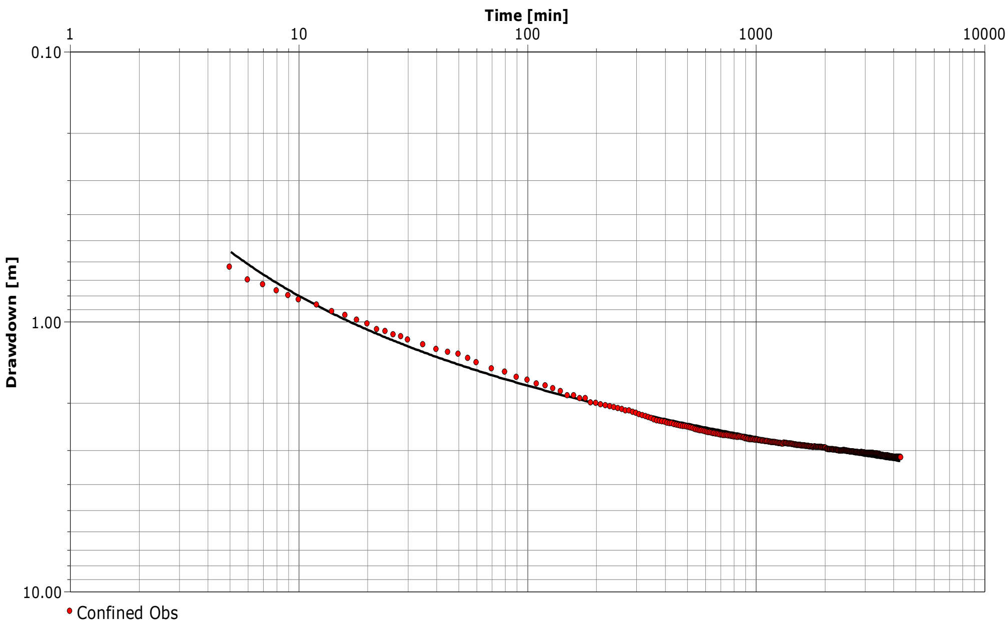


Figure 6 Theis-type curve and observed drawdown for the TCSA observation well at SA1 site

The Theis-type curve also fitted the early time data and the resultant transmissivity and storage coefficient are 600 m^2/d and 3.63x10^{-4} respectively (Fig. 7).

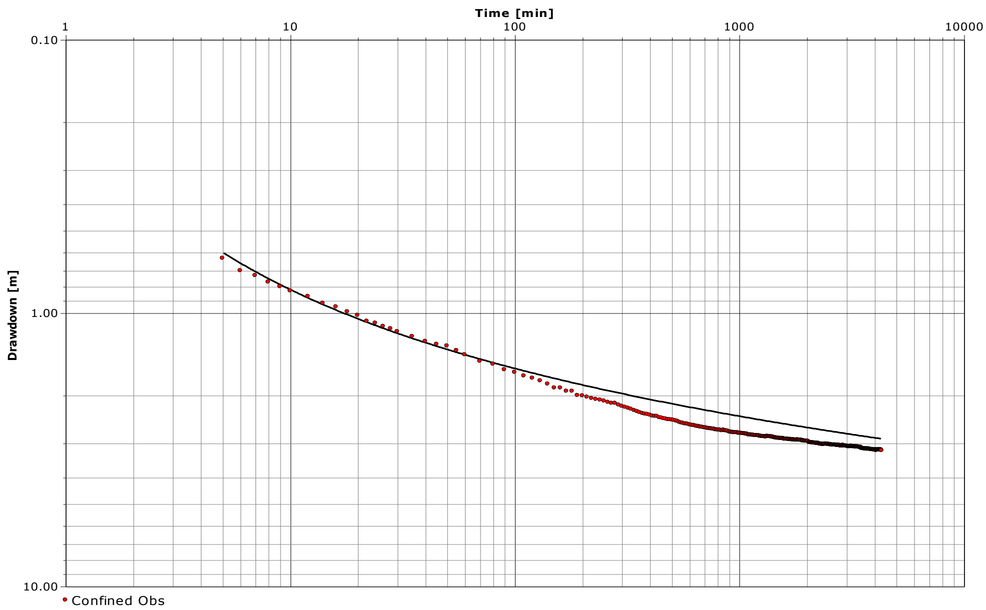


Figure 7 Theis-type curve fitted to the early time of drawdown data for the TCSA observation well at SA1 site

The deviation of the drawdown data from the Theis-type curve after 100 minute of pumping indicated the presence of a barrier boundary or zone of lower transmissivity within the TCSA. The fit between the observed drawdown data and the type curve was obtained with a barrier boundary at 138 m from the production well (Fig. 8). The resultant transmissivity and storage coefficient are 655 m^2/d and $2.70x10^{-4}$ respectively.

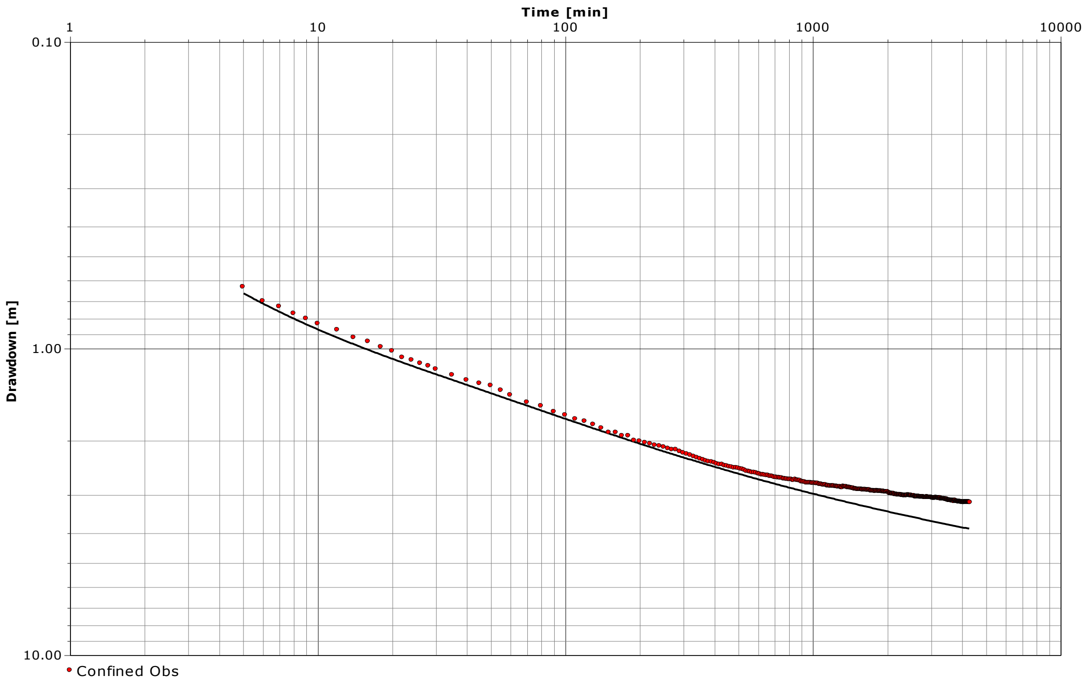


Figure 8 **Theis-type curve and observed drwadown for the TCSA observation well at SA1 site, with boundary**

Leaky Aquifer

From Figure 4, these data show a slower rate of decline after 100 minutes of the pumping test, which results in a deviation from the Theis-type curve and may suggest a leakage into the confined aquifer through the aquitard. The Hantush-Jacob (1955) solution was applied to the observed drawdown data from the TCSA observation well. The results are shown in Figure 9 and Table 2. The boundary condition applied to the leaky solution is similar to the Theis solution.

The transmissivity of the TCSA using the leaky aquifer solution is 446 m^2/d and storage coefficient of $6.39x10^{-4}$. The vertical hydraulic conductivity of the upper aquitard is $2.70x10^{-3}$. The vertical hydraulic conductivity value that has been obtained should be used carefully because of the lack of early records from the data loggers and the complexity of the data-point curve which makes interpretation difficult and could affect the results.

A TCSA clay layer of one metre thickness was encountered at a depth of 33 to 34 m below ground surface within the aquifer and was also intersected in the TCSA aquifer observation well. This clay layer may have affected the analysis and hence the resultant hydraulic properties. However the observed drawdown in the Mepunga Formation and the TCSA aquitard show a decline in water level after about 600 minutes of pumping, which indicate leakage is occurring; the TLA observation well is showing a slight rise in the water level at the early time and more evident after about 600 minutes as explained in Figure 4.

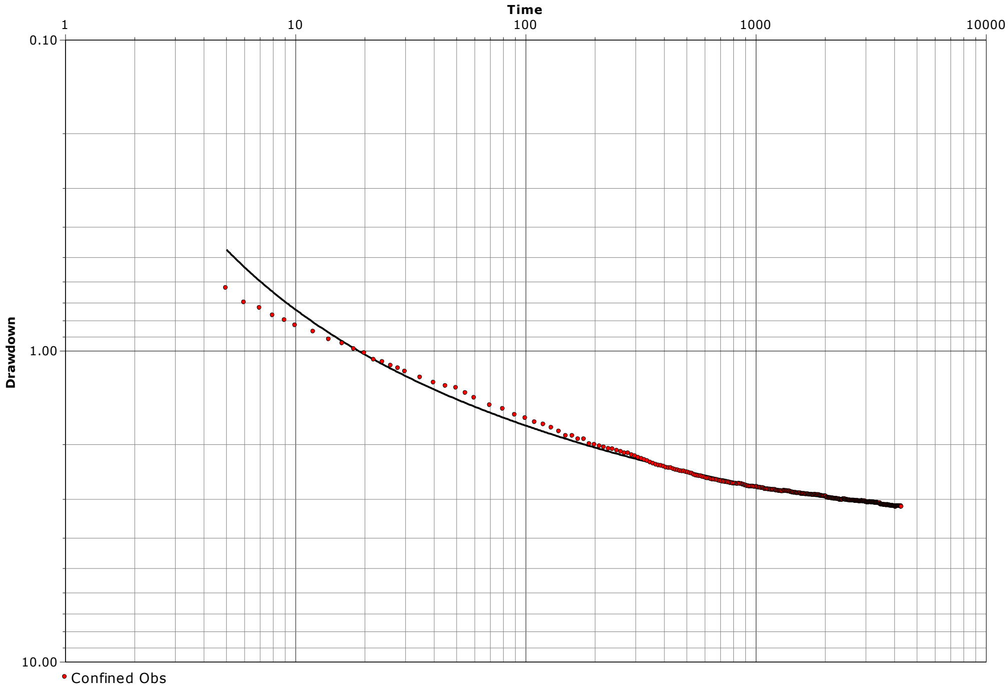


Figure 9 **Hantush-Jacob solution of these data obtained from the TCSA observation well at site SA1, with boundary**

Table 2 is a summary of TCSA properties at site SA1 using the Theis confined aquifer solution and the Hantush-Jacob leaky aquifer solutions. The results of the hydraulic properties of the TCSA obtained by the Theis confined solution with no boundary and the leaky methods with a boundary are close, which may need a cautionary approach when applying the leaky model.

Table 2 **Summary of the analysis methods and aquifer hydraulic properties obstained from the confined aquifer observation well at site SA1**

Solution	Analysis method	Leakage factor (β)	Hydraulic Resistance (min)	Transmissivity of production aquifer (m^2/d)	Storage Coefficient of production aquifer	Vertical hydraulic conductivity of upper aquitard (m/d)
Theis	Confined	n/a	n/a	496	5.30×10^{-4}	n/a
Theis early time	Confined	n/a	n/a	600	3.63×10^{-4}	n/a
Theis boundary	Confined	n/a	n/a	655	2.70×10^{-4}	n/a
Hantush-Jacob with boundary	Leaky	0.03	7.99×10^{6}	446	6.39×10^{-4}	2.70×10^{-3}

3.2. *SITE SA2*

The site is located within the forested area east of Nangwarry (Fig. 10). The depth to the TCSA is shallow, about 20 m below the ground surface. The TCSA aquitard is two metres thick along with six metres of overlying Mepunga Formation, which is composed of limonitic sand.

The wells at this site included:

- TCSA production well
- TCSA observation well, located 50 m E of the production well
- TCSA aquitard observation well, located 5m SE of the production well
- Mepunga Formation observation well located 5m SE of the production well
- TLA unconfined aquifer observation well, located 5m NE of the production well.

The summary of the main hydrogeological units at site SA2 is presented in Table 3. Appendix A provides a detailed description of the lithology.

Table 3 Hydrogeological units of site SA2

Depth (m) from	**To**	**Lithologic Description**	**Thickness (m)**
0	15	OVERBURDEN	15
15	17	BRIDGEWATER FORMATION	2
17	18	GAMBIER LIMESTONE	1
18	24	MEPUNGA FORMATION	6
24	26	TCSA – Clay Unit 1	2
26	45	TCSA – Sand Aquifer 1	19

Only three wells were available for monitoring during the pumping test. These were the TCSA production and observation wells and the aquitard observation well. The Mepunga Formation well had become backfilled with fine sand that had entered the well through the slotted casing and this now requires some rehabilitation work prior to any further investigation or monitoring.

The TLA was discovered to be dry at this site which is located close to the centre of a depression in the watertable.

The hydrogeological units and the configuration of the production and observation wells at site SA2 are presented in Figures 10 and 11.

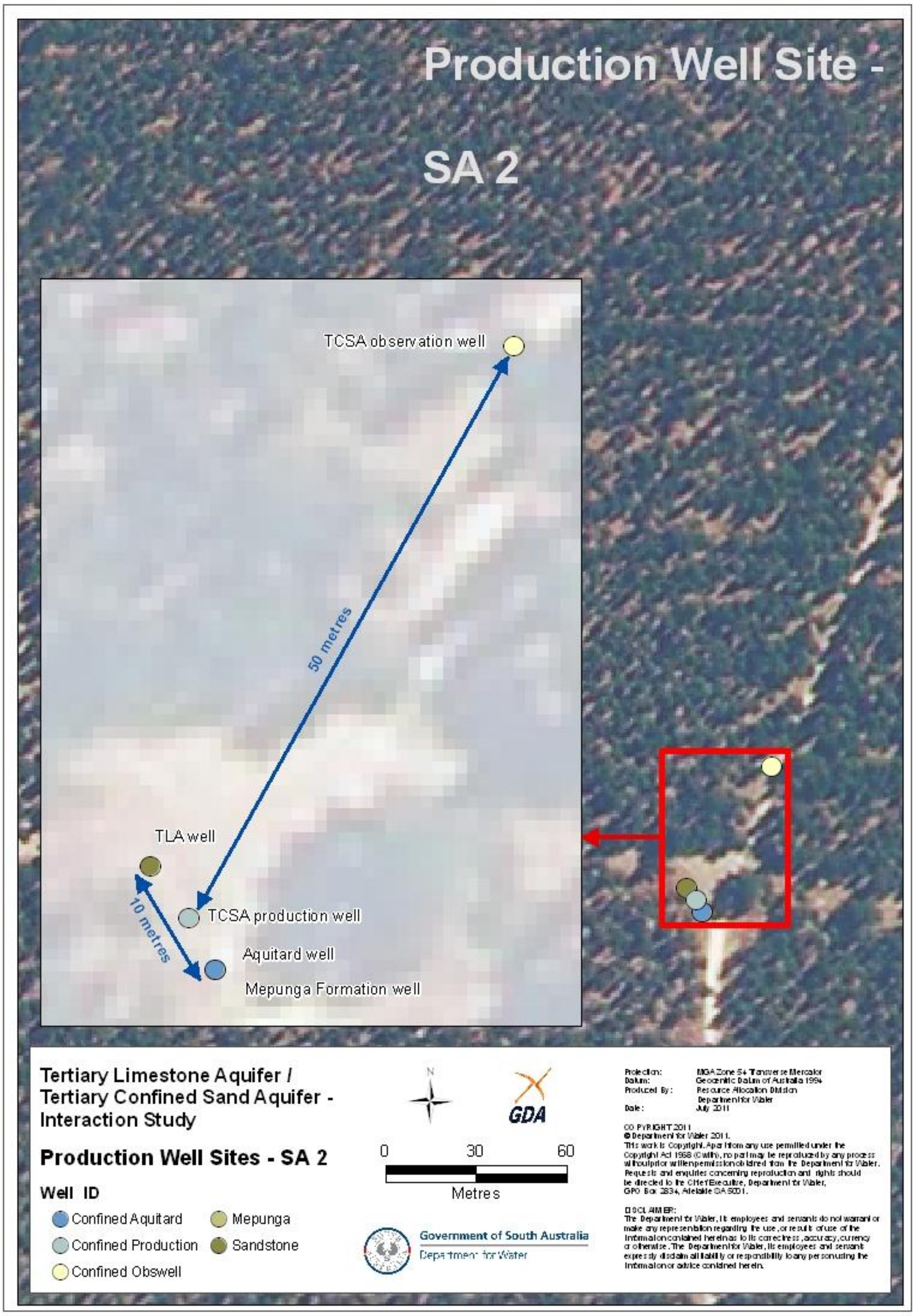


Figure 10 **Map showing the spatial distribution of the TCSA production well and the observations well at site SA2**

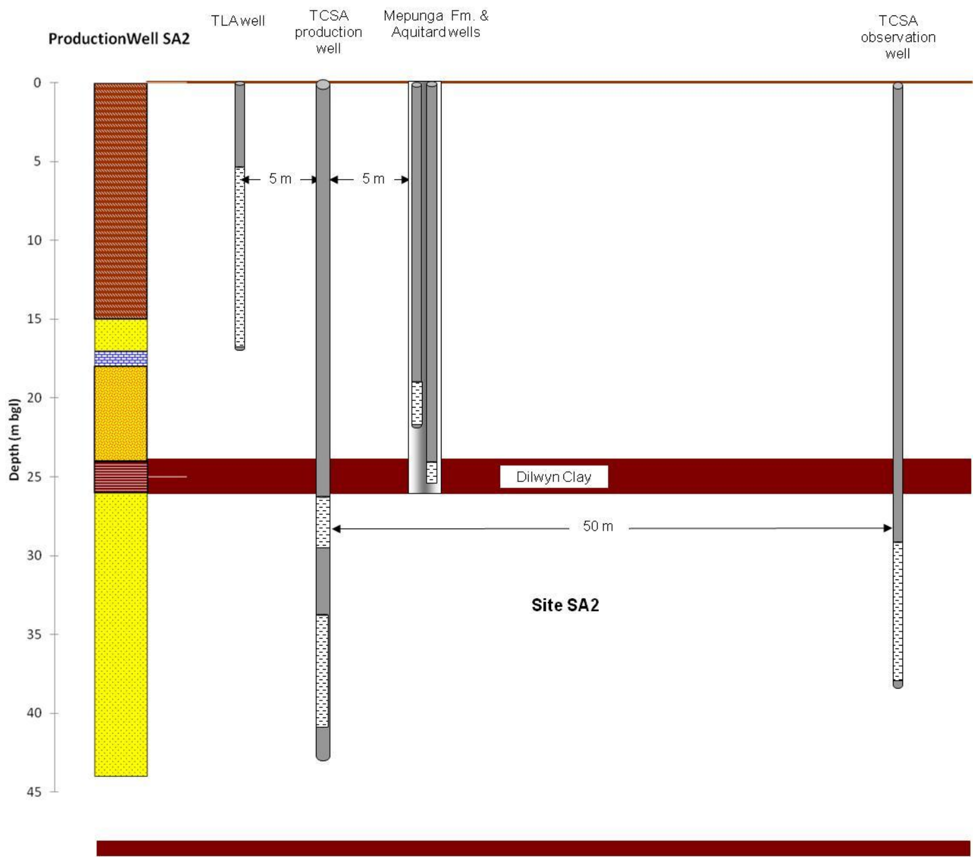


Figure 11 **Schematic cross-section of the lithological units and well configuration at site SA2**

3.2.1. WATER QUALITY

During the aquifer test, water parameters such as pH, salinity as EC (µS/cm) and temperature were recorded from an inline unit using a TPS 90FL multi-meter data logger. The salinity fluctuated between 690 µS/cm and 680 µS/cm during the course of the test and pH ranged between 7.20 and 7.08 (Appendix B).

3.2.2. CONSTANT RATE DISCHARGE TEST

The main objective of the pumping test was to determine the TCSA hydraulic properties and to assess the behaviour and response of the aquitard and the upper units to pumping stress.

The test commenced at 10:00 am on 7 July 2011 and was run for three days followed by a one day recovery period. A discharge rate of 28 L/s. was selected. Water levels were monitored manually and loggers installed in the observation wells completed in the TCSA and the aquitard. Setting the frequency of water level recording to 10 minute intervals may compromise the analysis and interpretation of the test data due to the missing of the early time data (0 to 10 min) which may be crucial for the assessment of the aquifer at the early stages. However some adjustment was made by adding the readings from early manual data to the logger records.

Aquifer Test ProV4.2 software (Schlumberger) was used to analyse the constant rate discharge test data.

During the aquifer test for the TCSA, the water level in the aquitard observation well showed little fluctuation until about 1000 minutes, after which a declining trend is evident (Fig. 12).

The time drawdown data for the TCSA observation well (Fig. 12) shows a steady decline for the first 10 minutes, followed by a slower rate of water level decline until about 200 minutes. After 200 minutes of pumping, the observed drawdown in water level indicates a steeper rate of decline in the water level to the end of the pumping test. The aquitard had only a minor change in the water level during the pumping period and the decline only started after 1000 minutes of pumping.

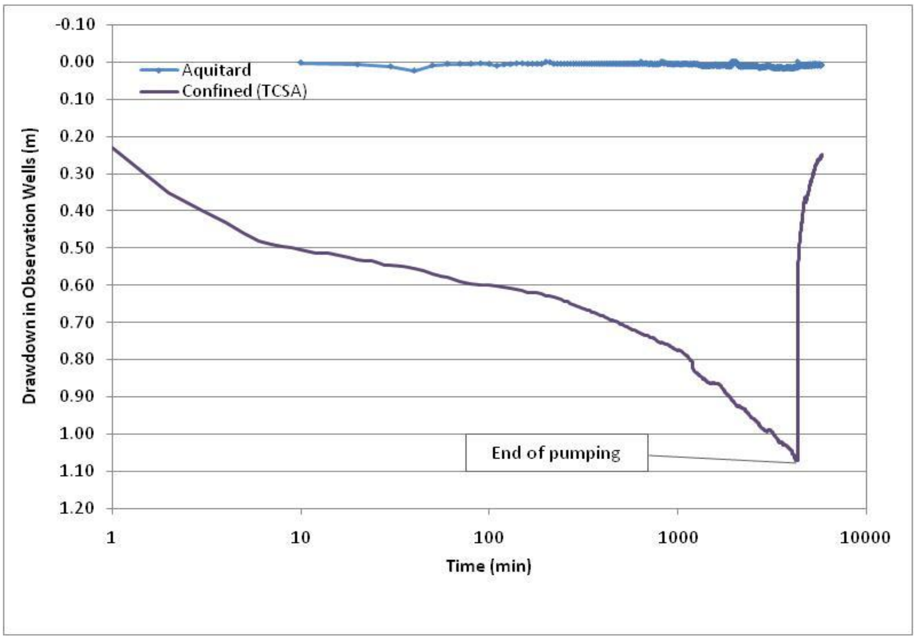


Figure 12 Drawdown in observation wells during pumping at site SA2

The resultant gently sloping drawdown data for the TCSA in Figure 12 could be due to leakage occurring from the aquitard between 10 and 200 minutes of pumping or the presence of a recharge boundary. The observed steeper rate of drawdown after 200 minutes may indicate the presence of a barrier boundary within the TCSA due to a change in the lithology of the aquifer, such as reaching a low permeability zone within the aquifer or the presence of a structural barrier such as a fault. A number of faults that have been identified through seismic interpretation occur within the area of investigation.

Theis Solution

The observed data does not fit onto the Theis confined type curve and consequently, the Theis solution was only applied to the early time of the pumping test period. The resulted aquifer properties are 1540 m^2/d and $1.25x10^{-4}$ for the transmissivity and storage coefficient values respectively (Table 4, Figure 13).

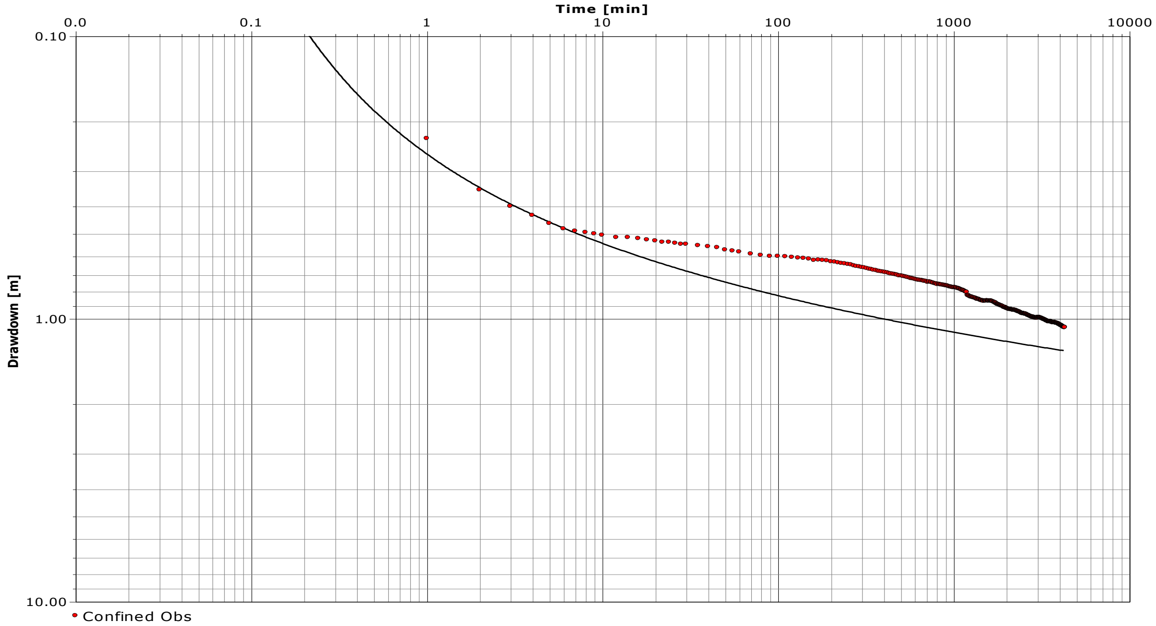


Figure 13 Theis early-time analysis of the TCSA observation-well drawdown data at site SA2

Leaky Aquifer

The slower rate of decline in the observed drawdown data after about 10 minutes of pumping indicates an occurance of leakage from the upper aquitard. The leaky aquifer model was applied to the drawdown data and the result is presented in Figure 14. The resultant transmissivity and storage coefficient of the TCSA and vertical hudraulic conductivity of the aquitard values are 1610 m^2/d, $1.36x10^{-4}$ and $4.36x10^{-2}$ m/d respectively.

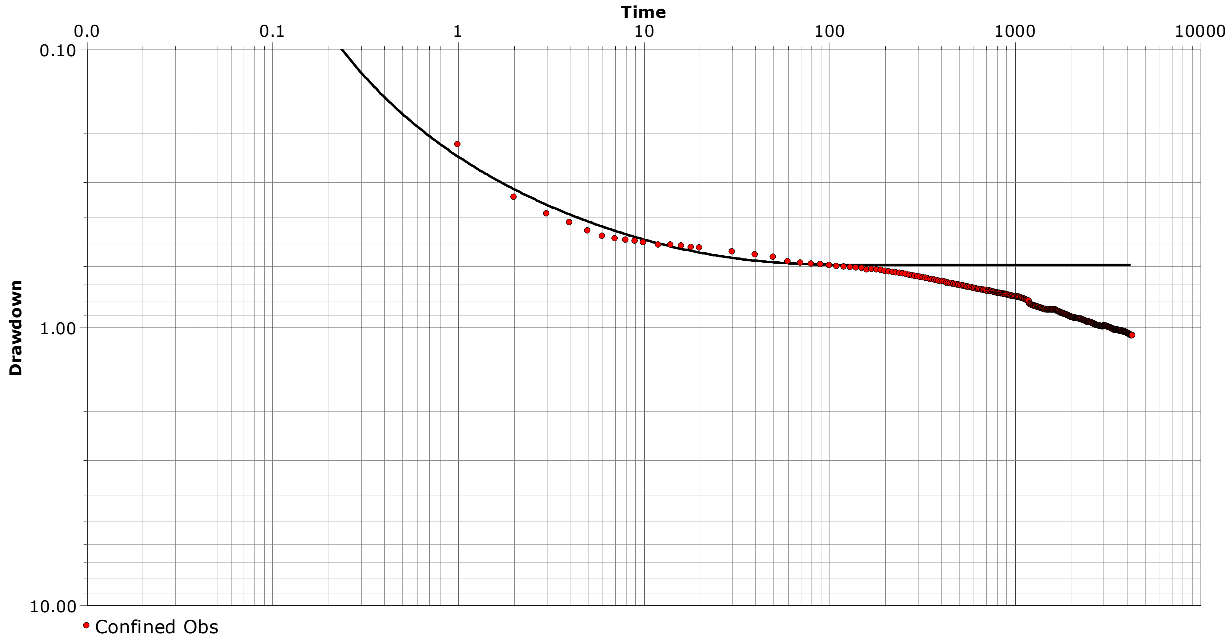


Figure 14 Hantush-Jacob analysis of the TCSA observation-well drawdown data at site SA2

Table 4 Summary of the analysis methods and aquifer hydraulic properties obtained from the confined aquifer obseravtion well at site SA2

Solution	Analysis method	Leakage factor (β)	Hydraulic Resistance (min)	Transmissivity of production aquifer (m^2/d)	Storage Coefficient of production aquifer	Vertical hydraulic conductivity of upper aquitard (m/d)
Theis early time	Confined	n/a	n/a	1540	1.25×10^{-4}	n/a
Hantush-Jacob	Leaky	0.1	2.64×10^{5}	1610	1.36×10^{-4}	4.36×10^{-2}

The transmissivity ranges from 1540 to 1610 m^2/d and storage coefficient varies from 1.25×10^{-4} to 1.36×10^{-4}. The hydraulic behaviour of the TCSA at this site is interesting as the observed drawdown data deviates from the Theis-type curve and may suggest that the site demonstrates a leaky aquifer at the early stage of testing with groundwater leakage from the aquitard (the Mepunga Formation and the aquitard clay of the TCSA). As pumping continues, the drawdown curve reaches a low permeability barrier zone.

The anomalous hydraulic behaviour of the aquifer system at this site could be due to:

- The production well being completed with two lengths of screen (26–29 m and 35–43 m) separated by blank casing. This completion was due to the occurrence of a fine sand unit between the two screen intervals.
- A nanoTEM geophysical survey indicated a discontinuity in the lithological sequence in this area (believed to be due to the presence of faulting), which may have caused the hydraulic barrier response in the aquifer test results (Zonge, 2010).

3.3. *SITE SA3*

This site was one of two that had been originally drilled by the Department of Mines and Energy to examine aquifer interaction in the Nangwarry area.

The site was equipped with multi piezometers installed in two large diameter wells. Figure 15 shows the location and spatial distribution of the TCSA production and the observation wells at this site.

The hydrogeological units and the configuration of the production and observation wells at site SA3 are presented in Figure 16.

The summary of the main hydrogeological units at site SA3 is presented in Table 5. Appendix A provides a detailed description of the lithology.

Table 5 Hydrogeological units of site SA3

Depth (m) from	to	Lithologic Description	Thickness (m)
0	16	BRIDGEWATER FORMATION	16
16	31	GAMBIER LIMESTONE	15
31	40	NARRAWATURK MARL	9
40	52	MEPUNGA FORMATION	12
52	56	TCSA – Clay Unit 1	4
56	68	TCSA – Sand Aquifer 1	12

The wells at this site included:

- TCSA production well
- TCSA observation well located 31 m SE of the production well
- Aquitard observation well located 23 m SE of the production well
- Narrawaturk Formation observation well located 5 m SE of the production well
- TLA unconfined aquifer observation well located 5 m SE from the production well.

Due to the presence of existing observation wells, only a production well was required to be drilled to allow aquifer testing to occur. A compromise that occurred was that the production well was drilled within approximately 5 m of the TLA aquifer observation wells in an attempt to induce drawdown in it, however that meant that the existing TCSA observation well was then located only 31 m away. At the six other South Australian and Victorian sites, this distance was kept to approximately 50 m.

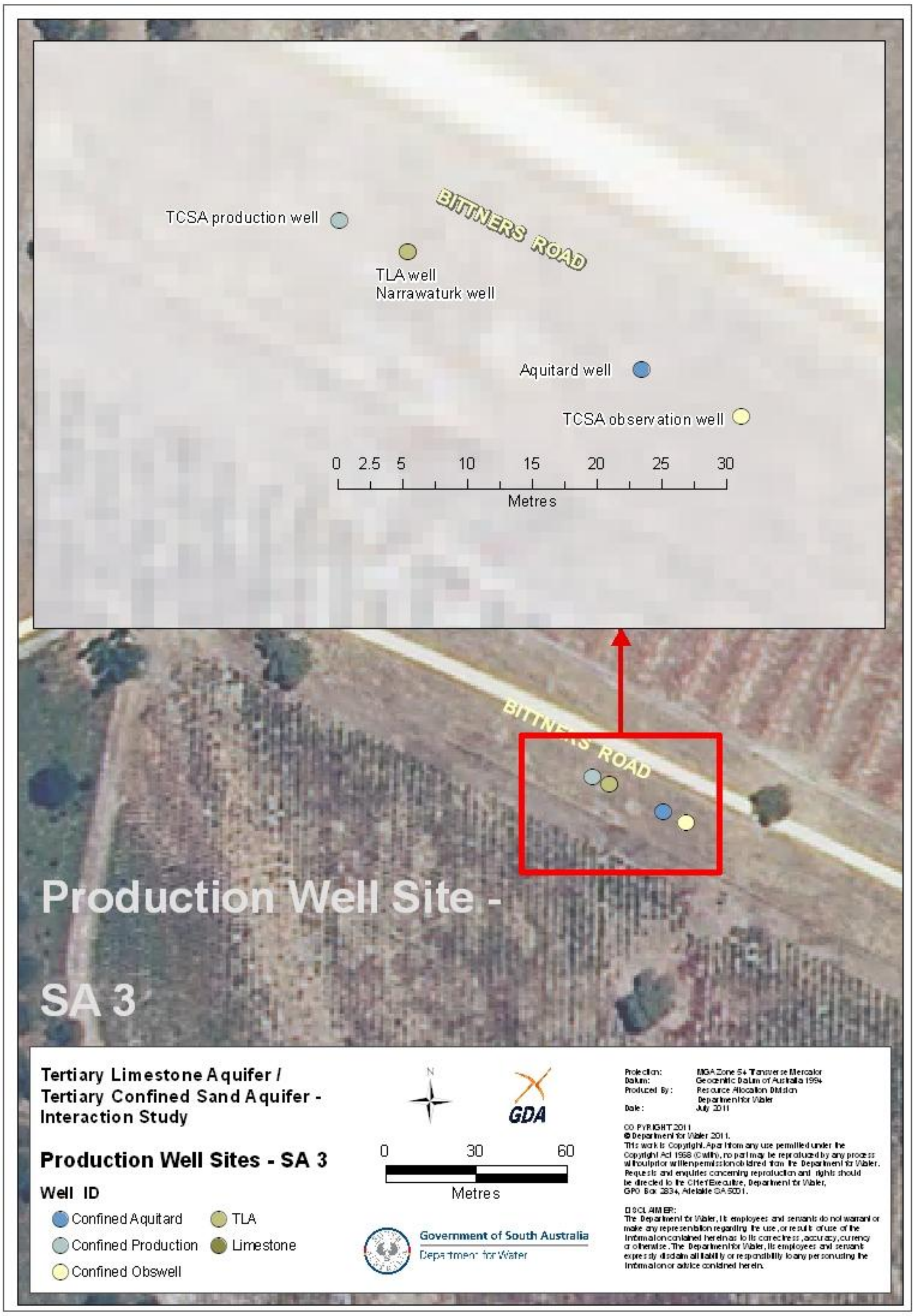


Figure 15 **Map showing the spatial distribution of the TCSA production well and the observations well at site SA3**

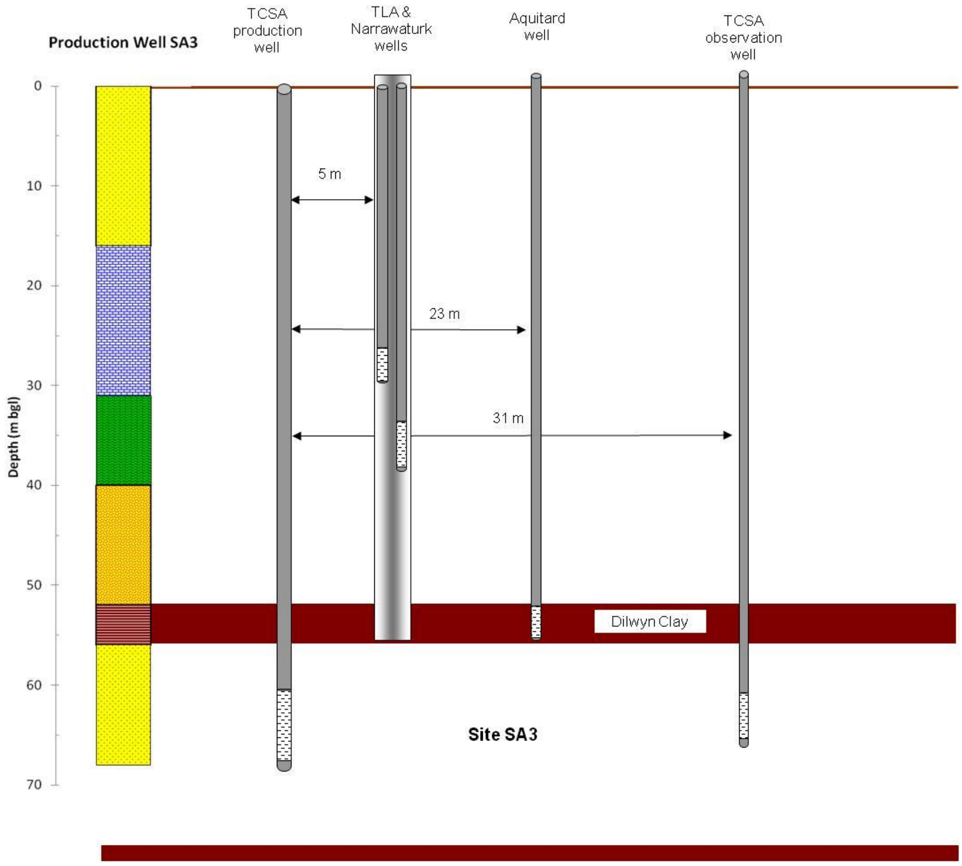


Figure 16 **Schematic cross-section of the lithological units and well configuration at site SA3**

3.3.1. WATER QUALITY

During the aquifer test, water parameters such as pH, salinity as EC (µS/cm) and temperature were recorded from an inline unit using a TPS 90FL multi-meter data logger. The salinity fluctuated between 1295 µS/cm and 1425 µS/cm during the course of the test and pH ranged between 8.5 and 7.1 (Appendix B).

3.3.2. CONSTANT RATE DISCHARGE TEST

The main objective of the aquifer test was to determine the TCSA hydraulic properties and to assess the behaviour and response of the aquitard and the upper units to pumping stress.

The test commenced at 10:00 am on 13 May 2011 and was run for three days followed by a one day recovery test. The test was conducted at a discharge rate of 40 L/s. Water levels were monitored manually and loggers installed in observation wells completed in the TCSA (NAN043), TCSA aquitard (NAN057), Narrawaturk Marl (NAN056)and the TLA (NAN055). Setting the frequency of water level recording to 10 minute intervals may compromise the analysis and interpretation of the test data due to the missing of the early time data (0 to 10 min), which may be crucial for the assessment of the aquifer at the early stages. However some adjustment was made by adding the readings from early manual data to the logger records.

Aquifer Test Pro V4.2 software (Schlumberger) was used to analyse the constant rate discharge test data.

Water level drawdown data from the TLA, the transitional limestone unit known as the Narrawaturk Marl and the aquitard did not indicate any significant declining trends during the test. The data from the aquitard observation well (Fig. 17) indicates a rise in water level and this is likely to be caused by the Noordbergum effect (Kim & Parizek, 1997).

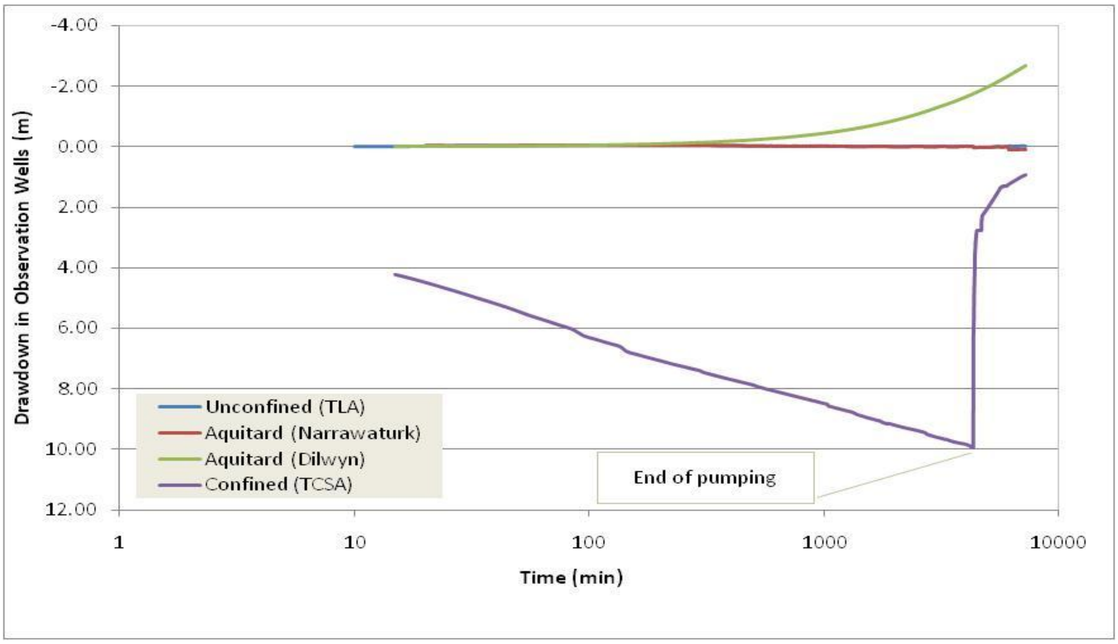


Figure 17 Drawdown in observation wells during pumping at site SA3

The observed drawdown response in the TCSA observation well is given in Figure 18. These data show a steady decline through the test to about 130 minutes of pumping. After this time period, these data slightly deviates and shows a slower rate in declining water level, which may indicate leakage is occurring from the upper aquitard units.

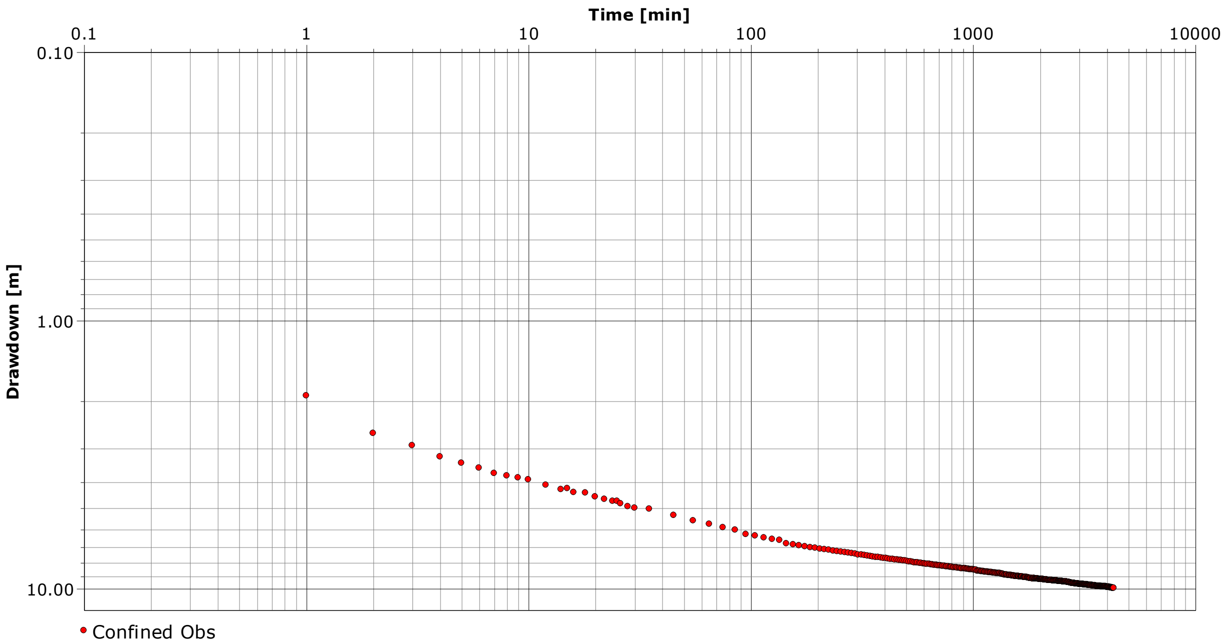


Figure 18 Time-drawdown plot of drawdown data obtained from the TCSA observation well at site SA3

Theis Solution

The Theis-type curve was fitted to the observed drawdown data. Figure 19 shows the match between the observed drawdown data and the Theis-type curve and indicates a reasonable agreement of these data. The obtained hydraulic properties of the TCSA using the Theis method are a transmissivity of 281 m^2/d and storage coefficient of $6.20x10^{-5}$.

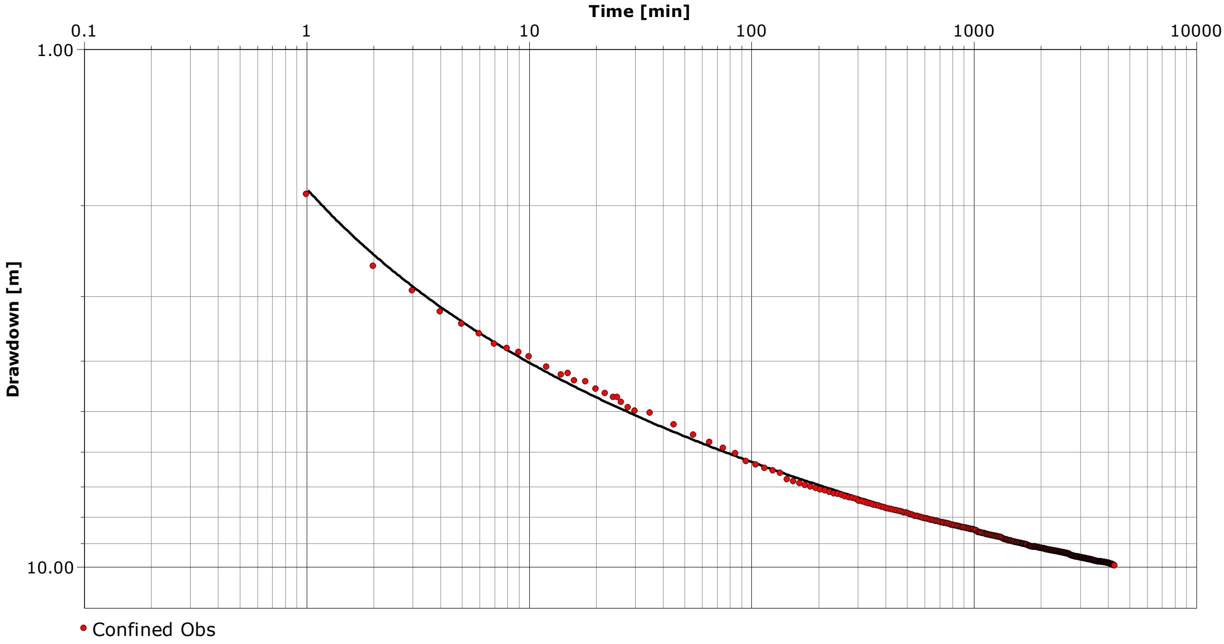


Figure 19 Theis time-drawdown analysis for these data obtained from the TCSA observation well at site SA3

Leaky Aquifer

The change in the drawdown slope after 130 minutes of pumping suggests the presence of leakage from the aquitard units. The Hantush-Jacob (1955) leaky model was applied to the observed drawdown data and Figure 20 is a presention of this data with the leaky aquifer type curve.

The leaky analysis resulted in a transmissivity of 267 m^2/d, a storage coefficient of $7.10x10^{-5}$ and a vertical hydraulic conductivity of $3.13x10^{-4}$ m/d for the TCSA. The aquitard at this location is about 25 m thick, comprising the Narrawaturk Marl, Mepunga Formation and the upper clay unit of the TCSA (Table 5).

The vertical hydraulic conductivity value that has been obtained should be used carefully because of the lack of early records from the data loggers, which makes interpretation difficult and could affect the results.

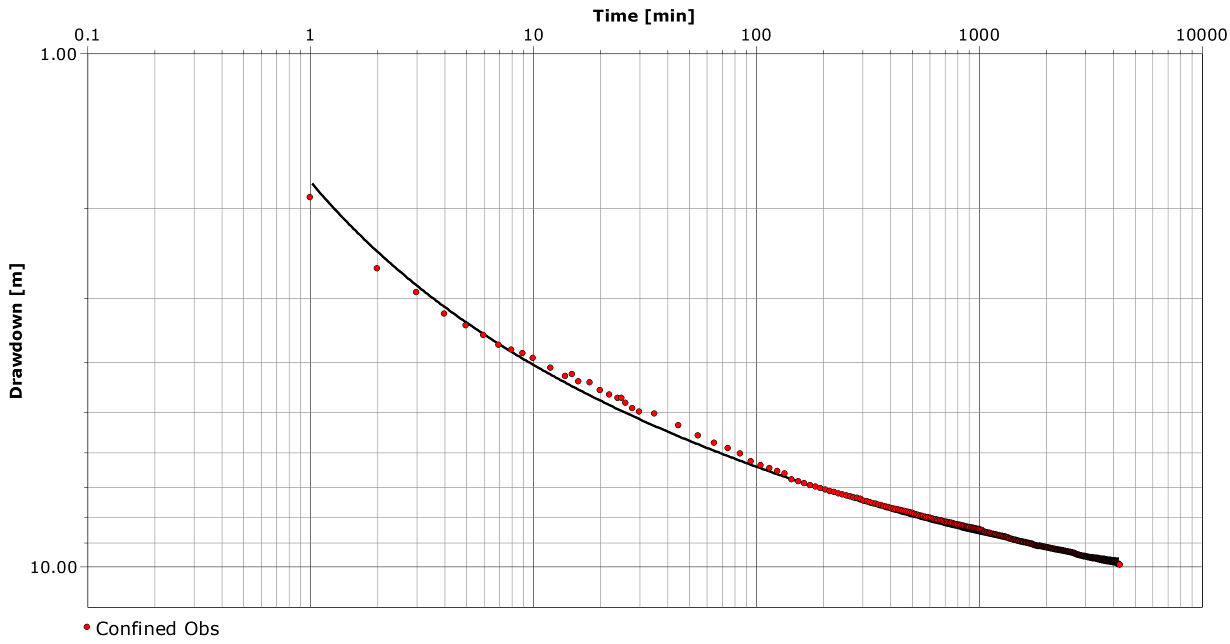


Figure 20 **Hantush-Jacob analysis for these data obtained from the TCSA observation well at site SA3**

Cooper-Jacob Method

The Cooper-Jacob straight line solution for the confined aquifer was also tested and fitted to the observed drawdown data. The results of this solution are a transmissivity of 283 m^2/d and storage coefficient of 5.98×10^{-5} for the TCSA at site SA3 (Fig. 21)

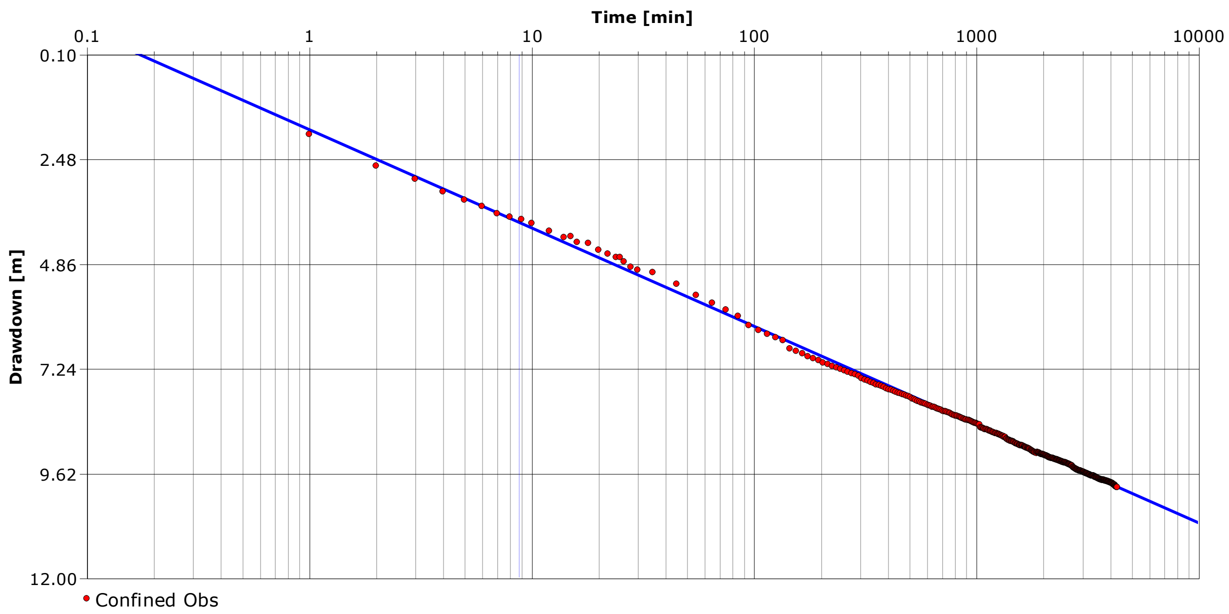


Figure 21 **Cooper-Jacob straight line analysis for these data obtained from the TCSA observation well at site SA3**

Table 6 Summary of the analysis methods and aquifer properties obtained from the confined aquifer observation well at site SA3

Solution	**Analysis method**	**Leakage factor (β)**	**Hydraulic Resistance (min)**	**Transmissivity of production aquifer (m^2/d)**	**Storage Coefficient of production aquifer**	**Vertical hydraulic conductivity of upper aquitard (m/d)**
Theis	Confined	n/a	n/a	281	6.20×10^{-5}	n/a
Hantush-Jacob	Leaky	0.003	8.75×10^{7}	267	7.10×10^{-5}	3.13×10^{-4}
Cooper-Jacob	Confined	n/a	n/a	283	5.98×10^{-5}	n/a

3.4. *SITE SA4*

This site was the second that had been originally drilled by the Department of Mines and Energy to examine aquifer interaction in the general Nangwarry area. Figure 22 shows the location of the TCSA production well and the observation well spatial distribution. The site was equipped with multi piezometers, installed in large diameter wells.

At this site only a production well was required to be drilled to allow aquifer testing to occur. A compromise that occurred was that the TCSA production well was drilled within about 5 m of the TLA observation well in an attempt to induce drawdown in it; however that meant the existing confined observation well was located only 25 m away. At the other six South Australian and Victorian sites, this spacing was kept to about 50 m. Table 7 summarises the main hydrogeological units at this site and Figure 23 is cross-section showing the spatial configuration of the production well and the observations wells. The summary of the main hydrogeological units at site SA1 is presented in Table 1. Appendix A provides a detailed description of the lithology.

Table 7 **Hydrogeological units of site SA4**

Depth (m) from	to	Lithologic Description	Thickness (m)
0	2	OVERBURDEN	2
2	6	BRIDGEWATER FORMATION	4
6	21	GAMBIER LIMESTONE	15
21	25	MEPUNGA FORMATION	4
25	32	TCSA – Clay Unit 1	7
32	35	TCSA – Sand Aquifer 1	3
35	37	TCSA – Clay Unit 2	2
37	68	TCSA – Sand Aquifer 2	31

3.4.1. WATER QUALITY

During the aquifer test, water parameters such as pH, salinity as EC (µS/cm) and temperature were recorded from an inline unit using a TPS 90FL multi-meter data logger. The salinity fluctuated between 1374 µS/cm and 1323 µS/cm during the course of the test and pH ranged between 7.2 and 7.6 (Appendix B).

3.4.2. CONSTANT RATE DISCHARGE TEST

The main objective of the aquifer test was to determine the TCSA hydraulic properties and to assess the behaviour and response of the aquitard and the upper units to the pumping

The constant rate aquifer test was conducted at a discharge rate of 50 L/s, targeting the sand unit in TCSA. Water level drawdown was recorded from an observation well installed into the TCSA (NAN042), aquitard (NAN048), Mepunga Formation (NAN047) and the TLA (NAN046) units.

The constant rate aquifer test commenced at 09:30 am on 6 May 2011 and ran for three days followed by a one day recovery test. Aquatroll data loggers were installed in each of the observations wells (Fig. 23), except the production well. Water level drawdown was also recorded manually from all the wells. The duration of the water level records were set at 10 minutes intervals for the data loggers and the manual records. Setting the frequency of water level recording to 10 minute intervals may compromise the interpretation of these data due to the missing of the early data (0 to 10 min), which may be crucial for the assessment of the aquifer at the early stages and the fitting of the observed drawdown data with the type curves. Therefore no adjustments were made to the early logger records.

Figure 22 **Map showing the spatial distribution of the TCSA production well and the observations wells at site SA4**

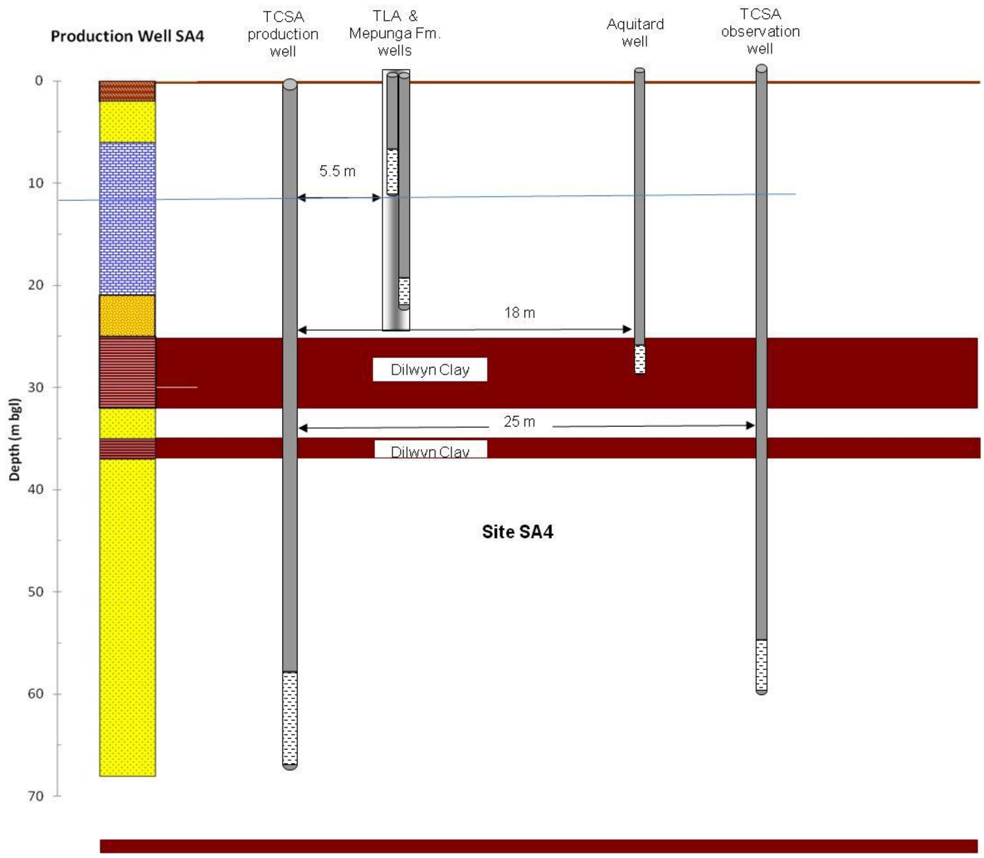


Figure 23 **Schematic cross-section of the lithological units and well configuration at site SA4**

AquiferTest ProV4.2 software (Waterloo Hydrogeological software) was used to analyse the constant rate discharge test data.

The observed drawdown data from the TLA, aquitard (Mepunga Formation) showed no significant changes during the aquifer test. However the observed drawdown data from the TCSA aquitard observation well showed a slight rising trend during the test period (Figs. 24 & 25), and this could be due to the Noordbergum effect (Kim & Parizek, 1997).

The confined aquifer observation well showed a decline in response to pumping from the production well.

The time-drawdown in the TCSA observation well for the constant rate discharge of the confined aquifer is presented in Figure 26. These data shows a steady decline with time throughout the aquifer test procedure.

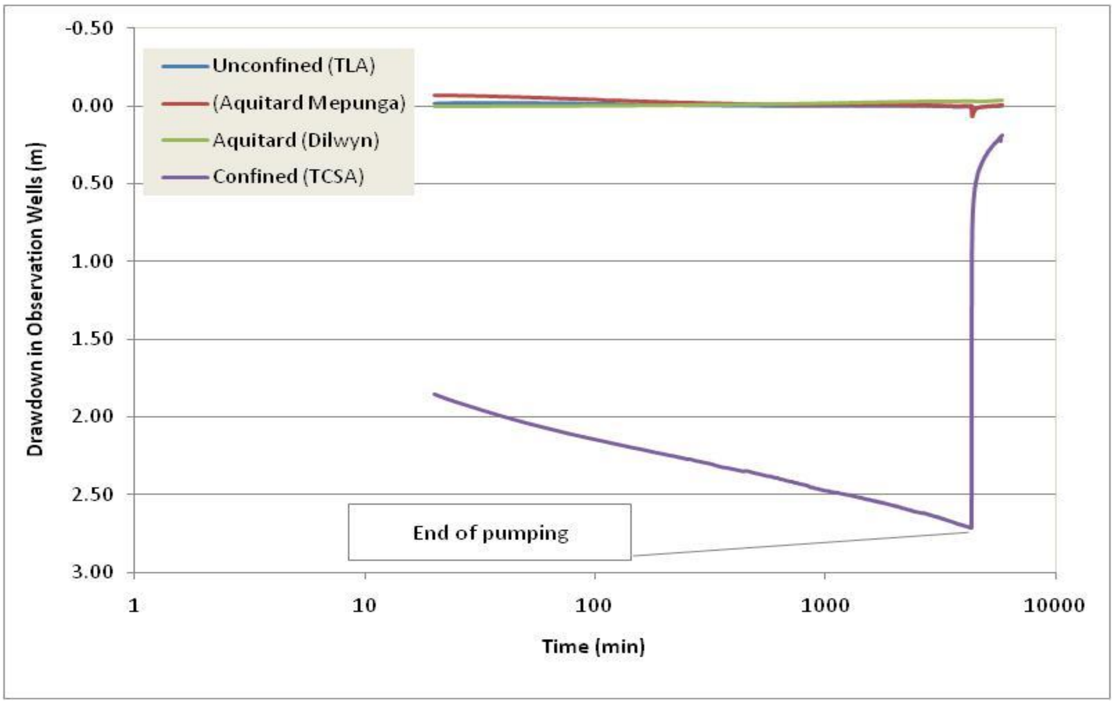


Figure 24 **Drawdown in observation wells during pumping at site SA4**

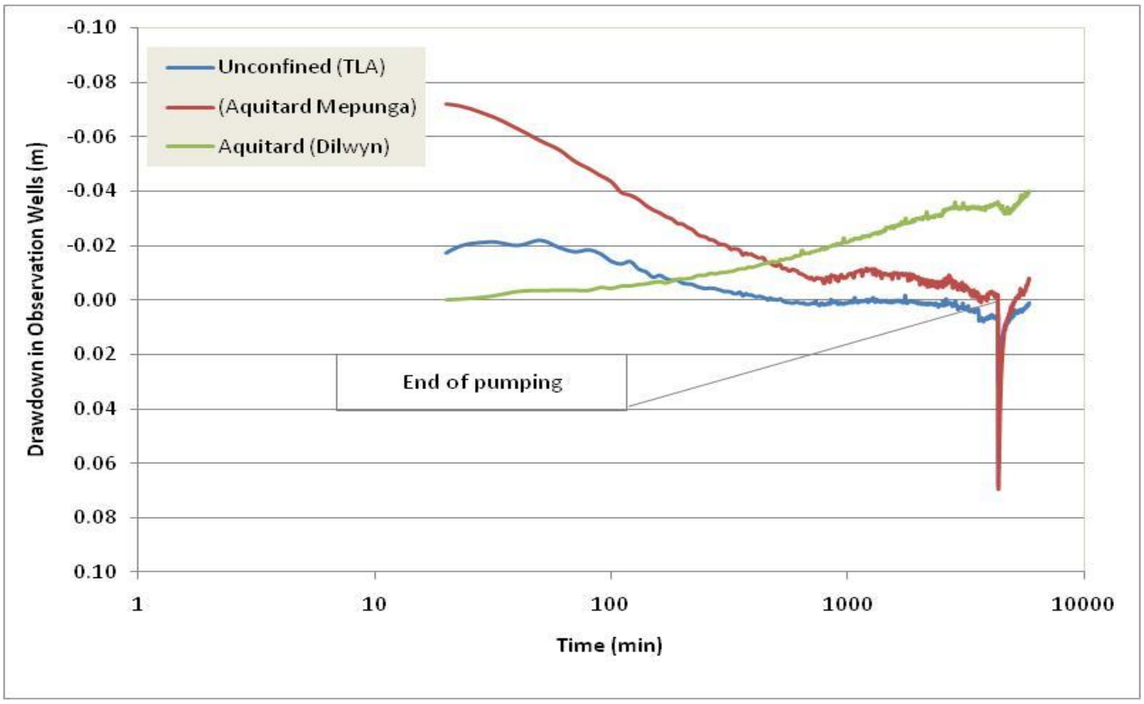


Figure 25 **Drawdown in the unconfined (TLA), aquitard (Mepunga) and aquitard (Dilwyn) observation wells during pumping at site SA4**

The drawdown data from the TCSA observation well (Fig. 26) shows a change in the declining rate after about 90–100 minutes of pumping. Due to the lack of the early drawdown data, it is not clear if this change is due to the presence of leakage from the upper aquitard, or due to a boundary condition.

The missing early-time drawdown data may affect the interpretation and the matching of the observed data with the relevant type curve model. However, for this site the Theis solution for confined aquifer, Cooper-Jacob straight line and the leaky solutions were applied.

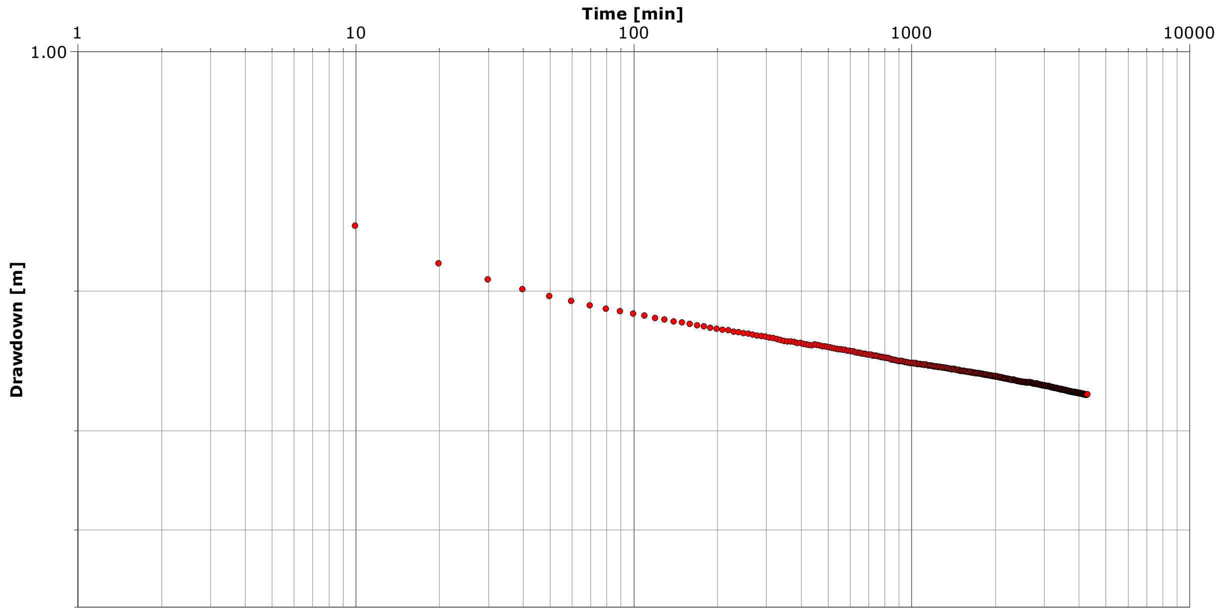


Figure 26 **Time-drawdown plot of water level data obtained from the confined observation well at site SA4**

Theis Solution

Figure 27 represents the fitting of these data with the Theis-type curve. The resultant aquifer hydraulic properties are 2230 m^2/d and 1.43×10^{-5} for the transmissivity and storage coefficient respectively.

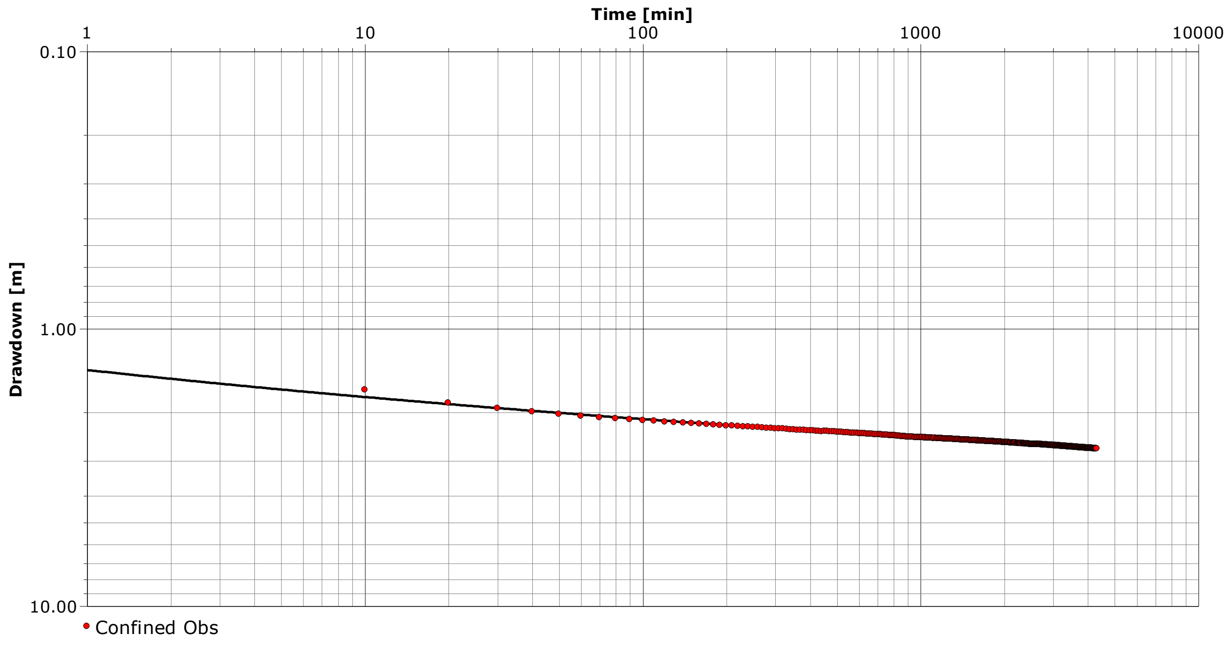


Figure 27 **The fit of the observed drawdown data to Theis-type curve for the TCSA observation well at site SA4.**

Cooper – Jacob Solution

The drawdown data were fitted with the Cooper-Jacob straight line (Fig. 28) resulting in a transmissivity of 2260 m^2/d and storage coefficient of 1.16x10^{-5} for the TCSA aquifer observation well at this site.

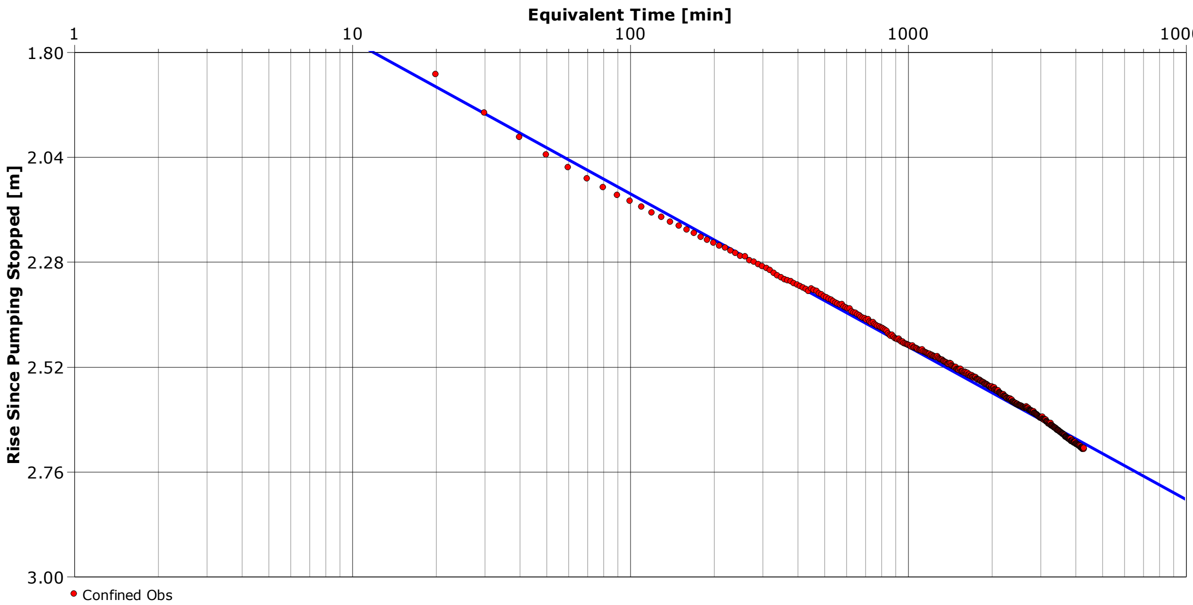


Figure 28 Cooper-Jacob straight line analysis for these data obtained from the TCSA observation well at site SA4

Leaky Aquifer

The leaky aquifer model was applied to these data and the Hantush-Jacob (1955) solution was used for the analysis. Figure 29 presents the match between the observed drawdown data and the leaky aquifer type curve.

The Leaky aquifer solution resulted in a transitivity of 1610 m^2/d, a storage coefficient of 5.36x10^{-4} and a vertical hydraulic conductivity of the aquitard is 2.87x10^{-3} m/d. The vertical hydraulic conductivity value that has been obtained should be used carefully because of the lack of early records from these data loggers, which makes interpretation difficult and could affect the results.

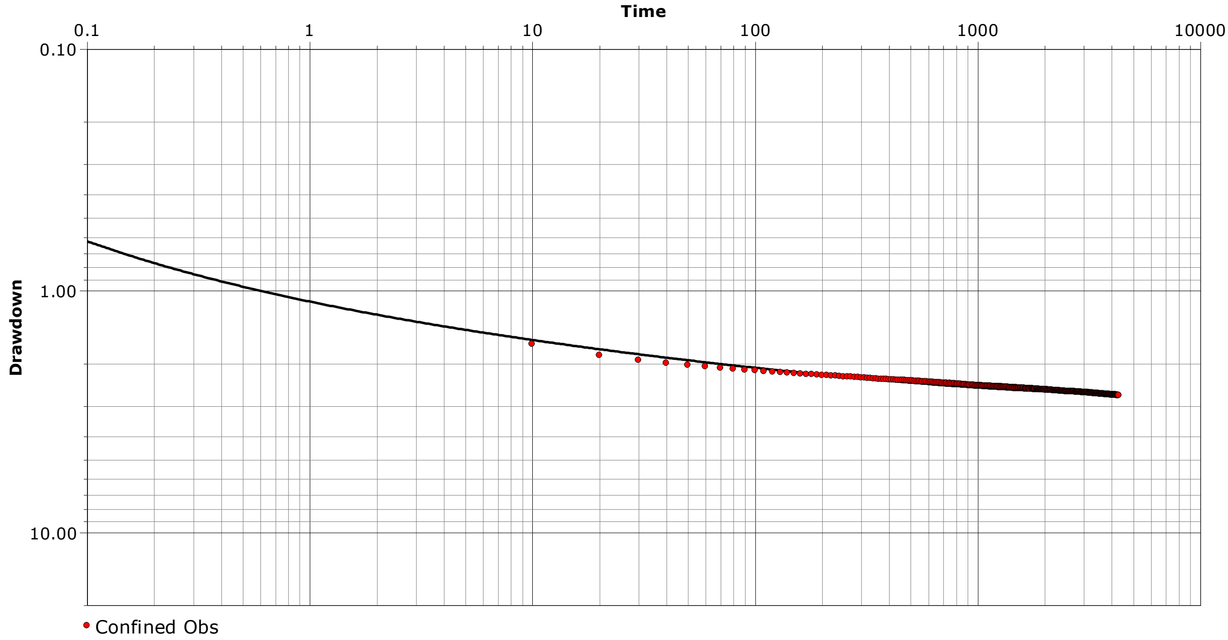


Figure 29 The leaky-aquifer solution of the observed drawdown data from thye TCSA observation well at site SA4

Table 8 Summary of the analysis methods and resulted aquifer properties for the confined aquifer at site SA4

Solution	Analysis method	Leakage factor (β)	Hydraulic Resistance (min)	Transmissivity of pumped aquifer (m^2/d)	Storage Coefficient (pumped well)	Vertical hydraulic conductivity of the upper aquitard (m/d)
Theis	Confined	n/a	n/a	2230	1.43×10^{-5}	n/a
Cooper-Jacob	Confined	n/a	n/a	2260	1.16×10^{-5}	n/a
Hantush-Jacob	Leaky	0.002	5.52×10^{6}	1610	5.36×10^{-4}	2.87×10^{-3}

4. DISCUSSION

The lithology of the TCSA shows variations between the four aquifer test sites, SA1, SA2, SA3 and SA4. This variation in the lithological sequence is also observed in the overlying aquitard and unconfined units of the TLA. The hydrogeology of a site will affect the response in the water levels to the pumping from the production well.

The results of the constant discharge rate aquifer test of the TCSA at SA1, SA3 and SA4 indicates that the aquifer is confined with a reasonably thick aquitard, consisting of the top clay layer of the TCSA, the Mepunga Formation, Narrawaturk Marl (site SA3) and the marly basal limestone unit of the TLA.

The response of the observed drawdown data from the TCSA observation wells has a close match with the Theis-type curve and indicates the presence of a thick aquitard with low vertical hydraulic conductivity. At site SA3, the TCSA is likely to be a confined aquifer and little leakage may occur if stressed for long periods of pumping.

It should be noted that the aquifer properties obtained from the TCSA observation well data at site SA4 needs to be used with care due to a lack of early drawdown data which may compromise the interpretation and the results.

However the application of the leaky model suggests that the confined aquifer can receive leakage from the upper aquitard units if stressed for a long period of pumping. The leakage may be less or slowest at sites SA3 and SA4. The results of the aquifer test of the TCSA at site SA1 indicates the presence of a barrier boundary, which could be due to the drawdown cone reaching a zone of lower permeability within the TCSA.

The hydraulic behaviour of the TCSA at site SA2 shows a different response to pumping. This site is in an area where recharge to the unconfined aquifer is low due to forestry land use and the depth to the TCSA is also shallow. The TLA was discovered to be dry and no drawdown record was collected during the period of the pumping test.

The observed drawdown data in the TCSA at site SA2 shows a gentle decline until the 10 minute time period of the pumping followed by a slower declining trend, which could be due to induced leakage from the upper aquitard units or the presence of a recharge boundary. Another declining trend is evidenced after 200 minutes. This decline could be due to the cessation of the leakage or the drawdown curve reaching a boundary barrier or zone of low permeability within the TCSA.

The lithological description of the production well at site SA2 shows a variation in the grain size of the production zone within the confined sand unit. This variation, or anisotropic nature, of the confined aquifer at this site may have affected the observed drawdown response The Mepunga Formation observation well was filled by drilling residual and no water level data were recovered from this well.

The water level response from the aquitard well at site SA2 does not show any significant changes except for minor fluctuations (which could be due to barometric pressure) until the 1000 minute time interval. After this time some decline in water level is observed.

5. CONCLUSIONS AND RECOMMENDATIONS

The analysis of the aquifer test data at sites SA1, SA2, SA3 and SA4 indicates that the confined aquifer at these sites can be leaky. The vertical hydraulic conductivities for the aquitard at these sites were 2.7x10-3 m/d, 4.36x10-2 m/d, 3.13x10-4 m/d and 2.87x10-3 respectively.

The results of the aquifer test also indicated the presence of a boundary within the TCSA at site SA1, which could be due to a zone of lower permeability.

The TCSA observation well at site SA2 showed a different response to pumping from the production well to that observed at sites SA1, SA3 and SA4.

The Noordburgum effect was observed in the observation well monitoring the unconfined (TLA) at site SA1 and the aquitard observation wells at sites SA3 and SA4.

The analysis of the aquifer test data from site SA4 indicates the importance in recording the response of the water level during the early time of the test, which can affect the interpretation and results of the analysis.

For future pump testing programs it is recommended that:

- at all sites, additional short term pumping (100–120 min) with higher intensity of data records (seconds) for the early time period of the pumping test using data loggers and manual record of data be performed on the observation wells completed in the non TCSA units, to estimate the aquifer hydraulic properties
- the Mepunga Formation observation well at site SA2 is cleaned out back to original depth and a short term pumping or slug test is run on this well
- the early time period of pumping is captured to assist with the assessment of the aquifer responses in the very early stages of the pumping test.

APPENDICES

A. LITHOLOGY LOGS

Project: TLA/ TCSA INTERACTION STUDY
Permit Number: 193358 Backfilled (Y/N):**N**
Date Completed: 30/3/2011 Total Depth (m): **46**
Unit No: Drill Method: **Mud Rotary**
Drillhole Name: **BGWR_SA1** Drilling Company: **Water Dynamics**
Logged By: Jeff Lawson Driller: Greg Cram

Coordinates
Easting: 475928 Ground Elevation (m AHD): **TBD**
Northing: 5851638 Reference Elevation (m AHD): **TBD**
Zone: **54** Reference Point Type: **TOC is ground level**
Datum: **GDA94**

General Comments:
This is the first well drilled on this site to ascertain the geology for further completions.

Lithological Description

Depth (m)		Major Lith Unit(s)	Lithology	Formation
From	To			
0	0.5	TOPSOIL	Brown, sandy soil.	RECENT
0.5	1	CLAY	Brown, soft pliable. Minor fine sand.	RECENT
1	2	SANDSTONE	Pale yellow, strongly cemented, fine grained. Mixture of well rounded fossil pieces and sand. Minor brown silt.	BRIDGEWATER FORMATION
2	3	MARL	Pale yellow. Close to an even mix between the sandstone and marl.	BRIDGEWATER FORMATION
3	5	SANDSTONE	Pale grey. Strongly cemented fine grained mix of carbonate and sand.	BRIDGEWATER FORMATION
5	6	SANDSTONE	Lost circulation. Small cavity – suspected coarse oyster shells.	BRIDGEWATER FORMATION
7	8	MARL	Bit sample. Off white, soft and pliable. Minor limestone material. Good quality fossil material, bryozoa sticks.	GREENWAYS MEMBER
8	11	MARL	Pale yellow. Marl is not as strongly bounded. Much higher percentage of unconsolidated high quality fossil material. Occasional strongly cemented fragments.	GREENWAYS MEMBER
11	12	MARL	Pale brown. Percentage between the marl and solid fragments close to 50:50.	GREENWAYS MEMBER
12	13	MARL	Pale brown. Soft, plastic, well bounded. Reduced percentage of limestone fragments.	GREENWAYS MEMBER
13	14	MARL	Increased percentage of unconsolidated fossil fraction. Increasing amount of calcite	GREENWAYS MEMBER
14	15	LIMESTONE	Off white to pale grey. Mixtures of some marl (cream) and strongly cemented medium to fine grained fragments. Some fossils to 4 mm. Sand present so this	GREENWAYS MEMBER

Depth (m)		Major Lith Unit(s)	Lithology	Formation
From	To			
			zone is starting to transition.	
15	16	CLAY	Mottled brown, orange and off white. Transition zone – dominantly Mepunga Formation with fine iron stained sand and clay. Some uphole fossils still present.	MEPUNGA FORMATION
16	17	CLAY	Pale orange. Soft, pliable. Strongly embedded with fine sand, mainly iron stained but occasional limonitic grains.	MEPUNGA FORMATION
17	18	CLAY	Light brown. As above.	MEPUNGA FORMATION
18	20	CLAY	Brown lignitic clay. Soft, pliable. Fine sand embedded in the clay giving a gritty feel.	MEPUNGA FORMATION
20	21	CLAY	Brown lignitic clay with variations. Unusual for a clay sequence there are strongly cemented fragments essentially composed of sand with inclusions of unidentified fossil material.	MEPUNGA FORMATION?
21	23	CLAY	Mixture of light brown and some darker brown, well bounded clay. Fine sand embedded in the clay.	MEPUNGA FORMATION?
23	24	CLAY	Not strongly bounded. High calcareous component. Erosional surface or uphole contamination.	MEPUNGA FORMATION?
24(26)	25	SANDSTONE/ SILTSTONE	Dark brown. Mix of fine sand and silt bound in weakly cemented chips.	DILWYN FORMATION
25	26	SANDY SILT	Dark brown. Fine sand embedded into a weakly bound siltstone. Minor Marcasite (pyrite).	DILWYN FORMATION
26	28	SANDSTONE/ SILTSTONE	Dark brown. Matrix of silt and fine sand in strongly cemented fragments. Minor Marcasite (pyrite).	DILWYN FORMATION
28	30	SANDY CLAY	Dark brown. High percentage of fine sand resulting in weakly bound clay.	DILWYN FORMATION
31	32	SAND	50% average 0.65 mm	DILWYN FORMATION
33	34	SAND	50% average 0.50 mm	DILWYN FORMATION
35	36	SAND	50% average 0.49 mm	DILWYN FORMATION
37	38	SAND	50% average 0.64 mm	DILWYN FORMATION
39	40	SAND	50% average 1.70 mm	DILWYN FORMATION
41	42	SAND	50% average 0.79 mm	DILWYN FORMATION
43	44	SAND	50% average 0.84 mm	DILWYN FORMATION
45	46	SAND	50% average 0.79 mm	DILWYN FORMATION

Water Cut Information

Depth (m)		Depth to Water (m)	Supply			Water Analysis		
From	To		L/s	Test Length	Method	Sample No	Salinity	Salinity Unit (mg/L/EC)

Casing and Production Zone Information

Case or Prod Zone	Depth (m)		Diam. (mm)	Material	Aperture	Cementing		
	From	To				Y/N	From (m)	To (m)
	30	33	200	Stainless steel	0.7 mm	Y	surface	30
	38	45	200	Stainless steel	0.7 mm			

Project: TLA/ TCSA INTERACTION STUDY
Permit Number: **193397** Backfilled (Y/N):**N**
Date Completed: **11/3/2011** Total Depth (m): **44**
Unit No: Drill Method: **Mud Rotary**
Drillhole Name: **BGWR_SA2** Drilling Company: **Water Dynamics**
Logged By: Jeff Lawson Driller: Greg Cram

Coordinates
Easting: 489666 Ground Elevation (m AHD): **TBD**
Northing: 5844646 Reference Elevation (m AHD): **TBD**
Zone: **54** Reference Point Type: **TOC is ground level**
Datum: **GDA94**

General Comments:
The test well was completed as the production well. All lithology is referenced to ground level.

Lithological Description

Depth (m)		Major Lith. Unit(s)	Lithology	Formation
From	To			
1	2	SAND	Light brown, unconsolidated. Sub-angular to sub-rounded fine sand. Frosted to iron stained grains. Minor clay.	RECENT
2	3	CLAY	Pale grey, soft, pliable, well bound clay.	RECENT
3	4	CLAY	Mottled pale grey to orange. Strongly bounded clay. Fine sand embedded in the clay.	RECENT
4	5	CLAY	Orange. Soft, pliable, well bounded clay. Very fine sand embedded in the clay.	RECENT
5	7	CLAY	Pale orange. As above with minor sand.	RECENT
7	9	CLAY	Light brown to pale orange. Minor sand.	RECENT
9	11	CLAY	Pale orange. Minor sand.	RECENT
11	13	CLAY	Light brown. Clay is well bound but not as heavy as above. Minor sand.	RECENT
13	15	CLAY	Pale yellow clay. Starting to breakup due to minor fine, strongly cemented sandstone fragments (10 – 15%).	RECENT
15	17	SAND	Medium to coarse sand in pale yellow marl. Grains to 5 mm. Possible erosional zone.	BRIDGEWATER FORMATION
17	18	MARL	Mottled pale yellow to brown. Fine sand embedded in the marl. Occasional slightly coarser grains.	GAMBIER LIMESTONE
18	19	SAND	Very coarse well rounded grains.	DILWYN FORMATION
19	20	SAND	50% Sand average 1.25 mm	DILWYN FORMATION
20	21	SAND	50% Sand average 0.87 mm	DILWYN FORMATION
22	23	SAND	50% Sand average 1.05 mm	DILWYN

Depth (m)		Major Lith. Unit(s)	Lithology	Formation
From	To			
				FORMATION
26	27	SAND	50% Sand average 1.80 mm	DILWYN FORMATION
27	28	SAND	50% Sand average 0.91 mm	DILWYN FORMATION
28	29	SAND	50% Sand average 0.83 mm	DILWYN FORMATION
29	30	SAND	50% Sand average 0.61 mm	DILWYN FORMATION
30	31	SAND	50% Sand average 0.46 mm	DILWYN FORMATION
31	32	SAND	50% Sand average 0.37 mm	DILWYN FORMATION
32	33	SAND	50% Sand average 0.28 mm	DILWYN FORMATION
33	34	SAND	50% Sand average 0.40 mm	DILWYN FORMATION
34	35	SAND	50% Sand average 0.58 mm	DILWYN FORMATION
35	36	SAND	50% Sand average 0.80 mm	DILWYN FORMATION
36	37	SAND	50% Sand average 0.92 mm	DILWYN FORMATION
38	39	SAND	50% Sand average 0.70 mm	DILWYN FORMATION
39	40	SAND	50% Sand average 0.71 mm	DILWYN FORMATION
40	41	SAND	50% Sand average 0.60 mm	DILWYN FORMATION
41	42	SAND	50% Sand average 0.69 mm	DILWYN FORMATION
42	43	SAND	50% Sand average 0.62 mm	DILWYN FORMATION
43	44	SAND	50% Sand average 0.62 mm	DILWYN FORMATION

Water Cut Information

Depth (m)		Depth to Water (m)	Supply			Water Analysis		
From	To		L/s	Test Length	Method	Sample No	Salinity	Salinity Unit (mg/L/EC)

Casing and Production Zone Information

Case or Prod Zone	Depth (m)		Diam. (mm)	Material	Aperture	Cementing		
	From	To				Y/N	From (m)	To (m)
Dilwyn aquifer	26	29	200	Stainless steel	0.7 mm	Y	surface	26
	35	43	200	Stainless steel	0.7 mm			

Project: TLA/ TCSA INTERACTION STUDY
Permit Number: **193388 & 193389** Backfilled (Y/N):**Y**
Date Completed: **04/03/2011** Total Depth (m): **68**
Unit No: Drill Method: **Mud Rotary**
Drillhole Name: **BGWR_SA3** Drilling Company: **Water Dynamics**
Logged By: Jeff Lawson Driller: Greg Cram

Coordinates
Easting: **495092** Ground Elevation (m AHD): **TBD**
Northing: **5844049** Reference Elevation (m AHD): **TBD**
Zone: **54** Reference Point Type: **TOC is ground level**
Datum: **GDA94**

General Comments:
Two wells were drilled at this site, a test well and production well. Because of the test well's location, which was not ideal for the aquifer testing, it was backfilled and replaced with permit well 193389.

Lithological Description

Depth (m)		Major Lith. Unit(s)	Lithology	Formation
From	To			
0	0.5	TOPSOIL	Brown, some yellow clay.	RECENT
0.5	16	SANDSTONE	Yellow – orange, medium grained, calcareous fossiliferous	BRIDGEWATER FORMATION
16	23	MARL	Grey- green. Calcareous with abundant shell.	GAMBIER LIMESTONE
23	31	LIMESTONE	White, fossiliferous, bryozoal.	GAMBIER LIMESTONE
31	35	MARL	Grey, calcareous, extremely glauconitic.	NARAWATURK MARL
35	40	MARL	Brown, fine grained. 10% iron stained grains. Shift zone between the Narawaturk marl and the Mepunga Formation	NARAWATURK MARL
40	52	SAND	Brown and grey, medium grained iron stained sand.	MEPUNGA FORMATION
52	56	CLAY	Brown to black carbonaceous.	DILWYN FORMATION
56	57	SAND	50% Sand Average 1.45 mm	DILWYN FORMATION
57	58	SAND	50% Sand Average 0.62 mm	DILWYN FORMATION
58	59	SAND	50% Sand Average 0.68 mm	DILWYN FORMATION
59	60	SAND	50% Sand Average 0.59 mm	DILWYN FORMATION
60	61	SAND	50% Sand Average 0.64 mm	DILWYN FORMATION

Depth (m)		Major Lith. Unit(s)	Lithology	Formation
From	To			
61	62	SAND	50% Sand Average 0.66 mm	DILWYN FORMATION
62	63	SAND	50% Sand Average 0.53 mm	DILWYN FORMATION
63	64	SAND	50% Sand Average 0.65 mm	DILWYN FORMATION
65	66	SAND	50% Sand Average 0.29 mm	DILWYN FORMATION
66	67	SAND	50% Sand Average 0.28 mm	DILWYN FORMATION
67	68	SAND	50% Sand Average 0.33 mm	DILWYN FORMATION

Water Cut Information

Depth (m)		Depth to Water (m)	Supply			Water Analysis		
From	To		L/s	Test Length	Method	Sample No	Salinity	Salinity Unit (mg/L/EC)

Casing and Production Zone Information

Case or Prod Zone	Depth (m)		Diam. (mm)	Material	Aperture	Cementing		
	From	To				Y/N	From (m)	To (m)
	57	64	200	Stainless steel screen	0.65 mm	Y	0	57

Project: TLA/ TCSA INTERACTION STUDY
Permit Number: **193390 & 193391** Backfilled (Y/N):**Y**
Date Completed: **25/02/2011** Total Depth (m): **68**
Unit No: Drill Method: **Mud Rotary**
Drillhole Name: **BGWR_SA4** Drilling Company: **Water Dynamics**
Logged By: Jeff Lawson Driller: Greg Cram

Coordinates
Easting: 487473 Ground Elevation (m AHD): **TBD**
Northing: 5838098 Reference Elevation (m AHD): **TBD**
Zone: **54** Reference Point Type: **TOC**
Datum: **GDA94**

General Comments:
Two wells were drilled at this site, a test well and production well. Because of the test well location which was not ideal for the aquifer testing, it was backfilled and replaced with permit well 193389.

Lithological Description

Depth (m)		Major Lith. Unit(s)	Lithology	Formation
From	To			
0	1	TOPSOIL	Grey, unconsolidated	RECENT
1	2	CLAY	Brown to yellow. Minor sand.	RECENT
2	6	SANDSTONE	Off white to yellow orange, moderately cemented. Fine grained.	BRIDGEWATER FORMATION
6	19	MARL	Grey, calcareous, fossiliferous. Abundant bryozoa.	GAMBIER LIMESTONE
19	21	MARL	Brown, calcareous, abundant iron stained sand. Start of the Mepunga.	GAMBIER LIMESTONE
21	25	SAND	Brown to yellow, unconsolidated. Iron stained sand.	MEPUNGA FORMATION
25	27	CLAY	Black to dark brown, carbonaceous. Minor sand and pyrite.	DILWYN FORMATION
27	32	CLAY	Clay and sand interbedded. Medium to thinly bedded.	DILWYN FORMATION
32	35	SAND	No recovery	DILWYN FORMATION
35	37	CLAY	Light brown carbonaceous clay and sand. Medium to thinly bedded.	DILWYN FORMATION
37	38	SAND	50% sand Average 0.70 mm	DILWYN FORMATION
39	40	SAND	50% sand Average 0.48 mm	DILWYN FORMATION
41	42	SAND	50% sand Average 0.36 mm	DILWYN FORMATION
42	43	SAND	50% sand Average 0.32 mm	DILWYN FORMATION

Depth (m)		Major Lith. Unit(s)	Lithology	Formation
From	To			
46	47	SAND	50% sand Average 0.49 mm	DILWYN FORMATION
47	48	SAND	50% sand Average 0.58 mm	DILWYN FORMATION
48	49	SAND	50% sand Average 0.68 mm	DILWYN FORMATION
51	52	SAND	50% sand Average 0.53 mm	DILWYN FORMATION
52	53	SAND	50% sand Average 0.45 mm	DILWYN FORMATION
53	54	SAND	50% sand Average 0.38 mm	DILWYN FORMATION
54	55	SAND	50% sand Average 0.49 mm	DILWYN FORMATION
55	56	SAND	50% sand Average 0.46 mm	DILWYN FORMATION
56	57	SAND	50% sand Average 0.46 mm	DILWYN FORMATION
57	58	SAND	50% sand Average 0.52 mm	DILWYN FORMATION
58	59	SAND	50% sand Average 0.74 mm	DILWYN FORMATION
59	60	SAND	50% sand Average 0.70 mm	DILWYN FORMATION
60	61	SAND	50% sand Average 0.58 mm	DILWYN FORMATION
61	62	SAND	50% sand Average 0.68 mm	DILWYN FORMATION
62	63	SAND	50% sand Average 0.83 mm	DILWYN FORMATION
63	64	SAND	50% sand Average 1.00 mm	DILWYN FORMATION
64	65	SAND	50% sand Average 0.64 mm	DILWYN FORMATION
65	66	SAND	50% sand Average 0.65 mm	DILWYN FORMATION
66	67	SAND	50% sand Average 0.62 mm	DILWYN FORMATION
67	68	SAND	50% sand Average 0.64 mm	DILWYN FORMATION

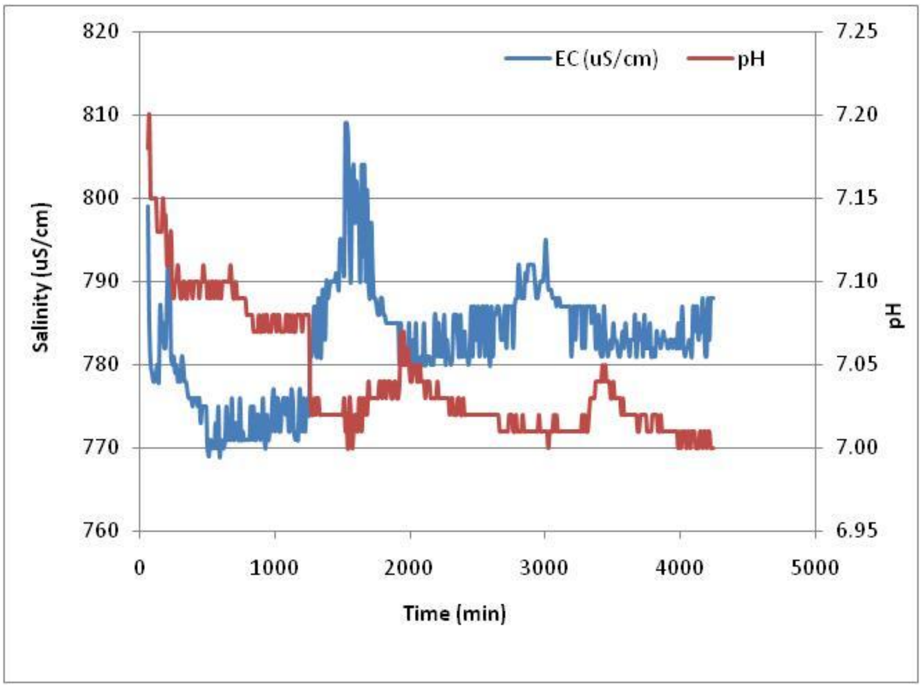
Water Cut Information

Depth (m)		Depth to Water (m)	Supply			Water Analysis		
From	To		L/s	Test Length	Method	Sample No	Salinity	Salinity Unit (mg/L/EC)

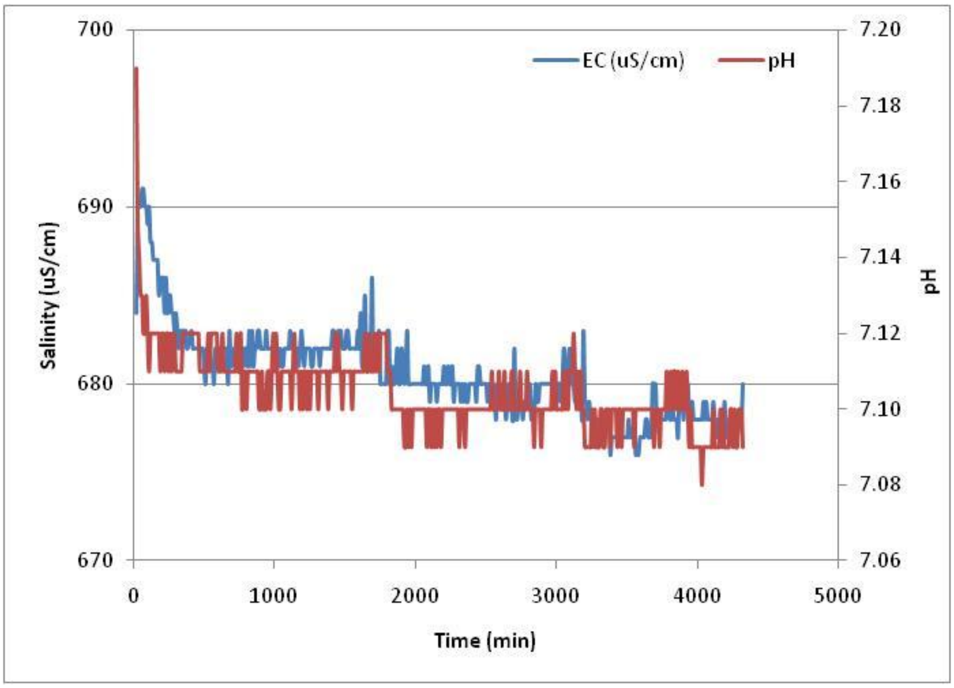
Casing and Production Zone Information

Case or Prod Zone	Depth (m)		Diam. (mm)	Material	Aperture	Cementing		
	From	To				Y/N	From (m)	To (m)
	59	68	200	Stainless steel screen	0.7 mm	Y	0	59

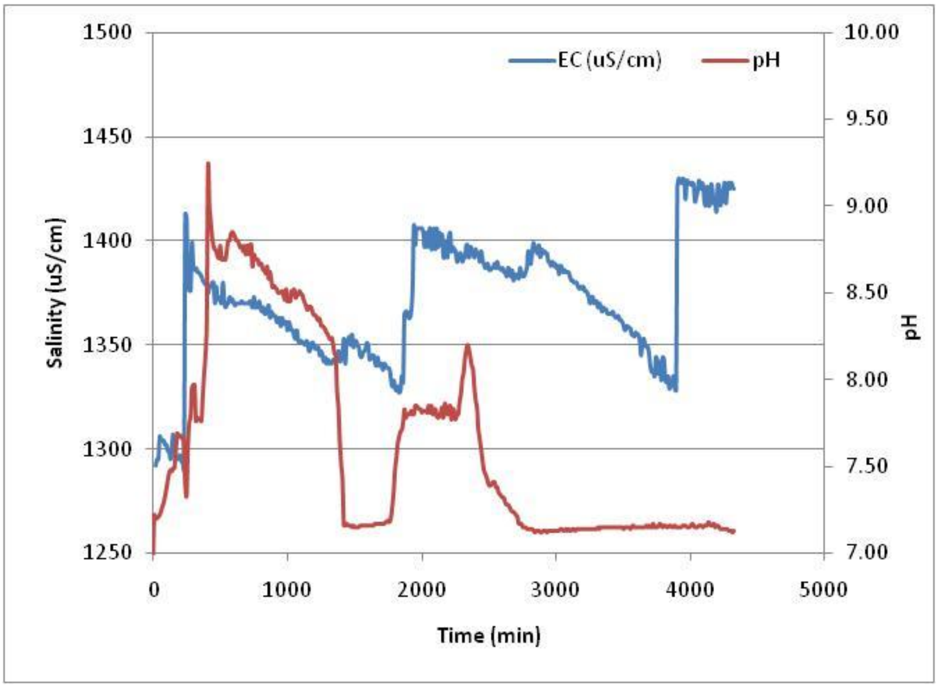
B. WATER QUALITY



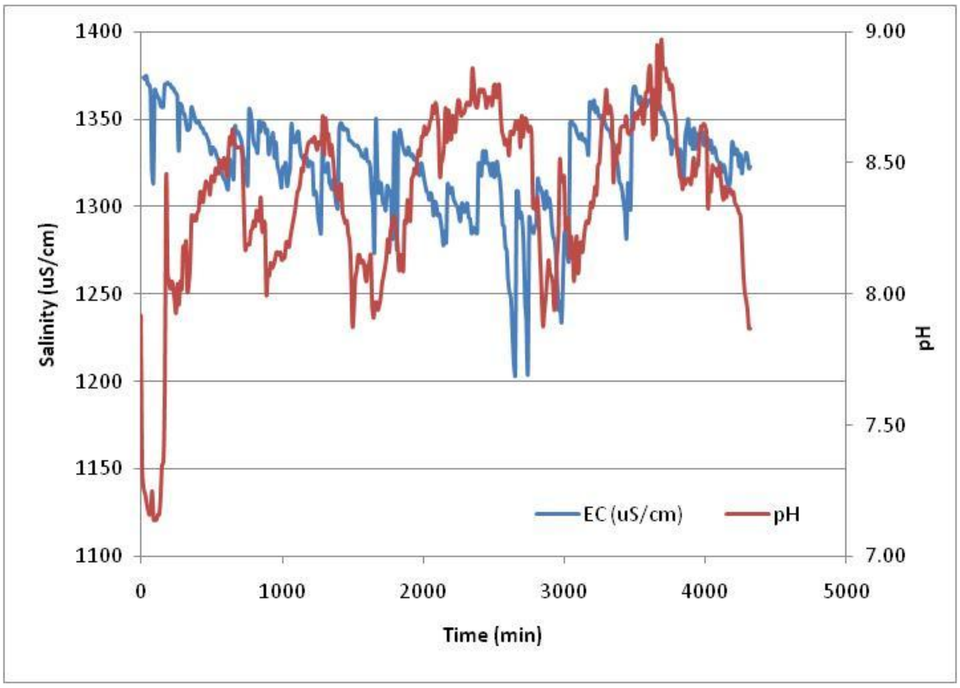
Salinity and pH of aquifer test discharge at site SA1



Salinity and pH of aquifer test discharge at site SA2



Salinity and pH of aquifer test discharge at site SA3



Salinity and pH of aquifer test discharge at site SA3

C. SUMMARY TABLE OF SA PUMPING TEST ANALYSIS RESULTS

Summary Table of SA Pumping Test Analysis Results

Site	Well	Solution		thickness of pumped aquifer	thickness of top aquitard	thickness of bottom aquitard	distance from PW	Leakage factor	Hydraulic resistance	Transmissivity of pumped aquifer	hydraulic conductivity of pumped aquifer	storage co-effient (pumped aquifer)	vertical hydraulic conductivity of top aquitard
				b	b'	b"	r	r/L	c (min)	T1	k1	S1	k'
		aquifer type	analysis model	m	m	m	m			m2/day	m/day	(-)	m/day
SA 1	confined	confined	Theis	***14***	N/A	N/A	50	N/A	N/A	496	*35.4*	5.30E-04	N/A
		confined	Theis with boundary	***14***	15	6	50	N/A	N/A	655	*38.9*	2.70E-04	N/A
		leaky	Hantush-Jacob 1955					0.03	7.99E+06	446	*31.9*	6.39E-04	2.70E-03
	aquitard	N/A	N/A				10	N/A	N/A	N/A	N/A	N/A	N/A
	mepunga	N/A	N/A				5	N/A	N/A	N/A	N/A	N/A	N/A
							average			532	*35.4*	4.80E-04	0.0027

Site	Well	Solution		thickness of pumped aquifer	thickness of top aquitard	thickness of bottom aquitard	distance from PB	Leakage factor	Hydraulic resistance	Transmissivity of pumped aquifer	hydraulic conductivity of pumped aquifer	storage co-effient (pumped aquifer)	vertical hydraulic conductivity of top aquitard
				b1	b'	b"	r	r/L	c (min)	T1	k1	S1	k'
		aquifer type	analysis model	m	m	m	m			m2/day	m/day	(-)	m/day
SA 2	confined	confined	Theis	***19***	N/A	N/A	50	N/A	N/A	1540	*73.4*	1.25E-04	N/A
		leaky	Hantush-Jacob 1955					0.01	2.64E+05	1610	*123.8*	1.36E-04	4.60E-02
	aquitard	N/A	N/A				5	N/A	N/A	N/A	N/A	N/A	N/A
	mepunga	N/A	N/A				5	N/A	N/A	N/A	N/A	N/A	N/A
							average			1575	*98.6*	1.31E-04	0.0460

Site	Well	Solution		thickness of pumped aquifer	thickness of top aquitard	thickness of bottom aquitard	distance from PB	Leakage factor	Hydraulic resistance	Transmissivity of pumped aquifer	hydraulic conductivity of pumped aquifer	storage co-effient (pumped aquifer)	vertical hydraulic conductivity of top aquitard
				b1	b'	b"	r	r/L	c (min)	T1	k1	S1	k'
		aquifer type	analysis model	m	m	m	m			m2/day	m/day	(-)	m/day
SA 3	confined	confined	Theis	***12***	N/A	N/A	31	N/A	N/A	281	*23.4*	6.20E-05	N/A
		Confined	Cooper & Jacob		25	N/A	31	N/A	N/A	283	*23.6*	5.98E-05	N/A
		leaky	Hantush-Jacob 1955				31	0.003	8.75E+07	267	*7.9*	7.10Ee-5	3.13E-04
	aquitard	N/A	N/A				23	N/A	N/A	N/A	N/A	N/A	N/A
	unconfined	N/A	N/A				5	N/A	N/A	N/A	N/A	N/A	N/A
							average			277.00	18.28	0.00	0.000313

Site	Well	Solution		thickness of pumped aquifer	thickness of top aquitard	thickness of bottom aquitard	distance from PB	Leakage factor	Hydraulic resistance	Transmissivity of pumped aquifer	hydraulic conductivity of pumped aquifer	storage co-effient (pumped aquifer)	vertical hydraulic conductivity of top aquitard
				b1	b'	b"	r	r/L	c (min)	T1	k1	S1	k'
		aquifer type	analysis model	m	m	m	m			m2/day	m/day	(-)	m/day
SA 4	confined	confined	Theis	***31***	N/A	N/A	25	N/A	N/A	2230	71.9	1.43E-05	N/A
		confined	Cooper & Jacob		11	2	25	N/A	N/A	2260	72.9	1.16E-05	N/A
		leaky	Hantush-Jacob 1955					0.002	5.52E+06	1610	51.9	5.36E-04	2.87E-03
	aquitard	N/A	N/A				18	N/A	N/A	N/A	N/A	N/A	N/A
	mepunga	N/A	N/A					N/A	N/A	N/A	N/A	N/A	N/A
							average			2033	65.6	0.00019	0.002870

UNITS OF MEASUREMENT

Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^{6} m^{3}	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^{4} m^{2}	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^{3}	volume
kilometre	km	10^{3} m	length
litre	L	10^{-3} m^{3}	volume
megalitre	ML	10^{3} m^{3}	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^{3}	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^{3}	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

GLOSSARY

Aquifer — An underground layer of rock or sediment that holds water and allows water to percolate through

Aquifer, confined — Aquifer in which the upper surface is impervious (see 'confining layer') and the water is held at greater than atmospheric pressure; water in a penetrating well will rise above the surface of the aquifer

Aquifer test — A hydrological test performed on a well, aimed to increase the understanding of the aquifer properties, including any interference between wells and to more accurately estimate the sustainable use of the water resources available for development from the well

Aquifer, unconfined — Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure

Aquitard — A layer in the geological profile that separates two aquifers and restricts the flow between them

Cone of depression — An inverted cone-shaped space within an aquifer caused by a rate of groundwater extraction that exceeds the rate of recharge; continuing extraction of water can extend the area and may affect the viability of adjacent wells, due to declining water levels or water quality

Confining layer — A rock unit impervious to water, which forms the upper bound of a confined aquifer; a body of impermeable material adjacent to an aquifer; see also 'aquifer, confined'

DFW — Department for Water (Government of South Australia)

EC — Electrical conductivity; 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C; commonly used as a measure of water salinity as it is quicker and easier than measurement by TDS

Groundwater — Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground; see also 'underground water'

Hydraulic conductivity (K) — A measure of the ease of flow through aquifer material: high K indicates low resistance, or high flow conditions; measured in metres per day

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes and the properties of aquifers; see also 'hydrology'

m AHD — Defines elevation in metres (m) according to the Australian Height Datum (AHD)

Mepunga Formation – a confined sand unit. It is a transitional unit between the Gambier Limestone and the Dilwyn Formation.

Model — A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions. Examples include estimating storm run-off, assessing the impacts of dams or predicting ecological response to environmental change

Narrawaturl Marl – transitional unit found at the base of the Gambier Limestone. Characterised by usually strong Glauconitic staining in a predominantly grey marl.

Observation well — A narrow well or piezometer whose sole function is to permit water level measurements

Obswell — Observation Well Network

Permeability — A measure of the ease with which water flows through an aquifer or aquitard, measured in m^2/d

Piezometer — A narrow tube, pipe or well; used for measuring moisture in soil, water levels in an aquifer, or pressure head in a tank, pipeline, etc

Potentiometric head — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer, measured in metres (m); also known as piezometric surface

Specific storage (S_s) — Specific storativity; the amount of stored water realised from a unit volume of aquifer per unit decline in head; it is dimensionless

Specific yield (S_y) — The volume ratio of water that drains by gravity, to that of total volume of the porous medium. It is dimensionless

T — Transmissivity; a parameter indicating the ease of groundwater flow through a metre width of aquifer section (taken perpendicular to the direction of flow), measured in m^2/d

Tertiary aquifer — A term used to describe a water-bearing rock formation deposited in the Tertiary geological period (1–70 million years ago).

Tertiary Confined Sand Aquifer (TCSA) – comprises the clay and sand units of the Dilwyn Formation.

Tertiary Limestone Aquifer (TLA) – for the purposed of this report is defined as groundwater contained within either the Sandstone of the Bridgewater Formation or the Gambier limestone.

Transmissivity (T) — A parameter indicating the ease of groundwater flow through a metre width of aquifer section

Underground water (groundwater) — Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground

Water quality data — Chemical, biological and physical measurements or observations of the characteristics of surface and groundwaters, atmospheric deposition, potable water, treated effluents and wastewater and of the immediate environment in which the water exists

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