DWLBC REPORT

Regional Disposal Strategy, Renmark Group Deep Injection: Phase II Feasibility Study

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Government of South Australia

Department of Water, Land and Biodiversity Conservation

Regional Disposal Strategy – Renmark Group Deep Injection: Phase II Feasibility Study

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Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation

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FOREWORD

South Australia's unique and precious natural resources are fundamental to the economic and social wellbeing of the State. It is critical that these resources are managed in a sustainable manner to safeguard them both for current users and for future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are managed so that they are available for all users, including the environment.

In order for us to best manage these natural resources it is imperative that we have a sound knowledge of their condition and how they are likely to respond to management changes. DWLBC scientific and technical staff continues to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

Rob Freeman
CHIEF EXECUTIVE
DEPARTMENT OF WATER, LAND AND BIODIVERSITY CONSERVATION

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Phil Paterson (DWLBC) for conducting flow testing.

Gary Greeves (Stoney Pinch Quarry) for earthmoving.

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1. EXECUTIVE SUMMARY

The Phase II Feasibility study has been built on initial work by the Knowledge and Information Division (KID) to develop alternative strategies for the disposal of saline groundwater in the Riverland. Since 2004, significant investment has been made in the Chowilla region to investigate deep aquifer disposal. Originally, it was proposed to inject groundwater into the Murray Group Limestone Aquifer at Gum Flat, however aquifer testing concluded that the Aquifer was not permeable enough to receive the large quantities of groundwater required to make a Salt Interception Scheme viable and the study was truncated.

Follow on work from the Murray Group Limestone study involved the investigation of the Renmark Group Aquifer as a possible alternative for deep aquifer injection. A three phased approach was adopted to minimise cost risks of which Phase I: Desktop Study was completed in November 2005 (Rammers et al, 2005). This study concluded that the Warina Formation may be a suitable aquifer for deep aquifer injection, provided risks from physical, chemical, biological and mechanical clogging; and disposal related seismic activity was low.

This study – Phase II Feasibility – sought to answer these questions by constructing an investigation well (WARINA 1) into the Renmark Group Aquifer and conducting flow testing, chemistry sampling, clogging studies and seismic analysis. WARINA 1 was drilled as an investigation well that would function as long-term monitoring well and was completed in the Warina Sands between depths 410–440 m. The well yielded at ~8 L/s under artesian conditions. Existing Monomon Sands wells were selected close to the investigation site, purged and sampled for a suite of chemical parameters. These results were used for clogging and geochemical modelling studies.

This report outlines the results and methods of the hydrogeological investigation performed by the Department of Water, Land and Biodiversity Conservation (DWLBC) including well construction, sample collection, lithological interpretation, geophysical logging and particle size analysis. Appendix 10 reports on the Clogging and Geochemical Modelling studies undertaken by the Commonwealth Scientific Industrial and Research Organisation (CSIRO) including chemical, geochemical and mineralogical interpretation of water and well cutting samples collected from the investigation site. Appendix 11 outlines the seismic hazards/risks associated with deep aquifer injection from case studies abroad, and then focuses on the known seismic activity in South Australia and the likelihood of induced seismicity at the Chowilla site. The study was undertaken by Environmental Systems and Services.

Results from construction show that WARINA 1 penetrated 36 m of Monomon Sands, 64 m of Lower Loxton/Bookpurnong/Winnambool clay (confining layer), 112 m of Murray Group Limestone (MGL), and 195 m of interbedded clay and sand which belong to the Ettrick and the Olney Formations. The *basal* Warina Formation comprised medium to coarse sands and gravel and was located 407–460 m below ground level (bgl). Detailed lithologic description for WARINA 1 is included in this report. The lithologic descriptions were based on drilling cuttings collected every 2 m, supplemented by geophysical log data. WARINA 1 was terminated in pre-Tertiary clays at 537 m.

Particle size analysis was undertaken on the Warina Sand samples and initial estimates were made for hydraulic conductivity. Results show that the Warina Sand is a poorly graded coarse sand, with an estimated hydraulic conductivity between 0.017 cm/s (15.45 m/d) to 0.56 cm/s (481.77 m/d). Estimates of hydraulic conductivity from a shut in flow test performed on the well are 16.85 m/d (0.0185 cm/s) to 19.18 m/d (0.0222 cm/s) which is less than the particle size analysis. The particle size analysis results were biased towards the higher hydraulic conductivities because a considerable amount of fine sands were lost during the sample collection process.

Clogging studies show that physical clogging from particulate matter in the source recharge water (Monomon Sands) and precipitation of iron hydroxides are the key risks for hydraulic efficiency during a Phase III injection trial. These risks can be reduced to acceptable levels by ensuring adequate settling of particulate matter prior to injection and reducing the time the source Monomon Sands water is exposed to air. This will prevent the equilibration of gas phases between the atmosphere and source recharge water and the oxidation of soluble Fe^{2+} to insoluble Fe^{3+}.

If an injection well is drilled in a Phase III study, the construction method will play an important role in the success of the project. Given that drilling is into an unconsolidated formation, the rate of clogging is highly dependent on the choice of drilling technique, the quality of the drilling, well design and completion, as well as flushing and redevelopment methods. Consideration of drilling fluid (biodegradable mud/bentonite) screen type, and completion technique (natural pack or gravel pack) will play an important role in determining the efficiency of the well and the outcome of any remediation work should clogging occur.

Seismic studies by McCue (2007) show that there is a very low likelihood that deep aquifer injection of the proposed method would have significant impact on seismic related activity. Most induced seismic events generated by aquifer injection in case studies abroad have been in wells deeper than 5 km and into basement rock. The shallow and porous nature of the sediments of the Renmark Group are largely different.

Recorded seismic events at Chowilla are sparse, and the lack of seismic monitoring equipment close to the SA/NSW/Victoria border has made it difficult to locate and record events in the area. It is likely that earthquakes felt at Chowilla would have their source from the lower Finders Ranges, an area some hundred kilometres from Chowilla.

As a precaution a small stand-alone network of up to six seismographs is recommended to record baseline seismic data and for monitoring during an injection trial. An operational plan should be adopted so that injection can be quickly stopped in the event of an earthquake. This will require an earthquake detection and alert system with 24 hour accessibility.

2. INTRODUCTION

The goal for constructing, sampling, chemical analysing and testing WARINA 1 was to collect geologic, hydrologic, hydrochemical and geochemical data with which injection and clogging assessment of the Warina Sands Aquifer could be made. It was hoped that the construction of this well would help to determine the capability of the Warina Sands in receiving large quantities of injected groundwater on a long term basis.

This report contains construction and scientific data gathered during drilling and from laboratory testing, including detailed analysis and interpretation of geologic, geophysical, hydrological and geochemical data. This report also contains information on contract and contract management, the drilling company, site supervision, roles and responsibilities of personnel, management of fluid used and generated during drilling, well construction, development, aquifer testing, groundwater analytical sampling, clogging potential, and potential for induced seismic activity.

A thorough Phase II study is required to outline the important scientific risks associated with deep aquifer injection. The most important outcome of Phase II is to determine whether the Warina Formation is capable of receiving the large volumes which would make an injection scheme viable; and to outline the risks of deep aquifer injection from a well clogging perspective.

It is hoped that a successful Phase II investigation will pave the way for a Phase III injection trial. The injection trial will involve the design and implementation of a large diameter injection well and the construction of multiple feeder production wells drilled close to the injection site. Significant resources and infrastructure will be required in establishing the trial, including the sourcing of power, which is currently unavailable on the Chowilla Floodplain.

3. OBJECTIVES

The primary scientific objectives for this work, as discussed in the drilling contract, include:

- Establish the presence, depth, and thickness of the Warina Sands aquifer; including overlying aquitards.
- Obtain hydrogeologic data from the Warina Sands aquifer to assess its suitability for saline groundwater disposal.
- Obtain water quality data from the shallow unconfined aquifer (Monomon Sands) and the targeted deep Warina Sands aquifer to assess well/aquifer clogging potential.
- Investigate induced seismicity risks associated with injection into the Warina Sands.
- Report on well construction success/failures.
- Make recommendations for a Phase III injection trial.

4. SITE LOCATION

4.1 *SITE PHYSICAL DESCRIPTION*

The Chowilla region is located ~40 km north-east of Renmark on the River Murray on the tri-state border of South Australia, Victoria, and New South Wales. The region covers an area of 17 700 ha (177 km^2) of Government owned and leasehold land (Fact Sheet 24, DWLBC). It is a Regional Reserve of ecological and hydrogeological significance to the Murray River which includes more than 100 km of anabranch creeks, great stands of river red gum forest, Mallee eucalypts, black box woodland and bluebush shrubland.

The area is relatively flat, typically rising from 15–25 m AHD. The Chowilla Region is located in a semi-arid environment with a mean annual rainfall of ~260 mm and average evaporation of 1960 mm/y. Most of the rain falls during the months of April to August. The mean daily maximum and minimum temperature for summer is ~32 ^{o}C and 15 ^{o}C respectively while the mean daily maximum and minimum temperature for winter is ~16–17 ^{o}C and 6 ^{o}C (Walker et al, 1996).

4.1.1 LOCATION OF INVESTIGATION WELL

The drillsite is located on the western side of the Chowilla Floodplain between Werta Wert Wetland and Monomon Creek (Fig. 1). The coordinates of the drillsite are **E** 488369 and **N** 4243449.

The Werta Wert site was selected after reviewing planned activities on the Chowilla Floodplain including a salt interception scheme and Chowilla Creek Regulator. In selecting the location, consideration was given to site access, elevation (m AHD), existing shallow observation wells (for groundwater sampling) and infrastructure (nearest power source[1]).

4.2 *SITE HYDROGEOLOGIC CONDITIONS*

The Warina Sands forms the basal and deepest section of the Renmark Group Aquifer and is the target aquifer for deep aquifer disposal. The Renmark Group aquifer is confined and is regionally extensive throughout the Murray Basin.

The principal water-bearing units of the Murray Basin in South Australia are the Loxton and Monomon Sands, MGL, and the Renmark Group. The non-water bearing Bookpurnong Formation separates the MGL formation from the Loxton and Monomon Sands, and the Ettrick Formation separates the MGL formation from the Renmark Group Aquifer. A summary of the Tertiary stratigraphy at the study site (Chowilla Floodplain) can be seen in Table 1. Figure 2 shows the Tertiary stratigraphy in the South Australian part of the Murray Basin.

A detailed geological and hydrogeological summary of the Warina Sands and other important hydrogeological units at the study site can be seen in the *Regional Disposal Strategy – Renmark Group Deep Injection: Phase 1: Desktop Study* (Rammers et al, 2005).

[1] *There is no connection to the main electricity grid anywhere on the Chowilla Floodplain. The nearest source is at Lock 6, ~5 km to the south-south-east.

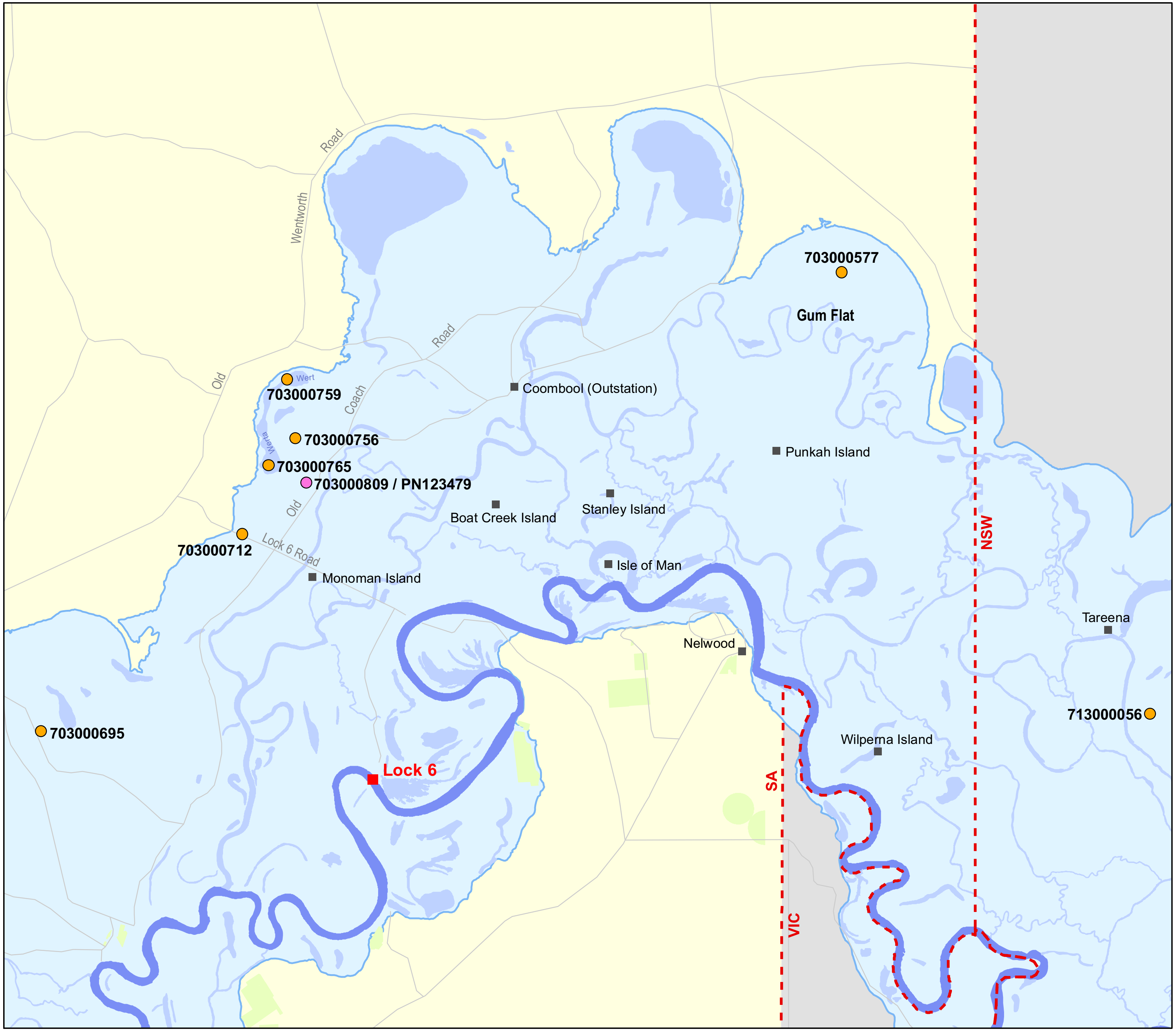


FIGURE 1: LOCATION MAP RENMARK GROUP OBSERVATION WELL

Locality

Lock

703000809 / PN 123479 Unit No.

Renmark Group Observation Well

703000756 Unit No.

Sampled Well, Monomon Formation

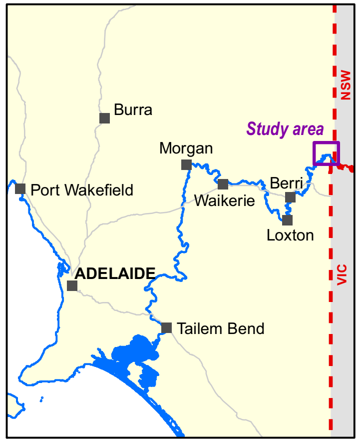
Road

Wetland

River Murray

1956 Flood level

Irrigated area 2001



0 1 2 km

Map Production: Resource Information Group
Department of Water, Land and Biodiversity Conservation

Map Projection: MGA Zone 54.
Map Datum: GDA94.

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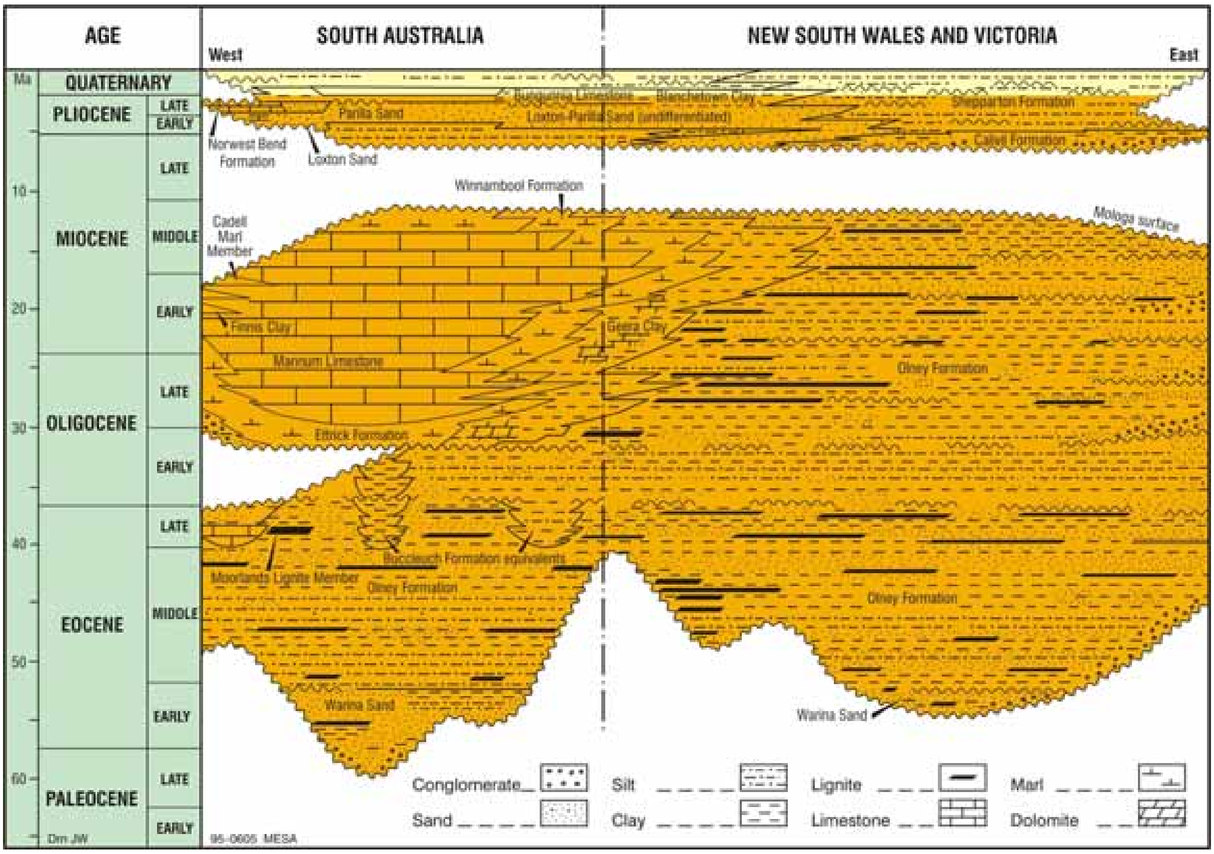

Figure 2. Tertiary stratigraphy of the Murray Basin (Drexel & Priess, 1995)

Table 1. Tertiary Murray Basin sediments at Chowilla

Age	**Name**	**Expected depth bgl** (m) **at Chowilla Floodplain**	**Comment**	**Regional water level** (m AHD)
Late Pleistocene to Holocene	Coonambidgal Formation	0–4	Sandy clayey topsoil.	
Late Pleistocene to Early Holocene	Monomon Sands	4–40	Medium to coarse sands and gravel.	16.5
Pliocene	Loxton Sands		Fine to coarse sands.	
Pliocene	Lower Loxton Clay	40–65	Silty clay.	
Late Miocene to Early Pliocene	Bookpurnong Formation	65–85	Grey green fossiliferous silts and clay.	
Late Oligocene to Middle Miocene	Winnambool Formation	85–100	Clayey Marl.	
Late Oligocene to Middle Miocene	Murray Group Limestone	100–200	Consolidated with hard bands.	27
Oligocene to Early Miocene	Ettrick Formation	200–250	Grey green glauconitic Marl. Grey fossiliferous fine-medium sand.	
Eocene to Middle Miocene	Olney Formation	250–400	Interbedded carbonaceous clays and sands.	
Eocene	Warina Sands	400–550	Medium to coarse sand and gravel.	32
Early Cretaceous	Coombool Member	>500		

5. WELL DESIGN AND CONSTRUCTION

5.1 REGIONAL WELLS AND PROPOSED WELL DESIGN

Stratigraphic information and structure contours generated during the Phase 1 Desktop Study (Rammers et al, 2005), regional well information, and hydrogeological literature were used to determine the target depth and well design for WARINA 1. Table 2 lists the regional Renmark Group Aquifer observation wells close to the Chowilla Site.

Table 2. Nearest regional Renmark Group observation wells.

Name	Unit number	Easting	Northing	Distance/ direction from WARINA 1	Depth to Top Tr* (m)	Depth to Bottom Tr (m)	Thickness Tr (m)
Cooltong 1	702900985	466804	6225568	28 km SW	236	557	321
North Renmark 1	702900004	470918	6225027	25 km SW	215	548	333
36782-4 (NSW)	713000009	512256	6241642	24 km E	258	488	230
Olney 1	702900002	498589	6228723	18 km SE	278	600	322
M155	703000002	459558	6275618	43 km NW	194	340	146
Loxton 2	702800002	462885	6177379	70 km WSW	204	412	408

* Tr denotes Tertiary Renmark Group (Drexel and Preiss, 1995)

Table 2 shows that the closest Renmark Group Observation well is ~20 km to the south-east (Olney 1), while the second is the 24 km to the east (NSW well 36782-4). The depth to the bottom of the Warina Formation for these wells is 600 m and 488 m respectively, while the aquifer thickness of the Renmark Group for these wells is 322 and 230 m.

5.1.1 WELL DESIGN

A conservative approach was taken in estimating the target depth of WARINA 1. The design was based on three stages, assuming that the maximum depth to the bottom of the Warina Formation would be 600 m.

Stage 1 would involve the drilling of a pilot hole to the top of the MGL, and installing surface control casing to isolate the shallow aquifers (Monomon Sands and Bookpurnong Formation) from the underlying MGL, Ettrick Formation, Olney Formation and Warina Sands. Drilling of a 311 mm hole to ~100 m, installing 203 mm PVC casing from 0–100 m, and then grouting, would ensure that the surficial aquifers (Monomon Sand) would be isolated from the underlying MGL and Renmark Group aquifers.

Stage 2 would involve drilling to the bottom of the Warina Sands with a 200 mm drill bit and geophysically logging the hole to refine the stratigraphy and aid in lithological interpretation. 100 mm Fibre-glass Reinforced Plastic casing (FRP) would then run to ~30 m above the well completion zone, and would ensure adequate isolation of the MGL, Ettrick and Olney Formation Aquifers from the Warina Sand.

Completion of the hole (Stage 3) with a 30 m, 75 mm wirewound stainless steel screen (Grade 316 stainless steel) would then take place by lowering the screen into the FRP casing to selected screen interval.

The construction design can be seen in Figure 3.

5.2 TENDERING

An Australian wide call was made for submission to tender for the construction of the Warina Sands investigation/observation well. Three drilling contractors responded to the tender to drill an investigation well, construct an observation well and provide a quote for an injection well.

Of the three that responded, only one was found suitable in meeting the tendering criteria (Sides Drilling Contractors Pty Ltd). Sides Drilling provided a thorough, well-considered tender bid, and although they had some non-conforming issues, these were considered minor and were appropriately negotiated prior to the awarding of contract. The other two tender bids (Drilltec Pty Ltd, K H Adams & Sons Pty Ltd) were considered to be non-conforming.

The tendering recommendation letter can be seen in Appendix 1.

5.3 CLEARANCES AND SITE ESTABLISHMENT

5.3.1 SITE CLEARANCES TO DRILL

Site clearances and permits to drill on the Chowilla Floodplain were obtained from various South Australian Departmental Agencies which included:

- Cultural Heritage/Native Title (Attorney Generals Department).
- Native Vegetation (DEH).
- Dam and mud pit excavation (DEH).
- Well Construction Permit (DWLBC).

Site clearances for underground cables/facilities including telecommunications, electricity and water supply were obtained through the dial before you dig website. Given the remoteness of Chowilla, there were no underground facilities at the site.

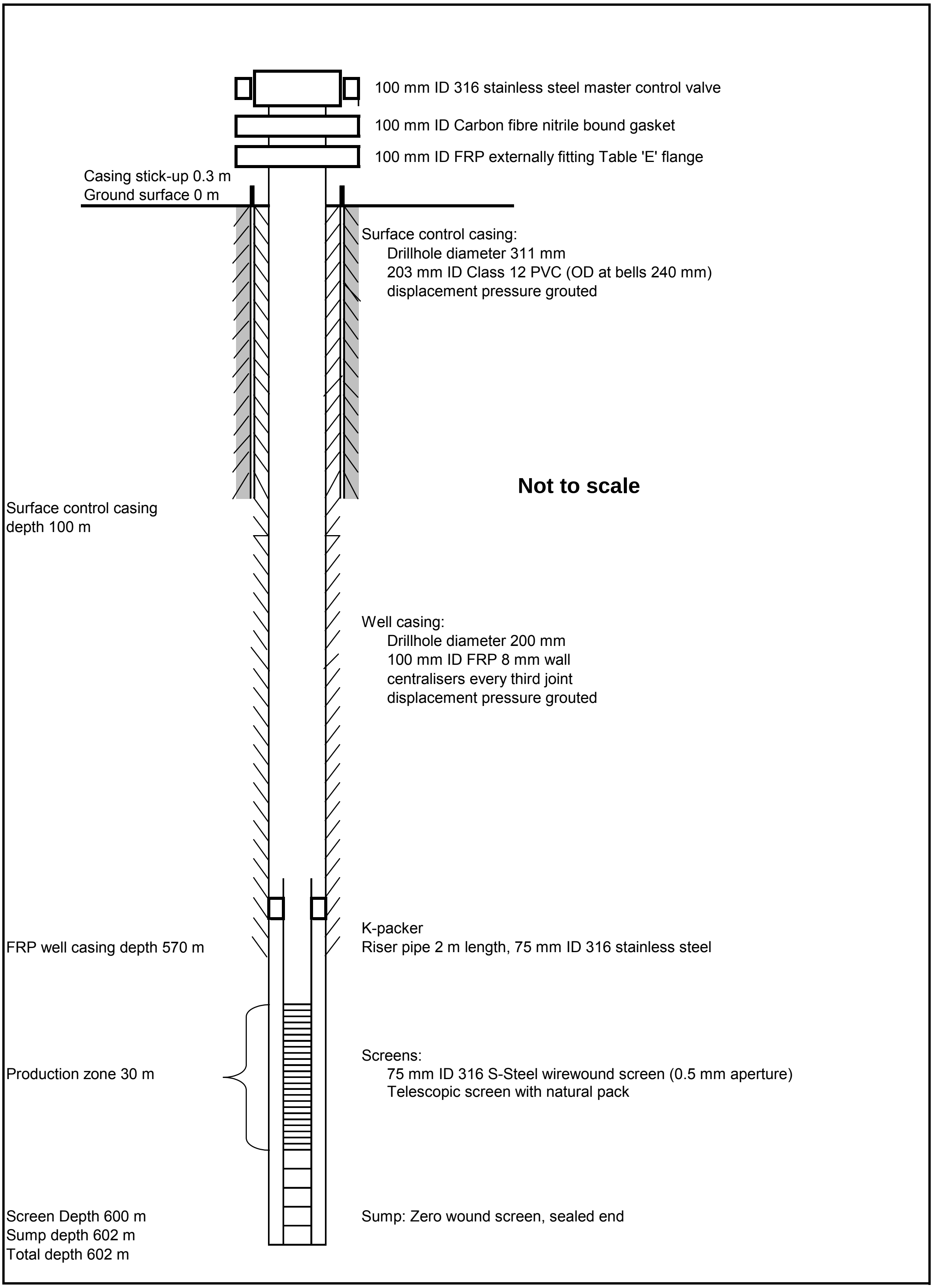

Figure 3. Proposed Warina Sands observation well

5.3.2 DRILL PAD AND SUMP CONSTRUCTION

A drill pad, an unlined holding dam and 3 unlined sumps (mud pits) were constructed on 8^{th} of January 2007 for the drilling and construction of the well WARINA 1. The pad was situated on flat terrain composed of alluvial clay and sand, surrounded by native vegetation in fair to good condition. The pad was constructed to accommodate all of the expected equipment and materials.

The drilling pad had dimensions of 8 x 38 m. The holding dam had dimensions of 21 x 21 x 1.5 m, and was used to store water for mixing of the drilling fluid, and to accommodate water produced during well development. Two of the sumps had dimensions of 3 x 2.5 x 2 m and were used to store, condition and circulate the drilling mud. The third sump had dimensions of 3 x 2 x 2.5 m and was used to collect and dispose of the cuttings as they arrived at the surface and pass through the shale shaker. Soils of the holding dam and the sumps consist of a layer of alluvial grey clay (Coonambidgal Clay).

Figures 4, 5 and 6 show the site layout including construction site, holding dam and mud pit.

5.3.3 DRILLING FLUID MANAGEMENT

The unlined holding dam storage sumps were used to manage all fluids used and generated during drilling, well construction, development and testing. The holding dam and sumps had a combined holding capacity >720 000 L. Source of water for drilling came from Monomon Creek, sourced from Campsite 15 ~2 km north of the site. The unlined holding dam was used to store water for drilling.

The dimensions of the dam were based on a 10-hour development period assuming that the well would yield at 10 L/s. The volume was then multiplied by two, giving a total dam capacity of 720 000 L.

5.3.4 SITE HEALTH AND SAFETY

Onsite health and safety was managed by Site Supervisor Peter Freeman of Sides Drilling. Onsite visitors were managed by Wellsite Hydrogeologists (Paul Magarey, Adrian Costar) who supplied hard hats and OHS information to visitors from the Adelaide and Berri Field Office (DWLBC).

A National Parks representative from DEH visited early in the mobilisation process to mark appropriate areas for vehicle access. This was to ensure that remnant stands of native vegetation were kept in tact and not affected by uncontrolled vehicle access from trucks, tractors and utility vehicles.

5.3.5 WASTE MANAGEMENT

All on-site waste was managed by Sides Drilling. Hard rubbish was removed throughout the drilling phase and disposed in a portable “mini skip” bin. Drill cuttings were disposed into a holding sump and buried at the completion of drilling.

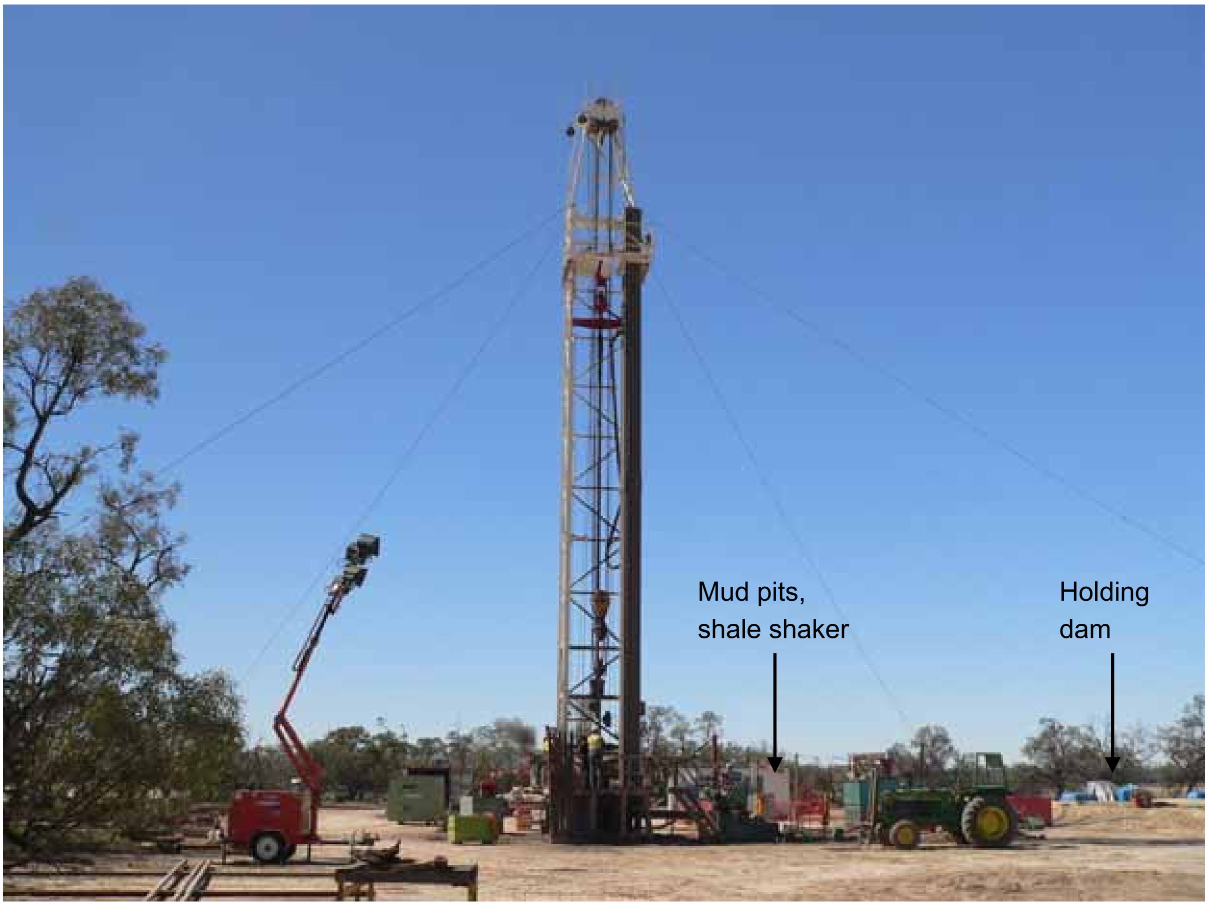

Figure 4. Drilling Rig and Construction Site near Werta Wert Wetland (photo courtesy Tony Herbert)

Figures 5, 6. Unlined holding dam and disposal sump (mud pit). The holding dam was used to store water during the mixing of drilling fluid; and to store water that was produced during development. The disposal sump collected unused sample cuttings as they passed over the shale shaker. The de-sander in the (top/middle) was used to separate the very fine material suspended in the drilling fluid that passed through the screen of the shale shaker (Photos courtesy Tony Herbert).

5.3.6 SITE RESTORATION

Upon completion of WARINA 1 Sides Drilling cleared all construction debris including accumulated rubbish. Gary Greeves of Stoney Pinch quarry backfilled and levelled out the construction pad, dam and mud pits to the satisfaction of the DEH.

5.4 DRILLING AND WELL CONSTRUCTION

The earthworks, mobilisation, drilling, casing, screening and development of WARINA 1 took ~3 weeks to complete. Appendix 2 shows a timeline of the events that took place throughout the drilling and construction phase; including setting of surface control casing, geophysical logging, setting of FRP casing, installation of well screen and development of the hole. Sides Construction/Drilling Report can be seen in Appendix 3. The Sides Drilling report includes information on drillhole diameter, penetration rates, mud viscosity, estimated lag time, materials used and drillers log.

Preparation of the drilling pad including construction of mud sumps and holding dam took place from Monday 8th of January 2007 to Wednesday 10th of January 2007. The Sides drilling team arrived on the 10th of January 2007 with the transportation of heavy machinery including mud pumps, drilling rods and tools. The 33 m Gardner Denver 2500 (GD 2500) drill rig arrived shortly after, and mobilisation of the drill rig and drilling platform commenced (Fig. 7).

5.4.1 DRILLING

A surface conductor hole was drilled by dry auguring a 375 mm hole on 13 January 2007 to a depth of 3 m below ground surface. 350 mm surface control PVC casing was then set to 3 m and centrally located in the hole. The bottom of the casing was cemented in place with cement grout which was placed into the annulus between the surface control casing and the drill hole. The surface control casing extended 300 mm above ground surface.

Drilling commenced on Sunday 14th January 2007 into the unconfined Monomon Sands and continued on a 24 hour basis until Saturday 27th January 2007. The hole was advanced using direct mud rotary drilling in which the uncased wall of the borehole was held in place at all times with the circulating fluid. The circulating fluid was a sodium based bentonite mud, mixed onsite using Aus-Gel as the base mud agent and freshwater sourced from the Monomon Creek. The mud was monitored and conditioned regularly to obtain optimum viscosity. Common additives that were used in conditioning included sodium bi-carbonate, Liqui-sperse, Soda Ash, Pac-R and Barites. More information on the timing of additives and quantity used can be seen in Appendix 3 (Sides Drilling Report).

Drilling of the main (pilot) hole with a 311 mm rotary bit commenced on 14 January 2007, (24 hours after the installation of the surface conductor hole) and continued to a depth of 104 m. This depth represents the top of the MGL aquifer. At this depth the drilling was suspended for installation and grouting of 203 mm ID Class 12 PVC casing from the surface to the top of the MGL aquifer. The casing was pressure grouted from the bottom (104 m) to the ground

Figure 7. The GD 2500 Drill Rig used to construct WARINA 1

surface with 5% bentonite grout. The well was re-entered after grout was cured and a 200 mm hole was drilled from the top of the MGL aquifer to a total depth of 537 m. The hole was cleaned top to bottom and geophysically logged.

5.5 COLLECTION OF GEOLOGIC INFORMATION

This section describes the sources of geologic data obtained from the well and the method of data collection. Geologic data collected from WARINA 1 consists of drill cuttings and a geophysical log. During drilling the cuttings were routed to a shale shaker tray to separate the samples from the drilling mud and to aid in the collection of samples (Fig. 8). The separated mud was recycled into the holding sumps and the drill cuttings were collected manually off the shaker screen at 2 m intervals throughout the drilling operation. During drilling effort was made to obtain enough material for duplicate and triplicate samples. The drill cuttings were collected as samples for lithological logging purpose, textural analysis, particle size analysis, geochemical analysis and mineralogy.

Figure 8. Shale Shaker used to separate the cuttings and drilling fluid for sample collection (photo courtesy of Tony Herbert)

The drilling cuttings were collected continuously and labelled as drilling progressed from ground surface to 508 m. Cuttings were not collected between the depths 508–537 m as they were contaminated by heavy rainfall on Saturday 27th of January 2007.

In the first 374 m, materials were collected for duplicate samples – including an archive sample and chip tray (reference) sample. The archive samples – each consisting of five hundred grams of drill cuttings collected at two meter intervals – were placed in vials and submitted to the PIRSA core library. Small portion of the cuttings (sub-samples) collected at 2 m intervals were placed in chip trays and were retained by DWLBC for reference purposes. Photos of the chip trays can be seen in Appendix 4.

Between 374–460 m cuttings were collected every 2 m for triplicate samples consisting of 500 g as archive (Glenside Core Library); 2 kg for particle size/mineralogical analysis; and ~50 g for chip tray (reference) samples.

Cutting samples were lithologically logged and can be seen in Appendix 5.

5.5.1 PROBLEMS ENCOUNTERED DURING SAMPLE COLLECTION

The main problem encountered during sample collection was that a proportion of fine sands were lost from the samples as they surfaced from the hole and passed over the shale shaker screen. The shale shaker screen was in place to separate the sample cuttings from the drilling fluid before collection for the wellsite hydrogeologists. Due to the wider aperture of the shale shaker screen, a proportion of the finer cuttings were lost during the separation process, and re-circulated through the drilling fluid. Some of the samples were recovered using a de-sander (see Fig. 6), however placing the recovered sediment to its correct depth proved impossible and could not be used in lithological interpretations.

5.5.2 GEOPHYSICAL LOGGING

The Geophysical Services Group (DWLBC) took a suite of borehole geophysical logs on Monday 22nd of January 2007 to 537.80 m (bottom of hole). The geophysical logs provided lithologic and stratigraphic information to complement the data retrieved from drill cuttings. The geophysical logs were interpreted to assist in the determination of well screen depth and interval, borehole lithology, lithology correlation as well as the chemical and physical characteristic of the site's groundwater. The suite of geophysical methods used was caliper, natural gamma, neutron, spontaneous potential (SP), medium induction and deep induction.

A composite log including recorded geophysical measurements matched to sample cutting lithology is presented in Figure 9.

From the geophysical log, the Warina Sands Aquifer is located from 407–460 m below ground level (bgl), identifiable from low gamma counts in correlation with high neutron counts.

5.5.3 MODIFIED WELL DESIGN

Prior to installation of the FRP casing concerns were raised (Peter Freeman – Sides Drilling) of the possibility of cementing the main part of the aquifer during grouting. In order to avoid this risk a conservative approach was taken to the screen design.

To support the screen a cement plug was spotted between 448–554 m. After two attempts (the plug was lost upon the first attempt) the drill rods were run into the hole and the plug located at 449 m.

A modified screen was then designed that would sit on the cement plug at 449 m.

This incorporated:

- Installing and cementing FRP casing from 0–398 m.
- blank 75 mm '316' grade stainless running inside the FRP casing from 390.7–410.7 m.
- 75 mm diameter stainless steel (grade 316) wire wound screen (0.5 mm aperture) from 410.7–441 m.
- 75 mm stainless steel (grade 316) blank running from 441–449 m.

FINAL DEPTH OF HOLE: 449 m.

Below 449 m was left as open hole. The final screen design deviated from the original screen design because completion depth was significantly less than anticipated. The completion details and final screen design can be seen in Figure 10.

Warina Sands (Renmark Group) Observation Well
Composite Water Well Log
Unit Number: 7030-809 Permit Number: 123479 Obs Number: N/A
Site 1

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Bore data	
Permit No.	123479
Unit No.	7030-809
Obs. No.	
Purpose	Investigation/Observation

Location Data	
Hundred	OH
Section No.	N/A
Easting (m AMG)	489874.1
Northing (m AMG)	6235279.9
Datum	GDA 94

Elevation data	m AHD
Ground Surface	
Ref. Point above Ground	
Ref. Point	
Top of open interval	
Bottom of open interval	

Drilling data	
Start date	14/01/2007
Finish date	31/01/2007
Driller	Sides Drilling
Drilling Method	Rotary
Circulation	Mud
Maximum depth (m)	537 m
Completed depth (m)	449 m
Samples logged by	Paul Magarey

Post-development data	
Date	19/05/2004
Depth to water below Ref. Pt. (m)	-11.01
SWL (m)	-11.61
RSWL (m AHD)	
Salinity Lab (mg/L)	14,638
EC Lab (uS/cm)	24,370
Yield (L/s)	8.0 L/s
Method	Artesian Flow

Completion data				
Hole Diameter	mm	From	To	Bit
	311	0.0	104.0	R/R
	200	104.0	537.0	R/R
Backfilled		From	To	Material
		N/A	N/A	N/A
Casing Diameter	mm	From	To	Material
	203	0.0	104.0	PVC
	100	0.0	392.0	FRP
	75	392.0	449.0	316 Stainless Steel
Open Hole	mm	From	To	Material
	N/A	N/A	N/A	N/A
		From	To	Type
Grout		0.0	392.0	Cement
Bentonite Seal		N/A	N/A	N/A
Gravel Pack		N/A	N/A	N/A

Chemistry		
pH	6.49	
TDS by EC	18,780	mg/L
EC	31,300	uS/cm
TDS by calc.	15,495	mg/L
Ca	529	mg/L
Mg	578	mg/L
K	75.1	mg/L
Na	6,530	mg/L
HCO3	351	mg/L
CO3	428	mg/L
Cl	4,860	mg/L
SO4	2120	mg/L
Nitrogen - Total	4.62	mg/L
Boron	N/A	mg/L

Geophysics	
Job No.	7602

GEOLOGICAL DETAILS

DEPTH (m) | ELEVATION (m AHD) | LITHOLOGY: UNIT, DESCRIPTION | CONSTRUCTION DETAILS and LITHOLOGICAL LOG | HYDRO DATA

COONAMBIDGAL FORMATION (Quaternary)

0 - 2 **CLAY** Silty. Light yellow brown.

2 - 4 **CLAY** Silty. Light yellow grey. Minor gravel.

MONOMON FORMATION (Quaternary)

4 - 6 **SAND** Mottled grey/white/orange, coarse 1 - 1.5 mm, sub-rounded. Opaque, clear, Fe stained quartz, minor biotite. Root fibres present.

6 - 8 **SAND** Mottled grey/white/orange, coarse 0.6 - 2.0 mm, poorly sorted, sub-angular, predominantly clear quartz with Fe staining.

8 - 10 **SAND** As above, slightly cleaner, some charcoal.

10 - 12 **SAND** Clean, medium to coarse, 0.5 - 3.0 mm, sub-rounded. Orange/clear/white quartz, Fe stained.

12 - 14 **SAND** Coarse, grey/white, 1.0 - 2.5 mm. Grey quartz grains. Lignite present ~50%.

14 - 28 **SAND** Grey to light grey, very coarse, tending to gravel. Well sorted, clean.

28 - 30 **SAND** Coarse, silty, clayey, dark grey/brown, 1.0 - 2.0 mm, minor gravel.

30 - 34 **SAND** Silty fine sand with coarse component (~40%), clayey. Grey to dark grey.

34 - 36 **SAND/GRAVEL** Light grey/white. 1.0 - 3.0 mm, sub-angular, clean.

LOWER LOXTON CLAY (Tertiary)

36 - 38 **GRAVEL** Sandy, silty, with minor gravel, brown. Coarse sands ~ 10 %.

38 - 54 **CLAY** Silty, with minor sand, brownish grey.

54 - 64 **CLAY** Silty, brown. Grading into Bookpurnong Formation at 64 m (fizzes HCL at 64 m).

BOOKPURNONG (Tertiary)

64 - 84 **CLAY** Olive with shell fragments. Fizzes HCL.

WINNAMBOOL (Tertiary)

84 - 100 **MARL** Grey marly limestone/clay, becoming gritty. Strong fizz with HCL.

MURRAY GROUP LIMESTONE (Tertiary)

100 - 104 **LIMESTONE** Grey/white, shelly. Component of marly clay present.

104 - 126 **LIMESTONE** Grey/white marly, minor shell fragments.

126 - 202 **LIMESTONE** Grey to light grey, hard at 126 m, becoming rocky with hard bands at depth.

202 - 212 **LIMESTONE/MARL** Whitish grey with minor olive. Warm.

ETTRICK (Tertiary)

212 - 222 **SILT** Fine to medium sandy silt. Olive grey tending to grey brown. Minor clay/quartz sand.

ETTRICK Yanac Member (Tertiary)

222 - 256 **SAND** Calcareous, fine-medium, grey with minor green; minor coarse component 0.06 - 0.03 mm.

256 - 260 **SAND** Clayey, with minor lignite. Grey brown, transition into Olney Formation.

OLNEY FORMATION (Tertiary)

260 - 264 **LIGNITE/PEAT** Heavy peaty lignite, becoming consolidated.

264 - 268 **CLAY** Brown, heavy with silt/lignite.

268 - 270 **SAND** Fine-medium, minor clay. Brown.

270 - 273 **CLAY** Silty, brown, minor quartz sand.

273 - 285 **SAND/GRAVEL** Greyish brown, coarse tending to gravel, 1.0 - 5.0 mm, unclean. Clay/silt particles stuck to sand grains. Fizzes, HCL.

285 - 328 **CLAY/SILT** Dark brown, clay silt, minor coarse sand (< 5%).

326 Clayey silt, minor sand <5%.

328 - 340 **SAND** Coarse (~60%), with fine-medium component. Lignite, brown/dark brown.

340 - 349 **SAND** Fine to medium, minor coarse component (~30%). Brown.

344 30% coarse 1.0 - 1.5 mm sand; 70% fine to medium (0.1 - 0.3 mm).

349 - 362 **CLAY** Brown, minor sand, <5%.

362 - 380 **SAND** Coarse, poorly sorted, 1.0 - 2.0 mm, some gravel, predominantly clear quartz, some opaque ~25 %.

380 - 407 **CLAY** Sandy, light brown.

WARINA (Tertiary)

407 - 460 **SAND** Coarse, with gravel 1.0 - 3.0 mm, poorly sorted, sub-rounded, opaque and clear quartz.

COOMBOOL MEMBER (Early Cretaceous)

460 - 468 **CLAY** Light grey, minor coarse sand.

468 - 470 **CLAY** Light grey, coarse sand ~10%.

470 - 508 **CLAY** Light grey, tending to brown.

TOTAL DEPTH 537 m

GEOPHYSICAL LOGS

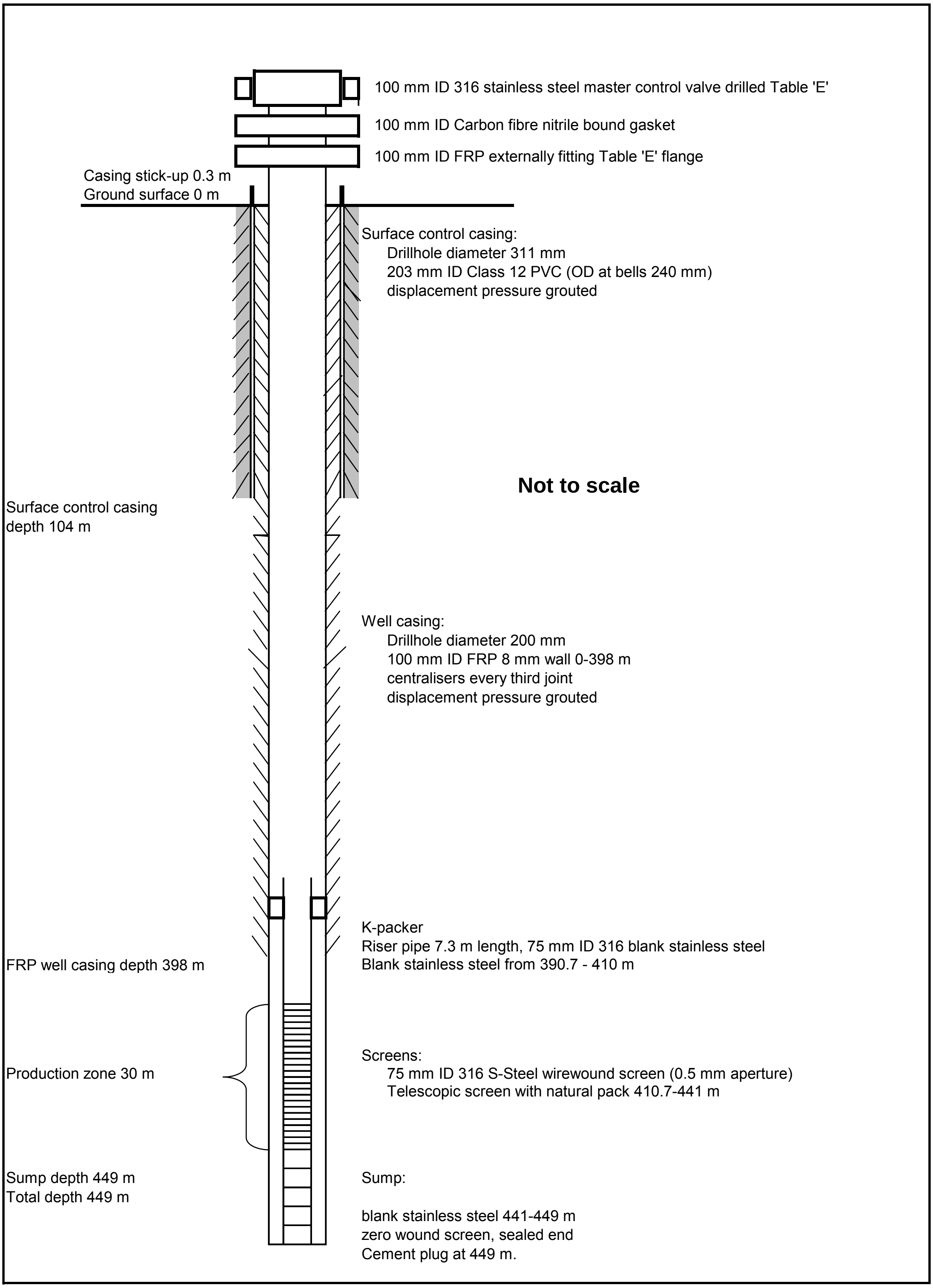

Figure 10. Final design of the Warina Sands Observation well

5.5.4 SCREEN INSTALLATION AND DEVELOPMENT

During installation, the screen was successfully lowered into the 100 mm hole and rested on the cement plug at 449 m. The open part of the screen sat between 410.7–441 m (bgl) and was connected to the FRP casing with a rubber seal. The screen was lowered into the hole with the aid of the drilling rods and was connected to the drilling rods by a “J-latch” (see Fig. 11).

A jetting tool consisted of five, 6 m lengths of galvanised pipe that had been welded together and had a diameter of ~50 mm. Holes were drilled into the sides of the pipe so that air/water could pass through and move into the screen, allowing drilling fluid and loose cuttings to be displaced from the hole. Once the screen had been lowered into the hole, and disconnected from the drilling rods, the jetting tool was lowered into WARINA 1 for development.

During the initial stages of development the drilling fluid (above the screen) was flushed from the hole and the well began to flow at ~0.5 L/s. The water produced was highly contaminated with drilling fluid and formation cuttings.

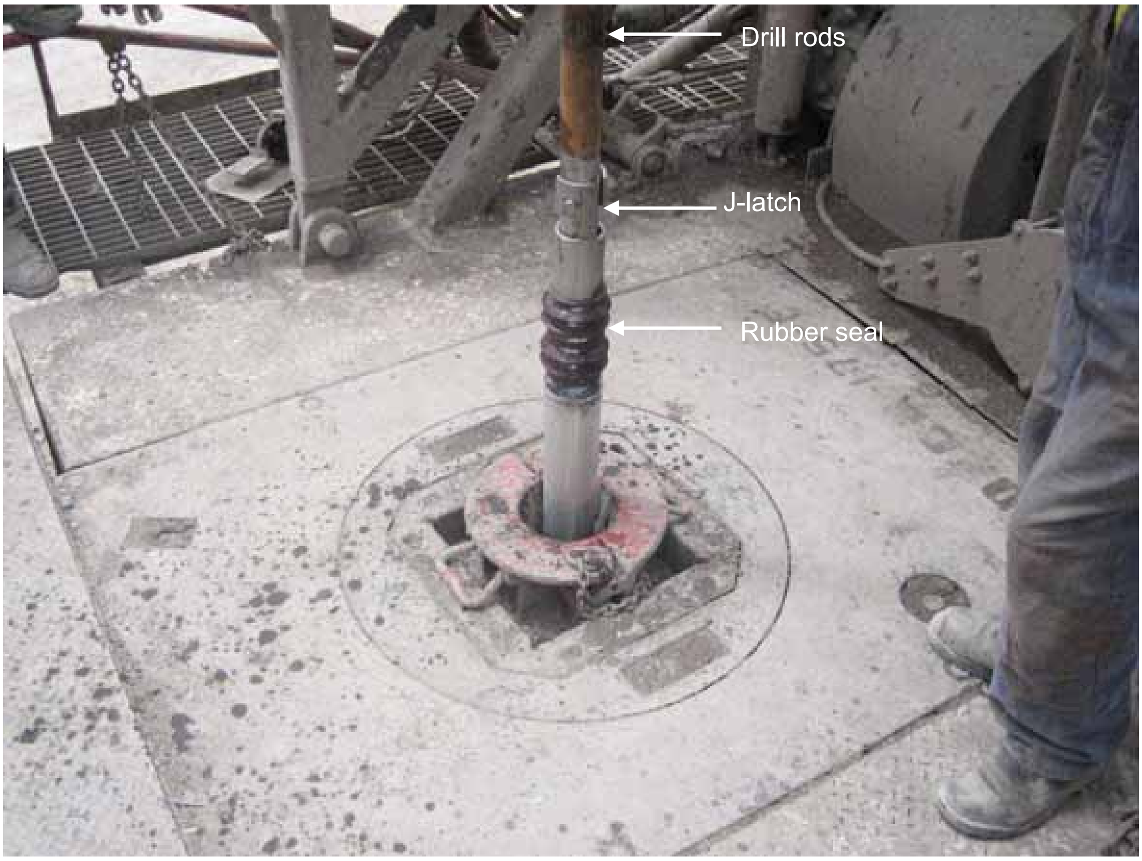

Figure 11. Drill rods, J-latch and rubber seal prior to lowering into WARINA 1

5.5.5 CONSTRUCTION PROBLEM

The jetting tool was lowered to the top of the screen assembly and after numerous attempts it was clear that the jetting tool would not enter past the J-latch. The jetting tool was pulled from the hole. After inspection of the jetting tool it was clear there was a serious problem as the bottom 6 m of pipe was missing from the jet string. After a number of attempts the loose drill rod was recovered from the hole. The galvanised pipe was then re-attached to the jet string and re-lowered into the hole. The jetting tool however did not pass through the J-latch and into the screen.

The rods were pulled from the hole and work stopped.

5.5.5.1 Downhole camera

A decision was made to obtain a downhole camera to inspect why the jetting tool would not enter the screen. Camera footage confirmed that the J-latch had been bent and was obstructing the opening to the screen. This probably occurred when the galvanised pipe broke away from the main line of the jetting string.

Consultation was made with drilling inspector Martin Fosdike (DWLBC) and other DWLBC staff as to whether the hole should be accepted in its current state, or whether further work should be done to rectify the problem. Consideration was given to the use of the well and the limitations that would be placed on DWLBC for further studies if the well were not developed properly.

A decision was made that Sides Drilling should rectify the problem; which would prevent the occurrence of a “Lost hole.” The yield of the hole had improved since removal of the drilling fluid (increased to 2.5 L/s) however the actual yield of the hole was anticipated at ~10 L/s.

Sides attempted to fix the problem by attaching a spear type tool to the end of the drill rods, and applying downward pressure to the damaged part of the J-latch. It was hoped that this would knock the damaged part of the J-latch into the screen, and allow the jetting tool to re-enter the hole.

Several efforts were made at punching into the J-latch, and afterwards the tool was removed from the hole. The downhole video camera was run to the top of the screen. Footage revealed that J-latch had been bent down into the screen, which allowed enough space for entry of the jetting tool and development to resume. After another attempt, re-entry into the screen was successful and the screen was developed top to bottom for 10 hours.

Figure 12 shows a camera still shot of the damaged J-latch after it had been bent into the hole.

5.5.6 POST DEVELOPMENT YIELD

After development the well flowed naturally to the surface at a field estimate of 9 L/s. The majority of loose material had been removed from the hole and the water was relatively clear. Small quantities of fine sand continued to be produced, and a bag of fine sand was collected and submitted to CSIRO for mineralogical analysis.

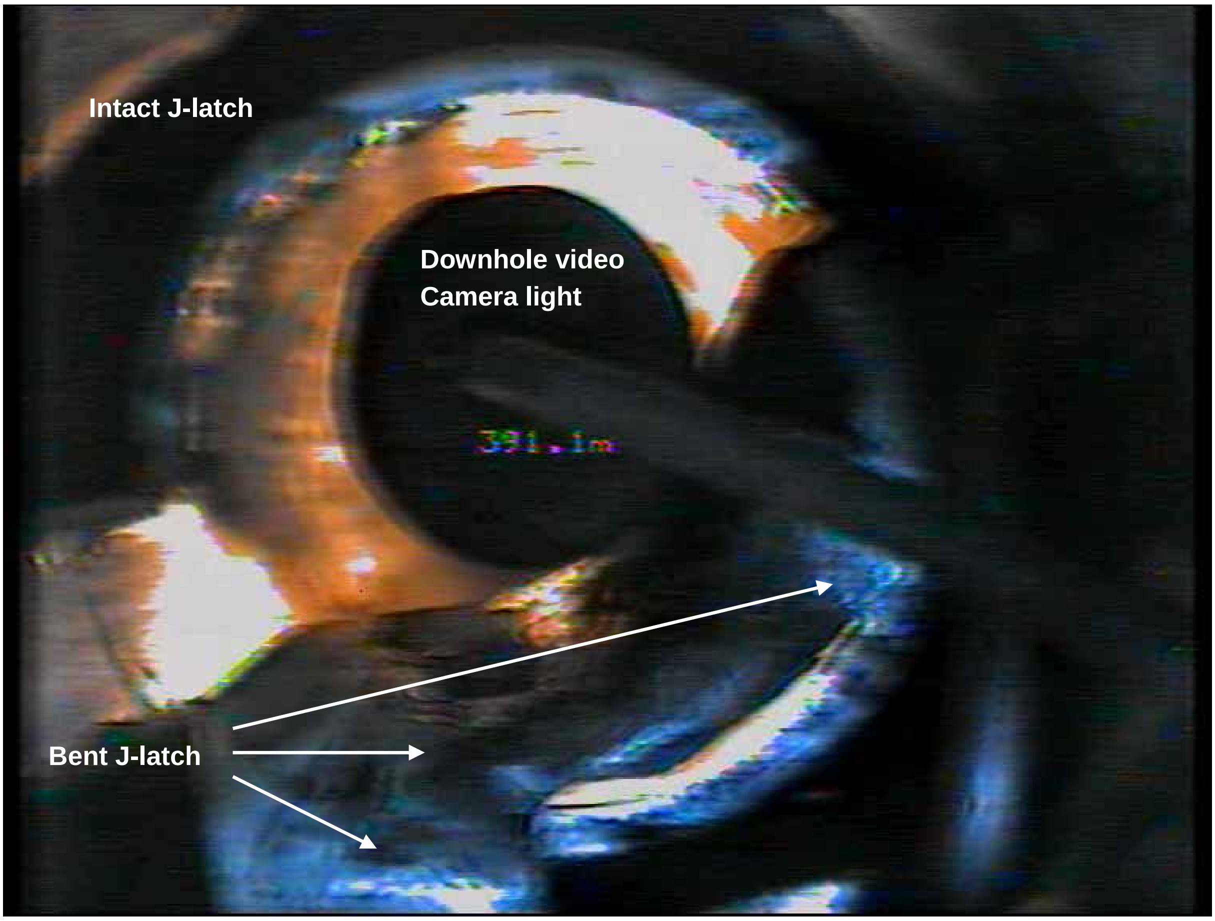

Figure 12. Downhole video camera still shot of bent J-latch

6. LITHOLOGY AND STRATIGRAPHY AT THE STUDY SITE

This section describes the lithology as interpreted from the cuttings collected from WARINA 1, and presents an interpretation of the hydrostratigraphic framework.

Lithologic correlation was made using the geological and borehole geophysical logs. Distinct intervals of elevated gamma activity were correlated with the clay sediments penetrated at various depths. The gamma peaks match with the clay sediments identified in the lithological log. High transmissivity zones in the Warina Formation were recognized by relatively low gamma readings with corresponding relatively high neutron reading. In contrast, the clay layers of low hydraulic conductivity are characterised by relatively high gamma readings and relatively low neutron reading. A lignite layer (at 260 m) is characterised by low gamma and low neutron readings and marks the beginning of the Olney Formation.

6.1 LITHOLOGY

Sedimentary units interpreted primarily from visual examination of drilling samples and interpretation of geophysical data, are discussed briefly in order of increasing depth. These interpretations may be refined upon further analysis of petrographic, geochemical, and mineralogical information, and geophysical logging data. More detailed descriptions are presented in Appendix 5 (lithological log) and Figure 9 (composite log).

Coonambidgal Clay and Monomon Sands (0–36 m bgl)

Drilling began in Quaternary alluvial deposits which are 36 m thick. The upper 2 m is composed of light yellowish brown to light yellowish grey silty clay (Coonambidgal Formation). Below this clay, the borehole penetrated 26 m of quartz sand (Monomon Sands) whose colour varies from white to grey; mottled grey to dark grey; with the upper part being iron (Fe) stained. This sand layer is lignitic from 8–14 m with some evidence of charcoal. In general, the sand is poorly to medium sorted, sub-rounded to sub-angular with grain size ranging from 0.5–3.0 mm diameter.

Lower Loxton Clay, Bookpurnong Formation and Winnambool Formation (36–102 m bgl)

Below the alluvium the borehole penetrated 48 m of silty clay between 36–84 m. This layer is divided into two units - the Lower Loxton Clay and the Bookpurnong Formation. The upper half of this layer, which is 28 m thick (36–64 m depth interval bgl) is assigned to the Lower Loxton Clay. Below the Lower Loxton clay 20 m of olive clay with shell fragments was penetrated (Bookpurnong Formation). Next, the borehole penetrated 16 m of shelly grey marl/clay with limestone layers belonging to the Winnambool Formation. These three units have a combined thickness of 64 m.

The Murray Group Limestone Formation (102–212 m bgl)

Below the clay/marl layer, a 110 m thick layer of Tertiary grey to light grey marly limestone with shell fragments was encountered between 102–212 m. This layer is assigned to the Murray Group Limestone Formation.

The Ettrick Formation (212–260 m bgl)

Immediately beneath the Murray Group Limestone was a 10 m olive green to grey brown sandy silt layer. Beneath this sandy silt layer is 38 m of fine/medium sand extending to 260 m. This bottom part of the Ettrick Formation is described as the Yanac Member (Barnett, pers comm. 2007).

Olney Formation (260–407 m bgl)

The Olney formation was encountered in the interval from 260–407 m bgl. A heavy peaty almost consolidated lignite layer was penetrated from 260–264 m. Below this the borehole penetrated a 143 m thick clay extending to 407.0 m bgl. This clay layer was interbedded with several layers of sand whose thickness range from 2–21 m. These sand layers were encountered from 268–270 m (fine-medium brown sand with minor clay); 273–285 m (greyish brown coarse sand tending to gravel, 1–5 mm); 328–340 m (lignitic brown to dark brown coarse (~60%) sand with fine-medium component); 362–380 m (poorly sorted medium/coarse grain quartz sand (grain size of 1–2 mm) with some gravels). The texture of the sand layers varies from clayey to gravely sand.

Warina Sands (407–460 m bgl)

Below the Olney Formation the borehole penetrated the Tertiary Warina Sands from 407–460 m bgl. The Warina Sands comprised medium to coarse, poorly sorted opaque and clear quartz sand with gravels (grain size of 1–3 mm).

The borehole was terminated at a depth of 537 m bgs after penetrating 77 m (460–537 m) of pre-Tertiary light grey to brown sandy clay. The clays belong to the Coombool Member of Cretaceous age.

6.2 HYDROSTRATIGRAPHY

The sediments penetrated at the site can be divided into the 13 hydrostratigraphic units based on lithologic, texture character and geophysical information. The depth and thickness of these units are described below in order of increasing depth.

Layer 1: Unconfined aquifer – Monomon Sands

The unconfined aquifer is composed of medium to coarse sand extending to 36 m bgl. Borehole geophysical logging (spontaneous potential) indicate that the depth to water level in this aquifer at the time of logging in January 2007 was about 5 m bgl.

Layer 2: Upper confining bed – Lower Loxton Clay, Bookpurnong Formation, Winnambool Formation

This layer was intersected between 36–102 m bgl. Layer 2 is made up of the Lower Loxton Clay (28 m of silty/sandy clay), Bookpurnong Formation (20 m of shelly clay) and Winnambool Formation (16 m of Marly Clay). The Winnambool Formation can be used as a marker between Layer 2 and Layer 3.

Layer 3: The Murray Group Limestone confined aquifer

This layer is characterised by a marly shelly limestone extending from 102–212 m bgl. The first 26 m of this limestone layer is shelly and marly; becoming consolidated from 126–212 m. Analysis of water level data in the area indicates the MGL aquifer is artesian on the floodplain, with a pressure level ~6.5 m above the ground surface.

Layer 4: Middle confining bed – Ettrick Formation

This layer is composed of sandy silt which was intersected between 212–222 m bgl.

Layer 5: Yanac Member of Ettrick Formation (Confined aquifer)

This layer is made up of fine to medium poorly sorted sand with a grain size varying between 0.06–0.3 mm. This layer was penetrated from 222–260 m and is known as the Yanac Member (Ettrick Formation).

Layer 6–12: Lower confining bed and sub-aquifers A, B and C – Olney Formation

These layers commence from 260 m bgl and is characterised by lignitic sandy clay which extends to 407 m bgl. Within this thick clay sequence a number of sand layers were intersected:

- Olney sub-aquifer A — 273–285 m — comprising coarse sand to fine gravel.
- Olney sub-aquifer B — 328–349 m — lignitic coarse to fine medium sand.
- Olney sub-aquifer C — 362–380 m — poorly sorted coarse grained sand (predominantly clear quartz).

Layer 13 : Warina Sand Confined Aquifer

This layer extends from 407–460 m bgl and is composed of poorly sorted, medium to coarse grained sand (predominantly opaque and clear quartz). The aquifer at the site is artesian with a hydraulic head of 11.24 m above ground surface. The flow test conducted at this site measure the flow at 7.95 L/s.

6.3 HYDRAULIC CHARACTERIZATION OF THE WARINA SAND AQUIFER AT THE SITE

The hydraulic characteristic of the Warina Sand penetrated at the site was determined by employing two methods - particle size analysis of 26 samples collected at 2 m intervals, and an aquifer flow test.

6.3.1 PARTICLE SIZE ANALYSIS AND PARTICLE SIZE DISTRIBUTION OF SAMPLES FROM THE TARGET ZONE

BS5930 - Standard Test Method for Classification of Soils for Engineering Purposes (British Standard Institution 1999) was used to classify the sediment for hydrologic purposes based on laboratory determination of particle-size characteristics. The BS5930 (British Standard 1999) test method, which defines soils in relation to their particle size, covers the quantitative determination of the distribution of particle sizes in soils that are larger than 90 µm (BS Screen Guage 0.09, opening microns 90) by sieving. A total of 26 sieve analyses were completed on injection zone sand sample, each sample weighing 500 g.

The following parameters: coefficient of uniformity U_c, coefficient of curvature C_c, percent fine sand, percent medium sand and percent coarse sand were used to describe the samples, shape of the grain-size curve and the physical properties to classify the sand samples collected from the injection zone and the predetermined screen interval of the investigation well. The percent finer passing was obtained by subtracting 100 from the percent retained on each sieve. The percent retained was calculated by dividing the mass retained on each sieve by the mass of the initial sample placed into the top of the sieve stack and multiplying the result by 100.

The coefficient of uniformity U_c, is defined by the following equation.

$$U_c = \left(\frac{D_{60}}{D_{10}}\right) \tag{1}$$

where D_{60} is the particle size diameter corresponding to 60% passing on the cumulative particle-size distribution curve; D_{10} the particle size diameter corresponding to 10% passing on the cumulative particle-size distribution curve. For very poorly graded soils, U_c is ~2–3, for very well graded soils U_c is >15. It should be noted that U_c = 1 indicates that the soil has all the same diameters. U_c can range up to 1000 (Holtz and Kovacs 1981).

The coefficient of curvature, C_C defined as

$$C_c = \frac{(D_{30})^2}{(D_{10}D_{60})} \tag{2}$$

where D_{30} is the particle size diameter corresponding to 30% passing on the cumulative particle-size distribution curve. A soil with a coefficient of curvature between 1–3 is considered to be well graded as long as the U_c >4 for gravels and U_c >6 for sands (Holtz and Kovacs 1981).

Shown on Figure 13 are the particle size distribution curves for 26 sand samples collected from the Warina Sand aquifer. The red represents the 26 samples average. The particle size distribution curves were plotted using the millimeter size openings of the sieves versus the percent finer for each sieve sample in accordance with BS 5930 (British Standard Institution 1999). The shape and position of the grading curves in Figure 13 indicates that the samples can be classified *as poorly graded coarse sand*, probably estuarine or floodplain alluvium.

[**Note**: The diameters used in determining the percent clay, percent silt and percent sand depend on the criteria associated with the various classification methods. For example the USDA classification boundaries are 0.002, 0.05 and 2.0 mm for percent clay, percent silt and percent sand, respectively. The Unified Soil Classification System (USCS) classification uses boundaries of 0.005, 0.075 and 4.75 mm for percent clay, percent silt and percent sand, respectively. The British Soil Classification System classification uses 0.002, 0.06 and 2.0 mm for percent clay, percent silt and percent sand, respectively].

Given the large amount of sieve analyses conducted on the soil samples obtained during the site investigation of the project, a statistical analysis is presented herein. *The statistic and grading* characteristics of the samples are summarized in Table 3. Table 3 presents statistical analysis data calculated from the combination of all sieved samples. The statistical analysis parameters chosen to describe the sieve analysis data were the average, median, mode, maximum value, minimum value, standard deviation, average deviation, and coefficient of variation. The average, median, and mode are all measures of central tendency. The maximum value, minimum value, standard and average deviations, and coefficient of variation are measures of dispersion. These parameters are used to give a qualitative measure of the variability of the data.

Table 3. Particle size statistical analysis data for RG aquifer samples (na=26)

	Minimum	Maximum	Average	Mode	Median	Standard deviation	Average deviation
D_{10} (mm)	0.23	0.78	0.530	0.580	0.580	0.180	0.147
D_{30} (mm)	0.68	1.00	0.925	0.090	0.930	0.090	0.070
D_{50} (mm)	0.97	1.20	1.100	1.100	1.100	0.040	0.028
D_{60} (mm)	1.10	1.40	1.200	1.200	1.200	0.060	0.040
$U_c=(D_{60}/D_{10})$	1.795	4.783	2.264	2.069	2.069	0.358	0.270
$C_c=(D_{30})^2/[(D_{10})(D_{60})]$	0.916	1.828	1.345	1.164	1.243	0.793	0.831
$C_g=D_{60}^2/(D_{10}D_{30})$	2.513	7.737	2.937	2.759	2.670	0.240	0.153

From Table 3 the average coefficient of uniformity U_c is about 2.26 and the average coefficient of curvature C_c is 1.34, an indication of the poorly graded sand. On average the samples are made up of 1.5% silt, 3.1% fine sand, 18.9% medium sand and 76.4% coarse sand. On the basis of these conclusions the sample can be described as poorly graded coarse sand.

As seen in Figure 14 the Warina Sands aquifer can be divided into two zones on the basis of the particle size distribution curves. The first zone, Zone 1 which starts from 410 to 442 m bgl can be distinguished from the second zone, Zone 2 which begins from 444 and ends at 460 m depth bgl. The two Zones have been distinguished by the effective particle diameters,

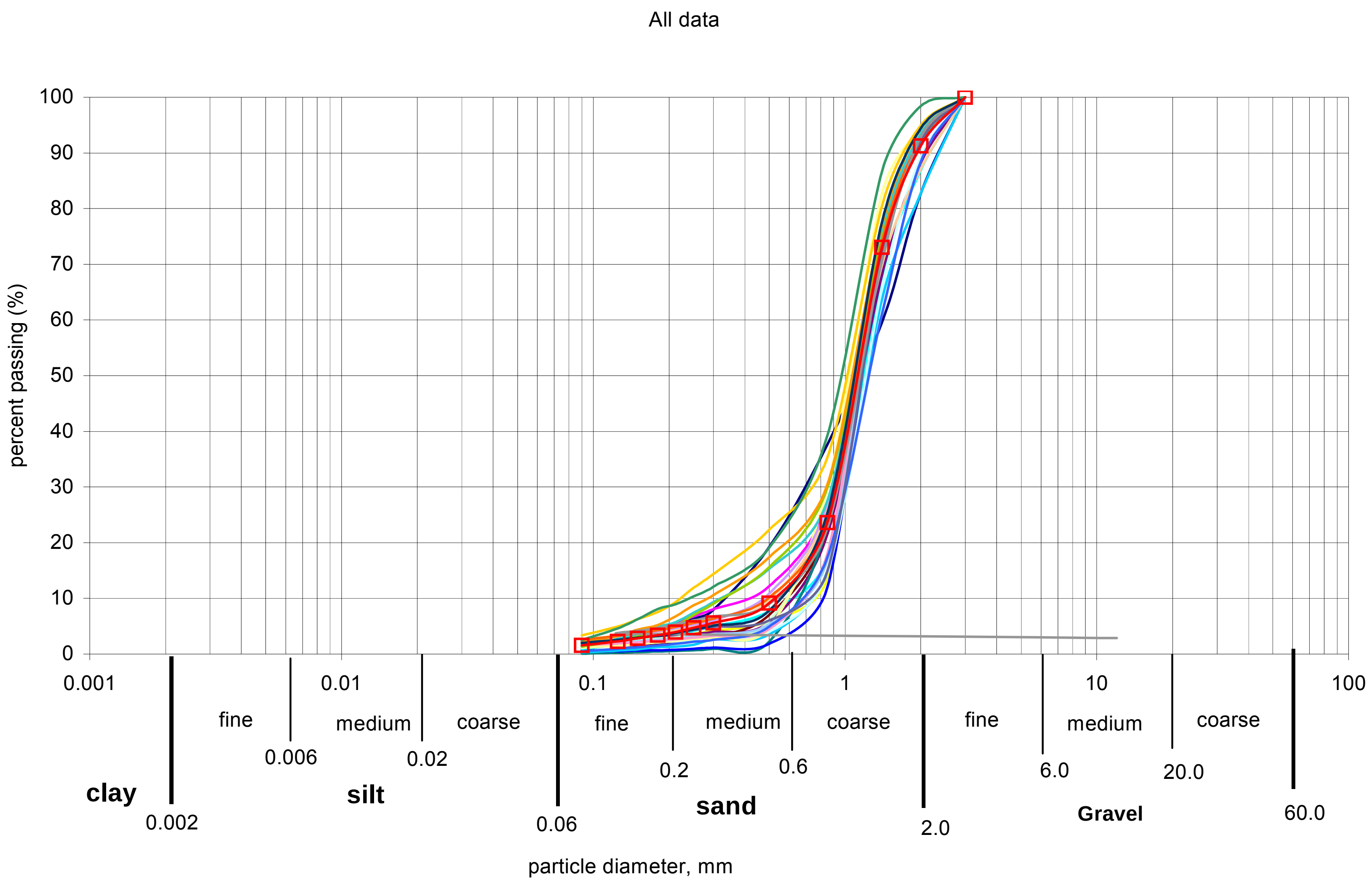

Figure 13. Particle size distribution curves for 26 samples collected from completion zone; red represents the 26 samples average

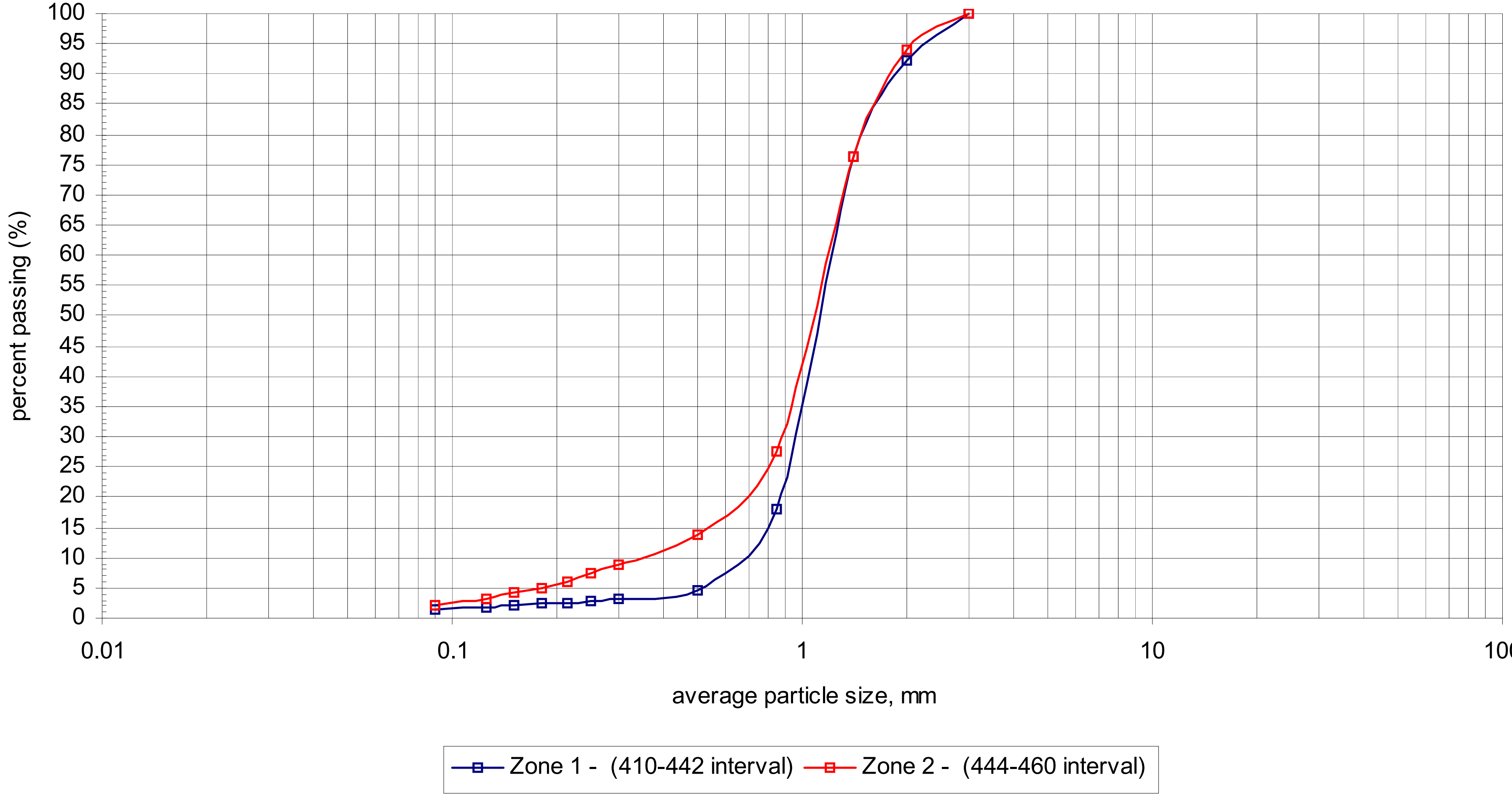

Figure 14. Average particle size distribution from Zones 1 and 2 in the Warina aquifer

with Zone 1 (the 410–442 m interval) generally bigger than the effective particle diameters in Zone 2 (444–460 m). These two zones are recognized on the gamma logs, where an indication of a thin (~1 m thick) clay layer separating the two zones is present between the 444–445 m depth interval. On the gamma log Zone 1 and Zone 2 are recognized in the 407–444 m depth and 445–459 m depth intervals, respectively.

Figure 14 represents the average particle size from the two zones. As can be seen in this figure the average effective particle diameters D_{10}, D_{15} and D_{20} are bigger in Zone 1 (410–442 m) than the effective particle diameters in Zone 2 (444–460 m), indicating that the permeability in Zone 1 is more likely to be higher than the permeability in Zone 2. The permeability in Zone 1, (410–442 m), is about two times higher than Zone 2 (444–460 m), if D_{10} is used as the effective particle diameter in terms of flow of water.

6.4 PRELIMINARY ESTIMATE OF HYDRAULIC CONDUCTIVITY AND SUSTAINABLE YIELD OF THE WELL

6.4.1 HYDRAULIC CONDUCTIVITY ESTIMATES BASED ON EMPIRICAL EQUATIONS USING PARTICLE SIZE DATA

There are many empirical correlations to hydraulic conductivity using grain size and size distribution of granular porous media. These correlations require the choice of a representative grain-size diameter and in some instances an estimate of porosity or void ratio. These empirical methods also typically assume constant aquifer fluid properties (density and viscosity) and homogeneous soil conditions. In addition to particle size, size distribution, fluid density, fluid viscosity and porosity, other factors that control the hydraulic conductivity of sand are particle shape, roundness and surface texture, particle orientation and packing.

Hazen 1893

A simple empirical relationship relating the hydraulic conductivity, K, to the effective grain size D_{10}, developed by Hazen 1893 is shown in Equation 3. In Equation 3 hydraulic conductivity K is in units of cm/s and D_{10} in units of cm.

$$K = (0.70 + 0.03T)C_H (D_{10})^2 \quad (3)$$

where D_{10} is defined as the grain-size diameter in which 10% by weight of the soil particles are finer and 90% of the soil particles are coarser, T is temperature in ^{o}C and the empirical coefficient (0.70+0.03T)C_{HAZEN}, is a function of soil type with typical values listed in Table 4.

Hazen formula is applicable for soils with effective diameters D_{10} between 0.01–0.3 cm and a uniformity coefficient U_C <5. Hazen's equation was developed for sand filters, which typically are looser.

Table 4. Values for the Hazen 1893 Empirical Coefficient when unit of D10 is in cm

Soil Type	$(0.70+0.03T)C_H$
Very fine sand, poorly sorted	40–80
Fine sand with appreciable fines	40–80
Medium sand, well sorted	80–120
Coarse sand, poorly sorted	80–120
Coarse sand, well sorted, clean	120–150

Krumbein and Monk 1943, suggested $(0.70+0.03T)C_H = 6.17 \times 10^{-4}$ for intrinsic permeability *k* and D_{10} expressed in cm^2 and cm, respectively.

Hazen equation is also expressed differently by relating hydraulic conductivity to *effective grain size* D_{10}, of an unconsolidated sample, sorting coefficient (C_h), the gravitational constant (g), density (ρ), fluid viscosity (μ), and a function of porosity [*f*(n)] by the following:

$$K = \frac{\rho g}{\mu} C_h f(n) D_{10}^2 \tag{4}$$

where $C_h = 6 \times 10^{-4}$ and *f*(n) = [1+10(n - 0.26)] and D_{10} expressed in cm. This equation is applicable for sediment with a uniformity coefficient $U_c=(D_{60}/D_{10}) < 5$.

Harleman et al 1963

$$k = \left(6.5x10^{-4}\right)\left(D_{10}\right)^2 \tag{5}$$

where k is the permeability in cm^2 and D_{10} the effective grain size in cm.

Krumbein and Monk 1942

$$K = 0.734\left(D_{50}\right)^2 \left(\frac{D_{16}}{D_{84}}\right)^{0.945} \tag{6}$$

where K is permeability in cm/sec, D_{50} is the diameter in mm corresponding to 50% finer, D_{16} is the diameter in mm corresponding to 16% finer and D_{84} is the diameter in mm corresponding to 84% finer.

Kozeny-Carmen

$$\mathrm{k} = \frac{\mathrm{C}\mathrm{D}_{\mathrm{eff}}^2 \phi^{\mathrm{m}}}{\left(1-\phi\right)^{\mathrm{n}}} \tag{7}$$

Kozeny-Carmen equation describes how porosity and grain size control intrinsic permeability k (cm^2), by incorporating a coefficient C, which describes tortuosity and the internal pore structure. D_{eff} is the effective particle size, ϕ is porosity, C is empirical constant usually taken to be equal to 0.02, typically m = 3 and n = 2 and also $3 \le m \le 9$ and n = 0.

Kozeny-Carmen-Bear 1972

This equation was developed for uniform spherical grains (θ = 6) and discussed in detail by Bear and Verruijt (1987).

$$K = \left(\frac{\rho g}{\mu}\right)\left[\frac{\phi^3}{(1-\phi)^2}\right]\left[\frac{D_p{}^2}{180}\right] \tag{8}$$

where ϕ is porosity and D_p grain size representative often D_{50}.

Amer and Awad 1974

$$K = C_{AA}(U_c)^{0.6} D_{10}^{2.32} = C_{AA} D_{60}^{0.6} D_{10}^{1.72}\left(\frac{n^3}{(1-n)^2}\right) \tag{9}$$

where D_{10} = effective grain size in mm, U_c is uniformity coefficient, θ is porosity and CAA is a constant.

Auberin et al 1996

$$K = c\left(\frac{\gamma_w}{\mu}\right)D_{10}^2\left(\frac{D_{60}}{D_{10}}\right)^{\frac{1}{3}}\left(\frac{n^{3+x}}{(1-n)^{2+x}}\right) \tag{10}$$

where K is permeability in cm/sec, c dimensionless proportionality constant, γ_w is unit weight of water, D_{10} is the diameter in cm corresponding to 10% finer, D_{60} is the diameter in cm corresponding to 60% finer, μ is dynamic viscosity (N s/m^2), n is porosity (-) and x material parameter.

Breyer 1975

This method is often considered most applicable for materials with heterogeneous distributions and poorly sorted grains. It is applicable for $1 < U < 20$, and 0.06 mm < d_{10} < 0.6 mm.

$$K = \left(\frac{g\rho}{\mu}\right)C_b D_e^2 \tag{11}$$

where $C_b = 6 \times 10^{-4}\log[500(D_{10}/D_{60})]$, D_e=effective grain diameter = D_{10} (cm)

Sherard et al 1984

$$K = 0.35(D_{15})^2 \tag{12}$$

This equation was derived for dense packed uniform filters with D_{15} in the range from 0.1–10 mm where K is median permeability in cm/s, D_{15} is the grain diameter in mm corresponding to 15% finer diameter. Sherard et al found the median K values they calculated in their filter tests fell between $K=0.2(D_{15})^2$ and $K=0.6\ (D_{15})^2$ with an average of about $K=0.35(D_{15})^2$. Sherard et al also found a good correlation between K and both D_{10} and D_{20} but poorer correlation for plots of K versus D_{25} and coarse sizes.

Preliminary estimates of hydraulic conductivity at various depth of the RG aquifer intercepted at the site were determined using the above equations and the grain-size analysis. Shown in Table 5 is the average saturated hydraulic conductivity values estimated using the particle size distribution curve average, which represents the average particle size of the Warina Sand aquifer collected from the samples and the empirical methods presented in this section (Fig. 15).

From Table 5 the calculated K value ranges from 0.01788 cm/s (15.45 m/d) to 0.5576 cm/s (481.77 m/d).

Table 5. Estimates of average hydraulic conductivity

Depth, m		Average grain diameter, mm (from 410–460 m interval)							
from	to	D_{10}	D_{15}	D_{16}	D_{30}	D_{50}	D_{60}	D_{84}	$U=(D_{60}/D_{10})$
		0.53	0.67	0.70	0.925	1.10	1.20	1.65	2.26

Empirical method	Estimated Hydraulic conductivity K, cm/sec	Comments
Auberin et al 1996	0.4472	Porosity of 30%, x=2.16 and c value of 0.1 was used.
	0.5576	Porosity of 30%, x=0 and c value of 0.02 was used.
	0.01788	Porosity of 30%, x=2.16 and c value of 0.004 was used.
Breyer (equation B)	0.5420	Breyer equation was used because the effective grain diameter ($D_e=D_{10}$=0.53 mm) was within the limits of 0.06 mm <De <0.6 mm, and the coefficient of uniformity U_c = 2.2642 was within the limits of 1 <$C_u = D_{60}/D_{10}$ <20. g=980 cm/s2,μ =0.0071 g/cm-s, ρ=0.9939 g/cm were used.
Harleman (equation Harl)	0.2593	g=980 cm/s2,μ =0.0071 g/cm-s, ρ=0.9939 g/cm were used.
Hazen (equation Hazen 1)	0.4966	Hazen Formula was used because the effective grain diameter ($D_e=D_{10}$) was within the limits of 0.1 mm <de <3 mm, and the coefficient of uniformity Uc was within the limits of $U_c = D_{60}/D_{10}$ <5. Hazen coefficient C_H = 100 and Temperature= 35.6°C were used.
Equation Hazen 2	0.3237	g=980 cm/s2,μ =0.0071 g/cm-s, ρ=0.9939 g/cm were used.
Kozeney-Camen-Bear (equation K-C-B)	0.5081	Porosity of 30% was assumed. $D_p=D_{50}$, g=980 cm/s2,μ =0.0071 g/cm-s, ρ=0.9939 g/cm were used.
Krumbien and Monk (equation K-M)	0.3950	
Sherard et al (equation S-D-T)	0.1571 (0.0898–0.2693)	The D_{15} from the particle size distribution curve is in the range from **0.1–10 mm**. Sherard et al found that the median K values they calculated in their filter tests fell between $K=0.2(D_{15})^2$ and $K=0.6(D_{15})^2$ with an average of about $K=0.35(D_{15})^2$.

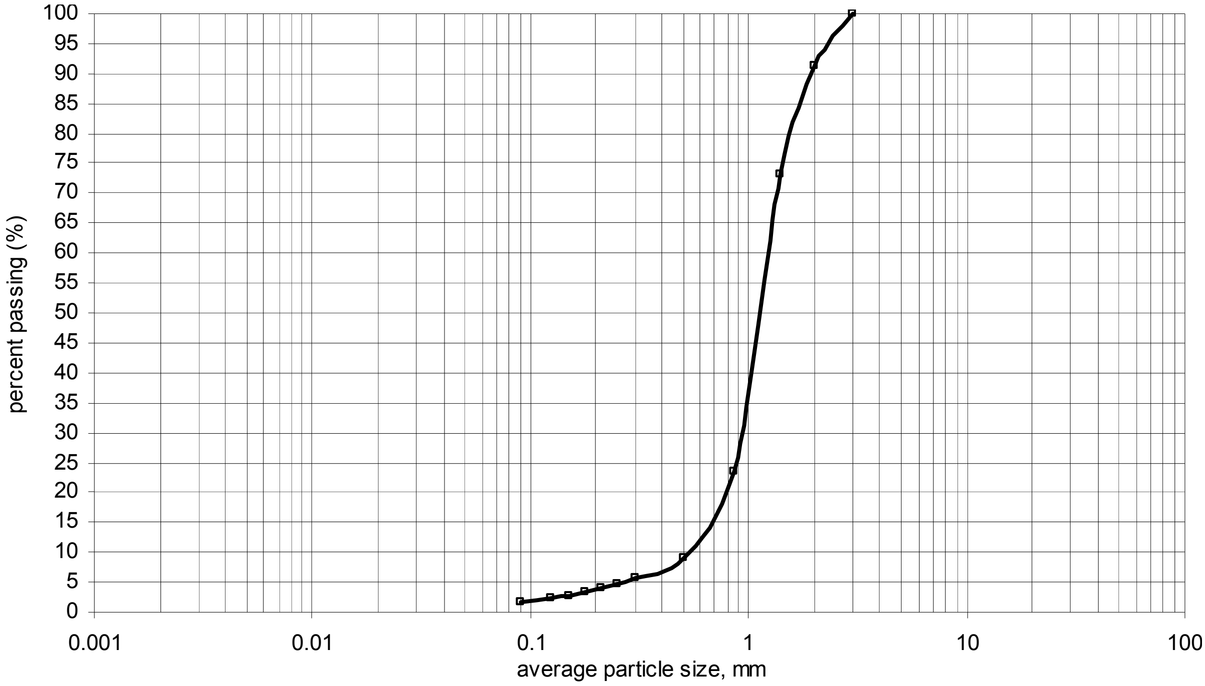

Figure 15. PSD curve based on averaged particle size from 410–460 m interval

6.4.2 FLOW TEST ANALYSIS

A Pump test was not carried out on the well because of the well diameter limitations. Since the well was under artesian flow conditions it was decided to conduct a flow test.

At completion of well construction and development the well was flowing at ~9.0 L/s. A Flow test was conducted from Tuesday 13th March 2007 to Wednesday 14th March 2007 with the objective to estimate the aquifer hydraulic conductivity. Parameters measured during the test included time (minutes), flow rate (L/s), flow pressure (kPa), shut-in pressure (kPa) and basic physio-chemical parameters (see Tables 6–8).

Table 6. Pressure changes to WARINA 1 during a 2-hour flow test

Test Date: 14/03/2007

Test starting time: 13:00 hours

Shut in pressure on arrival: 108 kPa

Time flow test begun: 13:25 hours

Time flow test stopped: 14:55 hours

Total amount of water discharge: 44.5 kL

Time	**Time since flowing started, minutes**	**Flowing pressure** (kPa)	**Temperature** (°C)	**Flow rate** (L/s)
13:25	0	9.5	–	7.65
13:35	10	9.0	–	8.00
13:40	15	9.0	35.6	8.00
14:00	35	9.0	35.7	8.00
14:35	70	9.0	35.8	8.00
14:55	90	9.0	35.7	8.00

Table 7. Pressure recovery during shut in test

Time (min)	**Pressure** (kPa)
0	9
0.5	116.5
1	117.0
2	117.0
3	117.0
4	117.0
5	116.5
6	116.0
7	116.0
8	116.0
9	116.0
10	116.0
15	116.0
20	115.5
25	115.0
30	115.0
40	115.0
50	114.0
60	114.0

Table 8. Flowing groundwater physical quality during flow test

Time	**DO** (ppm)	**EC** (Ms)	**Ph**	**MV**	**Temp**
13:40	0.21	26.2	6.55	-76	35.6
14:00	0.23	30.8	6.52	-176	35.7
14:35	0.88	30.9	6.48	-204	35.8
14:55	-0.08	31.3	6.49	-213	35.7

The initial aquifer pressure (shut-in pressure before the start of flow test) was 108 kPa. When the valve was released for flow to start the pressure dropped to 9.5 kPa and the flow rate dropped to 7.65 L/s. After 10 min the pressure dropped slightly to 9.0 kPa and the flow rate increased to 8.0 L/s. The pressure and flow rate then remained constant at 9.0 kPa and 8.0 L/s respectively from the 10 min mark to the end of the test. Figures 16–18 are plots of flow time (t_{wf}), versus flowing pressure (P_{wf}), pressure drop (P_i-P_{wf}), and flow rate (Q). The test lasted for 90 min and well discharged 44.5 kL of water.

Shown in Table 6 and Figure 19 is a plot of pressure recovery once the well was shut. As seen from the graph (Fig. 19), the pressure had stabilized prior to shut-in. The pressure build-up or recovery data shows that the well pressure rose from 9 kPa to ~117 kPa after less than 1 minute after the gate valve was closed. This shows that the well returned to pre-flowing pressure within seconds.

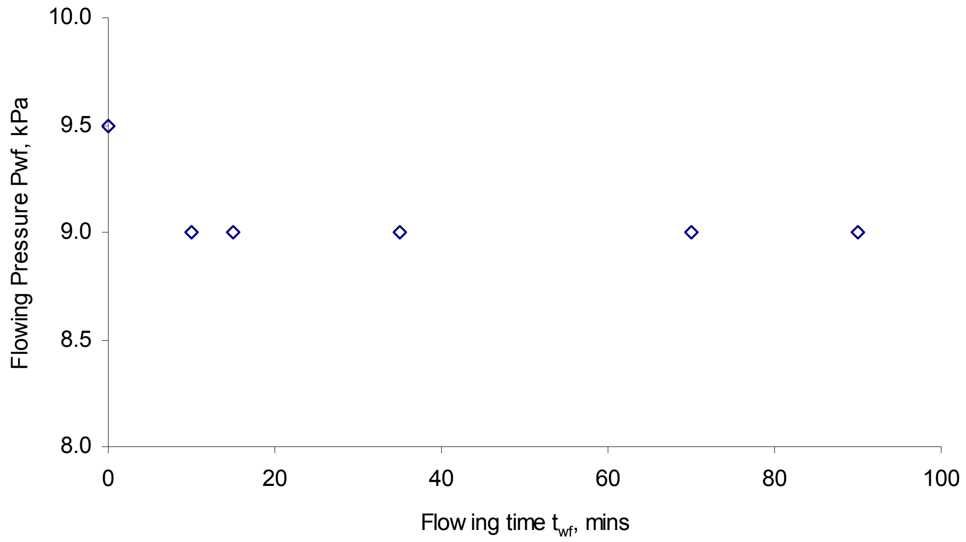

Figure 16. Flowing pressure P_{wf} against flowing time t_{wf}

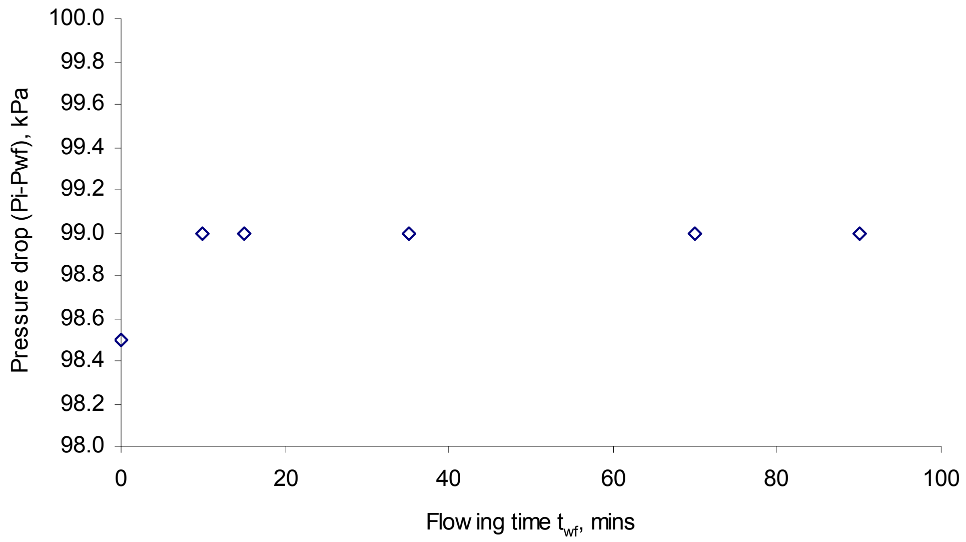

Figure 17. Pressure drop (P_i-P_{wf}) against flowing time t_{wf}

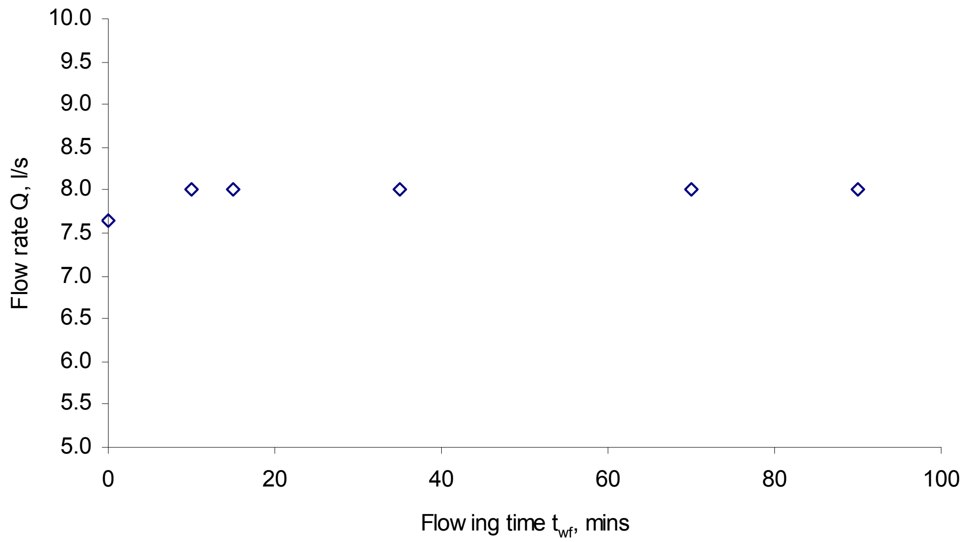

Figure 18. Well flow rate Q (L/s) against flowing time t_{wf}

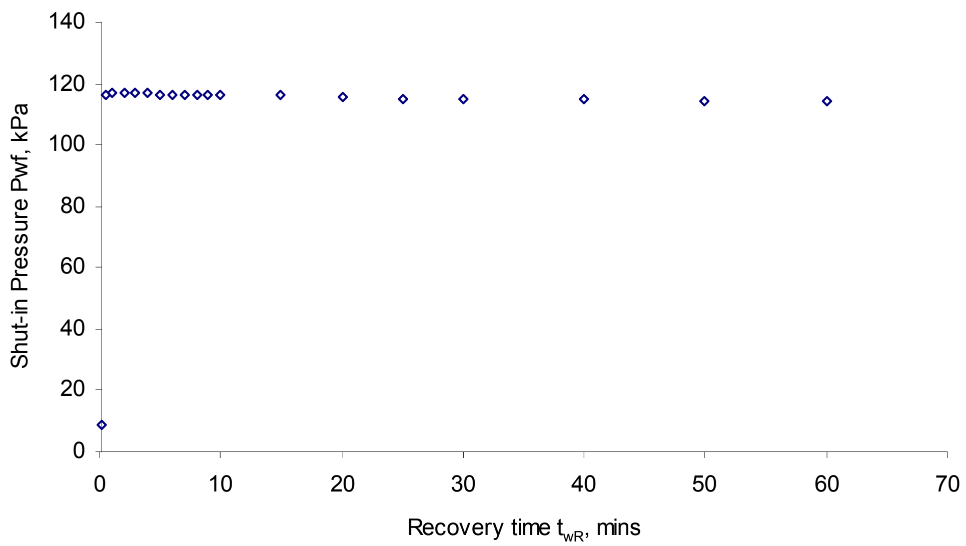

Figure 19. Pressure Recovery-time Shut-in (recovery) pressure against recovery time t_{wR}

These results indicate that the site is good for the proposed injection project, and an injection rate of at least 10 L/s is achievable or sustainable. The specific capacity of the well (which a measure of pumping rate per unit drawdown) at a flowing rate of 8 L/s was [(691.2m^3/d)/(0.92242 m) or 749.35 m^2/d]. At 20 L/s the drawdown would be 2.31 m.

(NOTE: The test was conducted 'immediately' after well construction and 'incomplete' development could affect the observed yield. Actual yield could be higher than 10 L/s. Also, the test duration was not substantially long to determine a more confident long-term yield).

Flowing pressure temperature-density correction

During the flow test the pressure in the Warina Sands aquifer was monitored with a pressure gauge located near the water surface at the wellhead rather than in the completion interval for practical reasons. The observed water surface elevation reflected the formation pressure as a function of the water density in the water column. The water-column density may vary as a result of temperature and water quality variation. When the density profile is constant, the water-surface elevation would vary linearly, with respect to the pressure in the Warina Sands aquifer after accounting for secondary components of the responses, such as barometric pressure variation and earth tides. However, flowing of water from the well could alter the temperature profile as a result of water moving from the completion interval to the surface, replacing the water in the column. Volume expansion (or contraction) as temperatures increase (or decrease) affects the water-surface elevation independent of the pressure changes in the Warina Sands aquifer, and the effect could be significant due to large temperature changes and/or long water-column length. So it was expected that substantial changes in the water column temperature profile (i.e., during flowing) would lead to an inaccurate record of the drawdown (pressure) response in the Warina Sands aquifer as recorded with the pressure gauge located at a substantial distance (~410 m) above the production zone. (This process could have been avoided by placing the pressure gauge at the top of the production zone; however, this was impractical).

The temperature of the flowing water was measured at regular time intervals during the flow test (Tables 6, 8). After flowing had begun, the temperature profile approached a new equilibrium of 35.7 °C. After flowing stopped, the temperature (profile) was expected to equilibrate back to the pre-flowing (ambient) profile. If it is assumed that the pre-flowing ambient temperature of the groundwater near the top of the casing was 25 °C then temperature correction could be made to the measured pressure.

In analysing the pressure response of the Warina Sands aquifer during the flow test, the effect of water column expansion (due to changes of temperature profile) on the measured water-level response was considered. Data for temperature versus density (Sampson pers comm., 2007) were used to calculate the density dependence on temperature for the flowing water temperatures measured.

Figures 20 and 21 are semi-log plots of the temperature-density corrected shut-in head build-up against Horner superposition time ($\frac{(t_p + \Delta t)}{\Delta t}$) and Agarwal equivalent time ($\frac{t_p \Delta t}{(t_p + \Delta t)}$), where t_p is the pseudo-flow time (= cumulative volume discharged divided by the most recent rate) and Δt is the elapsed time following flowing time, t. According to Horner and Agarwal a plot of shut-in head (or pressure) build-up against Horner superposition or Agarwal equivalent time function on a semi-log plot would give a straight line where the transmissivity ((kh)/(μB)), of the aquifer can be determined from the slope of the line through the following equation (in SI Metric Units).

$$\frac{kh}{\mu B} = \frac{0.1832Q}{m}$$

where Q is flow rate (m^3/min), B is formation volume factor (assumed to be 1.0), m slope of the semi-log straight line in (kPa/log cycle), h aquifer thickness (m), μ fluid viscosity (kP-min), k aquifer permeability (m^2).

The gradients calculated from Horner and Agarwal methods shown in Figures 20 and 21 are m_{Honer}=0.22 m/logcycle and $m_{Agarwal}$=0.25 m/min/logcycle respectively. Q is 8.0 L/s (or 0.48 m^3/min), and the calculated transmissivities are 0.3997 m^2/min (575.568 m^2/d) based on Horner method or 0.3517 m^2/min (505.448 m^2/d) from Agarwal method of analysis. With a screen length of 30.0 m this would give K values of 19.18 m/d (0.0222 cm/s) and 16.85 m/d (0.0185 cm/s). These hydraulic conductivity values are comparable with the value of 0.01788 cm/sec obtained from the application of Auberin et al 1996 empirical model when porosity of 30%, *x=2.16 and c value of 0.004 was used, but* substantially less than the values obtained from the other empirical models (Table 5). It can be concluded that estimating the hydraulic conductivity of the aquifer in terms of grading characteristics of the samples collected from the production zone can lead to underestimation or overestimation unless the appropriate method is used. It is therefore recommended that a long-term aquifer test using air-lifting method be conducted on the existing well to determine the aquifer hydraulic properties including aquifer loss.

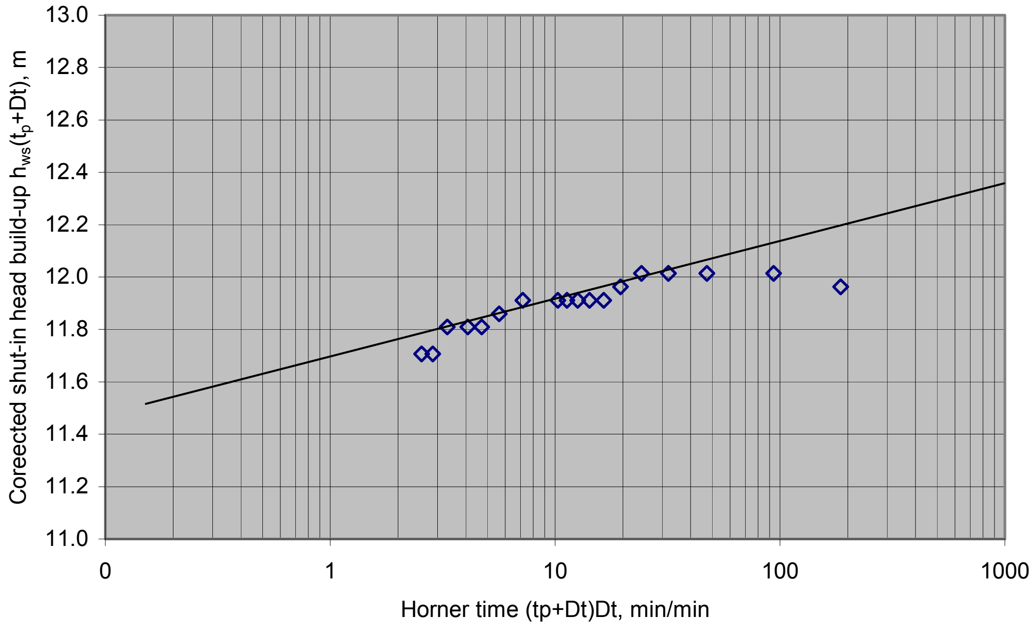

Figure 20. **Temperature-density corrected shut-in head against Horner time**

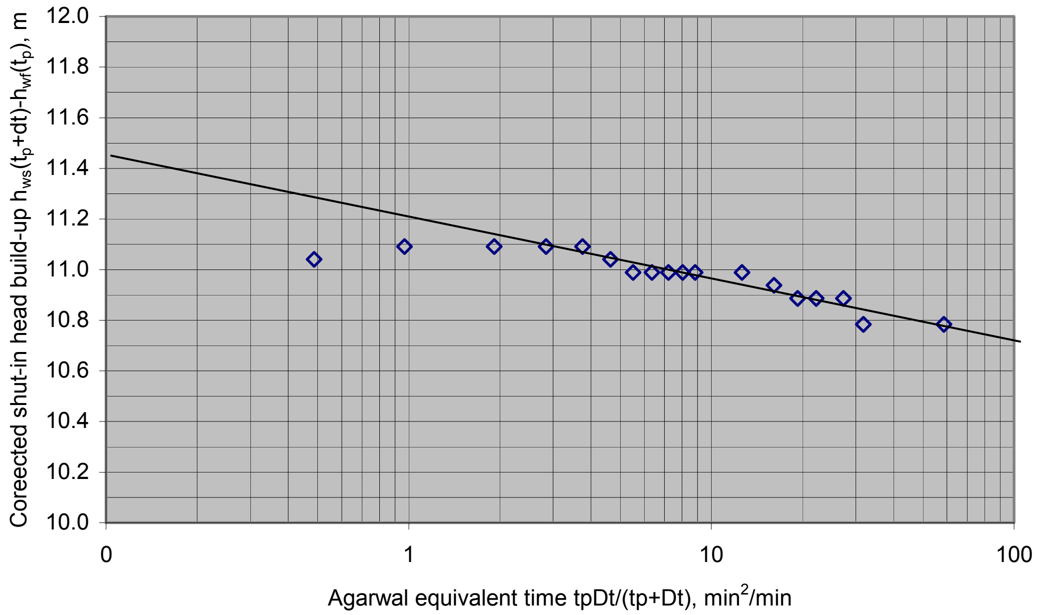

Figure 21. **Temperature-density corrected shut-in head against Agarwal equivalent time**

6.4.3 ESTIMATED SUSTAINABLE YIELD OF THE WELL

The sustainable yield of a well may be defined as the discharge rate that will not cause the water level in the well to drop below a prescribed limit identified from the nature and thickness of the aquifer and the depth of the well. A constant rate test is normally used to determine the sustainable yield of a well. If t_1 is the operation time in which the drawdown of the well is not to exceed a prescribed limit, s_p, when pumped at a discharge rate of Q_p. Also if $s_{obs}(t_1)$ is the drawdown observed in the well during a constant rate test with discharge rate Q_{obs} at the time t_1, then the sustainable yield Q_{sus} can be determined from:

$$Q_{sus} = Q_{obs} \frac{s_p}{s_{obs(t_1)}} \qquad (13)$$

where s_p is the drawdown of the well corresponding to the prescribed limit and s_{ob} (t′) is the drawdown at the time t_1 observed in the well during a test with a constant discharge rate Q_{obs}; t_1 represents the time in which the drawdown does not exceed the prescribed limit. In the flow test t_1 = 90 min, Q_{obs} = 8 L/s $s_{obs}(t_1)$=(108kPa-9kPa)=(11.081-0.923)=10.158 m. Substituting this values in above equation leads to

$$Q_p = 0.788 s_p \qquad \text{for } t_1\text{=90 min} \qquad (14)$$

where Q_p in L/s, s_p in m and injection operation time is 90 min. In Figure 22 the total duration of flow (operation time) is held constant at 90 min and sustainable yield corresponding to different values of prescribed limit in head is plotted.

The expression for drawdown $s_{obs}(t_1)$ is generally extrapolated from pumping tests conducted over a long period. Therefore, there are limitations to application of equation 13 and equation 14 in the calculation of the sustainable yield, especially where the test lasted for a few minutes and if aquifer system is very heterogeneous. Knowledge of relation $s_{obs}(t_1)$ over a longer period test is needed in order to determine the yield of the well with greater confidence.

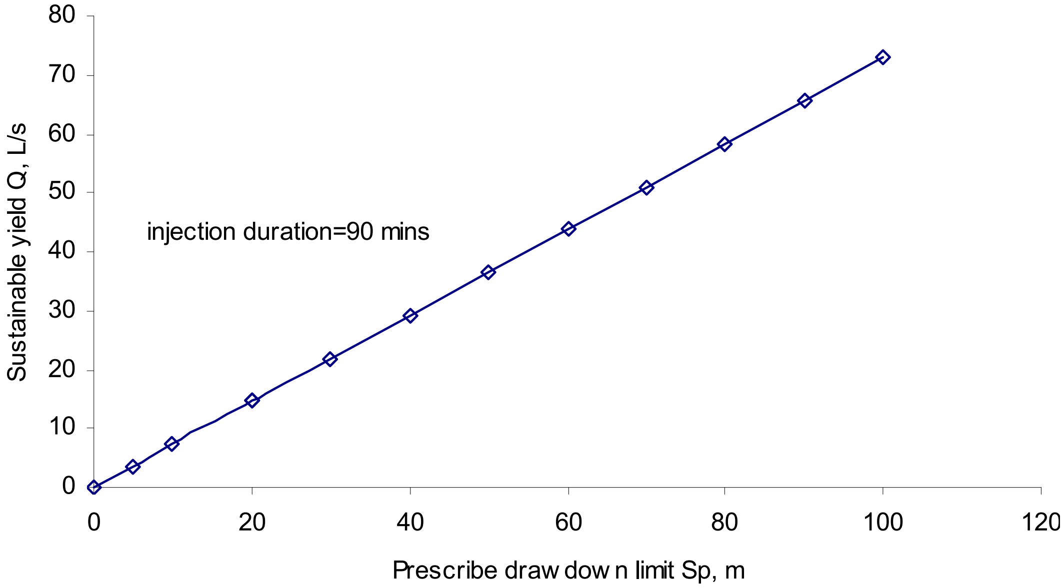

Figure 22. Estimated potential well sustainable yield based on 90 min duration of flow test

6.4.4 POTENTIAL EFFECT OF THE MIXING OF NON-UNIFORM WATERS

The flow test indicated that the temperature of the ambient groundwater flowing from the targeted zone of the Warina Sands aquifer was on average 35.7 ^{o}C. Hydraulic phenomena of excess head build-up during injection could happen if there is a temperature differential between the ambient aquifer temperature and the temperature of the water being injected. Large differences in temperature between the source water to be injected into the target aquifer and the ambient temperature of the native Warina Sands aquifer water would lead to significant change in the dynamic viscosity of the water and this has implications for the local fluid-transport properties of the aquifer. This can be illustrated as shown in Figure 23, which shows the range of temperature variation between the ambient aquifer temperature and the injected temperature (assuming the average source water temperature is 25 °C) and the resultant range of dynamic viscosity. As Figure 23 shows, as the temperature changes from the ambient aquifer temperature to the temperature of the source water injected (25 °C), the dynamic viscosity increases by 15%. The effect that this will have on the fluid-transport properties of the aquifer and hydraulics of the injection well can be shown by the relationship of aquifer hydraulic conductivity to the dynamic viscosity. Hydraulic conductivity (K), which is a function of several parameters, some of which are temperature-sensitive can be expressed by the following equation:

$$K = (k\rho g)/\mu$$

where k is intrinsic permeability, ρ fluid density, g acceleration due to gravity and μ dynamic viscosity. The density and viscosity both increase with decrease temperature; however viscosity decreases at a faster rate. Given that k is constant for a given aquifer type, g is constant, and ρ changes only to a minor degree with temperature changes, as the dynamic viscosity (μ) increases the aquifer hydraulic conductivity (K) would decrease linearly. This decrease in hydraulic conductivity would produce a non-linear change in flow rate. Therefore, as cold water is injected into a warmer aquifer the viscosity change caused by this cold water mass will produce a corresponding decrease in the aquifer hydraulic conductivity. This phenomenon would create a head build-up in the well that would be greater than theoretically expected.

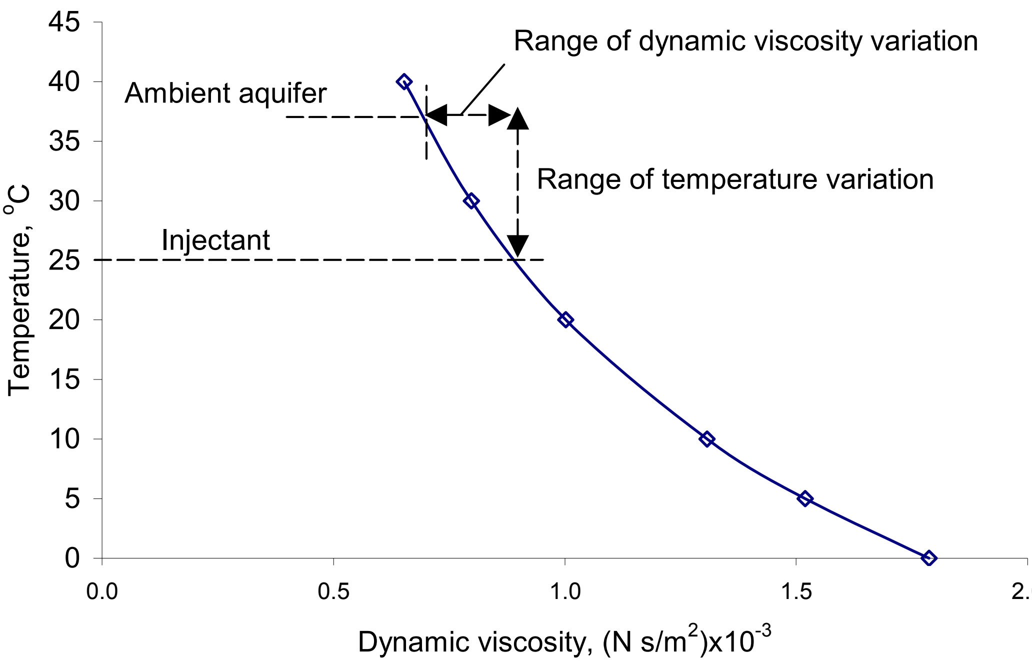

Figure 23. Temperature-dynamic viscosity effect of temperature change on dynamic viscosity

6.4.5 EFFECTS OF OTHER FACTORS

While the flow data indicated that water temperatures could be a factor that has the potential to affect the hydraulics of the injection well, there are a number of other factors that should be evaluated as part of the project which are common problems encountered in injection well processes. These processes include:

1. Suspended sediment in the recharge water causing clogging of the screen and/or gravel pack/aquifer material surrounding the screen.
2. Entrained air in the recharge water, which can result in two-phase flow if the air is forced out into the formation. This ultimately can cause air locking of the formation.
3. Microbial growth in the well that would result in slime buildup which can plug the screen and/or gravel pack/aquifer material surrounding the well.
4. Chemical reactions between the source water and the native Warina Sands aquifer water, which could cause precipitation that can clog the screened interval and/or gravel pack/aquifer material surrounding the screen.
5. Chemical reactions between the source water and the formation matrix that could result in dispersion of clay particles that could reduce the permeability in the vicinity of the injection well.
6. Geochemical reactions that could occur in the Warina Sands aquifer by the introduction of relatively oxygenated recharge water. As the Warina Sands aquifer is naturally a reducing environment there is the potential for iron and manganese precipitation due to the change in the redox potential in the vicinity of the well.

Data was collected to address these factors that could negatively impact the injection process. The data was analysed as part of an aquifer clogging study performed by CSIRO (Pavelic, et al 2007) with results included in Appendix 10.

6.5 GROUNDWATER CHEMISTRY CHARACTERISATION

Groundwater sampling for chemistry analysis

The goal was to collect physical, chemical and biological (groundwater) data that is representative of groundwater in the aquifers in the Chowilla region. The samples were collected from existing observation and production wells completed in the Monomon Sand aquifer and the Warina Sands aquifer. The groundwater samples were collected from the aquifers for physical, chemical and biological characterisation of injection water (groundwater from the unconfined aquifer - source) and water in the injection zone (groundwater from targeted deep aquifer - sink).

WARINA 1 and four Monomon Formation observation wells were sampled. The Monomon Formation wells were chosen as they give representative salinity of the local unconfined aquifer near Werta Wert wetland, the site at which a likely injection trial would source recharge groundwater. The four Monomon Formation wells had depths between 6.5–18.0 m and are located close to the investigation site (see location map Fig. 1). Table 9 gives well information including screen intervals for these wells.

Table 9. Sampled Monomon formation wells

Unit number	Name	Easting	Northing	Drill date	Latest depth	Hole diameter	Screen interval
703000759	WWOBS6B	488034.00	6245248.00	08/08/2004	12.00	80	10.0–12.0
703000756	WWOBS4	488177.00	6244222.00	04/08/2004	6.50	80	4.5–6.5
703000765	WWOBS8C	487709.00	6243746.00	09/08/2004	10.50	80	8.5–10.5
703000712	64226	487260.00	6242555.00	30/03/2004	17.07	80	15.07–17.07

6.5.1 SAMPLING METHODOLOGY

Groundwater samples were collected from Tuesday 10th April 2007 to Wednesday 11th April 2007. Prior to sampling, the static water level was measured from the top of casing (TOC) using an electric water level probe. The observation wells were then purged using a 12-volt submersible pump (Supertwister®) and water monitored with a YSI® multi-parameter meter/flow through cell for physical parameters pH, specific electrical conductivity (SEC), dissolved oxgen (DO), redox potential and temperature. The meter was calibrated with known standards prior to use in the field. Samples were collected once the physical parameters had stabilised, indicating that the sample was representative of the section of the aquifer that was screened. The total alkalinity (assumed to be HCO_3^- for the ranges of pH sampled) was also measured in the field using a HACH titration kit. Given the artesian nature of the Renmark Group no pumping was required for WARINA 1, as water flowed freely to the surface at a suitable rate, however a flow through cell was used to ensure physical and chemical parameters had stabilised prior to sample collection.

Water samples were submitted to the Australian Water Quality Centre (AWQC) for chemical analysis. Analysis included testing for major cations, major anions, total metals, nutrients, iron bacteria, bacteria colony count, biodegradable organic carbon (BDOC), total suspended solids (TSS), volatile suspended solids (VSS) and alkalinity. Major ion analysis was conducted on the groundwater samples that had been filtered through a 0.45 μm membrane filter in the field. Cations (Na^+, Mg^{2+}, K^+, Ca^{2+}, NH_4^+) were acidified with nitric acid (1% v/v HNO_3) to keep the ions in solution and analysed by Inductively Coupled Plasma Emission Spectrometry (ICP-ES). Anions (Cl^-, Br^-, SO_4^{2-}, NO_3^-) were analysed by Ion Chromatography (IC).

The results of the analysis and methods used are seen in Appendix 9. Chemistry data used to characterise hydrochemical properties of the Monomon Formation and Renmark Group aquifers are presented in the following section.

6.5.2 RESULTS AND INTERPRETATION

Table 10 represents the field measurements and the major ion results from the sampled wells. The major ionic species found in the ground water at the study area include Cl^-, SO_4, HCO_3, Na^+, Mg^{+2}, Ca^{+2}, K^+. These dissolved species represent ambient as well as background concentration and chemical composition of the groundwater from the Warina Sands and Monomon Formation aquifers.

Table 10. Hydrochemistry of sampled wells in the study area

Well 7030-	Sample date	Aquifer	Sample depth (m bTOC)	Parameter: pH	Temp (°C)	Specific Conductance (μS/cm)	DO (sat %)	Concentration (mg/L): Ca	K	Mg	Na	Cl	HCO_3	SO_4
809	10/04/2007	WS	410–440	6.83	36.08	40 530	0.8	529	75.1	578	6 530	4 860	428	2 120
712	10/04/2007	MS	15.07–17.07	6.29	21.6	48 750	1.9	596	161	1 440	11 200	18 100	296	6 300
759	11/04/2007	MS	10–12.0	6.46	19.5	63 310	1.0	627	213	2 040	16 200	26 500	321	9 480
765	11/04/2007	MS	8.5–10.5	6.39	20.15	46 950	0.9	576	145	1 460	11 100	7 600	364	6 390
756	11/04/2007	MS	4.5–6.5	6.75	23.26	48 660	1.9	492	148	1 270	10 700	7 050	672	5 430

Note:

WS Denotes Warina Sands

MS Denotes Monomon Sands

DO denotes dissolved oxygen

Table 11 presents the mean ambient/background ions and pH for the samples collected at the research site. During the sampling the mean specific electrical conductivity for the MS wells was measured at 51 917 µs/cm while mean pH was 6.47. This was compared to the Warina Sands Aquifer which had a specific electrical conductivity of 40 530 µs/cm and pH of 6.83.

Table 11. Summary of ambient/background hydrochemistry of groundwater from Monoman Formation and Renmark Group aquifers in the study area

Aquifer	Mean ion concentration (mg/L)							
	Ca	K	Mg	Na	Cl	HCO_3	SO_4	Total
MS	572	166	1 552	12 300	14 812	413	6 900	36 705
WS	529	75.1	578	6 530	4 860	428	2 120	15 120

6.5.3 CLASSIFYING GROUNDWATER TYPE

Major ion chemistry of the groundwater collected during sampling was examined using the Piper diagram (Fig. 24). By grouping Na^+ and K^+ together, the major cations are displayed on the one trilinear diagram (Ca^{2+}, Mg^{2+}, Na^+/K^+). Likewise, CO_3^{2-} and HCO_3^- are grouped, giving three groups for the major anions (Cl^-, SO_4^{2-}, CO_3^{2-}/HCO_3^-). By grouping the groundwaters into their chemical constituents, the dominant type of ions present in solution can be visually examined.

From Figure 24 it can be seen that groundwaters from the Warina Formation and Monomon Sands are Sodium/Potassium dominant with respect to Cations, and Chloride dominant with respect to anions. The ratio of major ions between Monomon and Warina Sands aquifers are very similar at the study site, and both groundwaters are characteristic of recharge/source water that has been influenced by evaporation.

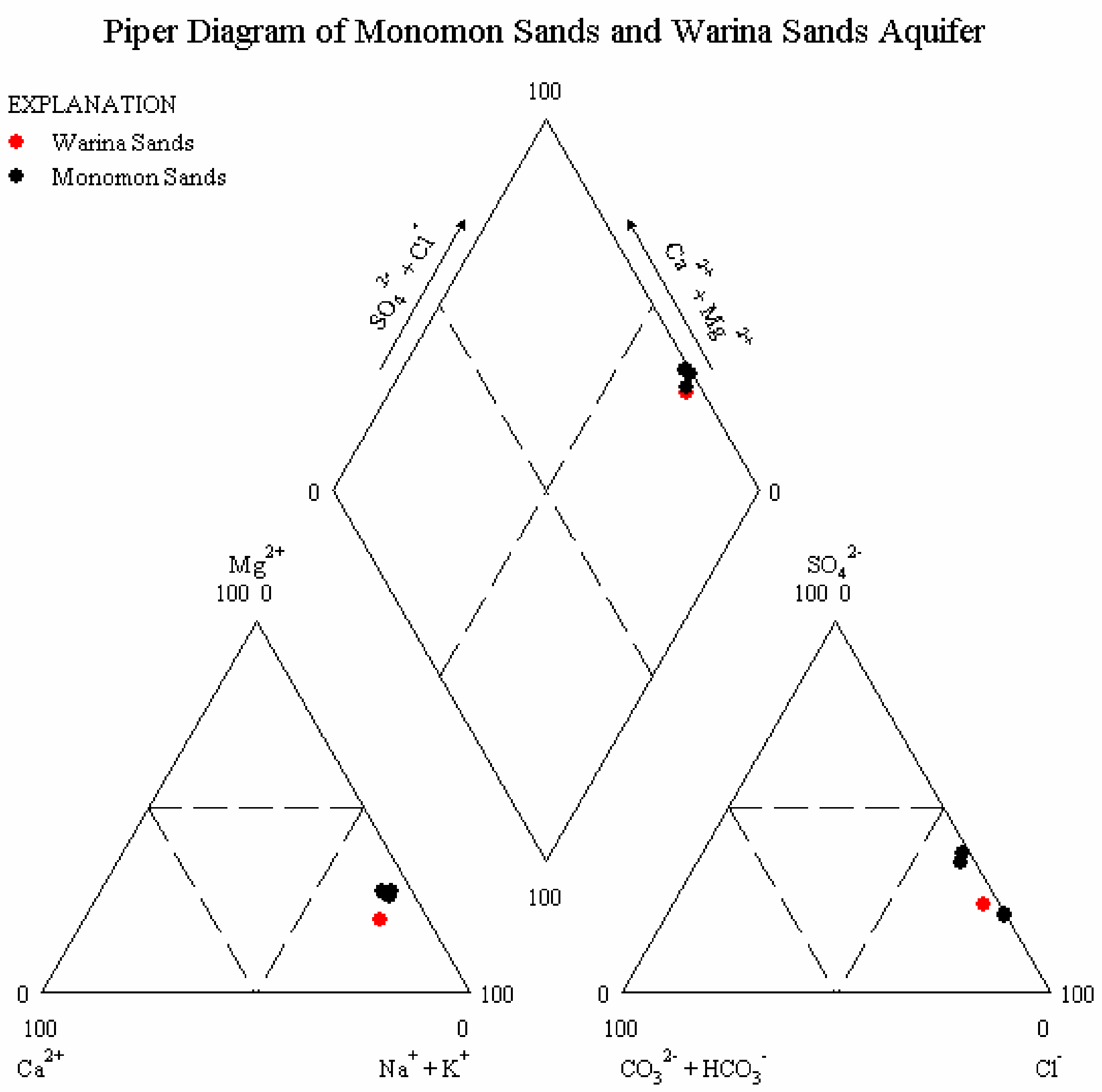

Figure 24. Piper diagram showing ratio of major chemical constituents in the Warina Sands and Monomon Formation Aquifers at the study site

7. CLOGGING STUDIES AND GEOCHEMICAL MODEL (CSIRO)

The CSIRO undertook studies on behalf of DWLBC to determine the risks of deep aquifer injection from a physical, biological, chemical and mechanical clogging perspective. Given that water from the Monomon Sands (recharge water) was going to be pumped into the Warina Sands, a sampling program was conducted by DWLBC to collect water samples from four shallow Monomon Sands wells situated on the Chowilla Floodplain. Further to these wells, CSIRO used chemical information from three other Monomon Sands wells that had been analysed during the MGL disposal study in 2005. These wells were analysed for a suite of chemical parameters. The results of the most recent sampling (2007) can be seen in Appendix 9. The location of the wells can be seen in Figure 1.

An outline of the main findings from the study show that:

- There are relatively high particulate levels in the recharge waters ranging from 15–73 mg/L. These would need to be reduced to <10 mg/L prior to injection into a production well.
- Aeration of recharge/source water prior to injection should be minimised. Aeration of the source water will convert soluble Fe^{2+} to particulate Fe^{3+}, which will need to be removed prior to injection.

Recommendations from the clogging study suggest that injection into the Warina Sands would not be entirely without risk, however these risks can be managed to acceptable levels by taking appropriate steps. Water quality improvement, drilling method, screen design and development of injection/shallow production wells, and reducing chemical changes during transport and storage of recharge water will be imperative for a successful Phase III Injection Trial.

The full report (Pavelic et al, 2007) can be seen in Appendix 10.

8. SEISMIC STUDY

An investigation was undertaken by Kevin McCue from the Australian Seismological Centre (Environmental Systems and Services) to determine the risk of induced seismic activity from deep aquifer injection. This is important given the proximity of the study site to major infrastructure, including Lock 6 and the Renmark township.

The study took into account the anticipated depth of injection, structural geology (known faults), stratigraphy and lithology of the target aquifer, and known seismic activity in the study area to estimate the likelihood of induced seismicity. Findings show that the risk of human induced seismic activity is low given the nature of the tectonic conditions at Chowilla and depth to which injection would take place. The proposed Phase III injection trial would dispose of saline groundwater into the Warina Formation at a depth less than 500 m, and into porous and permeable sediments. This is not considered a serious threat to induced seismic activity. Induced seismic activity from examples overseas generally involve injection to significant depth (usually greater than 5 km) and into basement rock. The geological conditions at the Chowilla site are largely different.

Below is a summary of important findings and recommendations by McCue, while the full report can be seen in Appendix 11.

- Tectonic earthquakes in Australia occur in an intraplate environment where seismic hazard and risk are low compared with interplate regions.
- The natural seismicity of Chowilla is low within this intraplate environment.
- Induced seismicity may occur when fluids are pumped deep underground depending on many factors such as the state of stress in the crust, the pumping pressure and volume, the depth of pumping and the permeability of the rock at the injection depth. At Chowilla, SA, none of these factors are critical.
- Induced seismicity caused by fluid injection into rock has occurred in deep boreholes at least several kilometres deep. The Chowilla injection will occur at a depth of only 600 m into saturated confined sands, above the basement interface.
- The Hamley Fault is too distant from the injection well to be considered a potential problem and unless fluid is pumped directly into the Chowilla Fault, it too is very unlikely to be reactivated given that the brine will be pumped into the Warina Sand member at shallow depth, the sand both porous and permeable.

Recommendations:

- A 6 station monitoring network of seismographs and accelerographs graphs should be installed to monitor any seismic activity in real time associated with fluid injection.
- Monitoring should begin now so that some record of pre-injection seismic activity can be made.
- A strategic operational plan should be adopted so that so that the fluid injection pressure and volume can be quickly decreased or stopped should seismic activity be recorded, and resumed after the fluid pressure has dispersed.

9. DISCUSSION AND CONCLUSIONS

The construction of WARINA 1 was successful in that the Warina Sand aquifer intersected had a suitable thickness for the intended purpose of deep aquifer injection. The collection of cuttings, completion of the observation well and collection of water samples fulfilled the objectives of the project. The construction of WARINA 1 will provide an important stratigraphic marker for future work on the Chowilla Floodplain, and will ensure adequate outcomes for future wells constructed to similar depths.

However, the quantification of hydrogeologic parameters such as aquifer hydraulic conductivity and transmissivity could not been performed to an adequate level. Due to limitations in the well diameter, hydraulic parameters have only been inferred from particle size interpretations and from a 90 minute flow test. The long term yield or injection capability of the well has not been tested to a level that can prove that the well can receive the large volumes of water produced during a salt interception scheme. This will need to be addressed prior to committing to a Phase III Injection Trial.

The original structure contours developed using information sourced from the literature indicated the top of the Warina Sand to be within the range of 370–420 m below ground level (Rammers et al*,* 2005). The lithological interpretations included in this report have been corrected to geophysical interpretations, and revised to their correct depth. Interpreted depths for the extent of the Warina Sands are from 407–460 m. A discrepancy of about 7 m was noted between the cuttings and the geophysical logs at depths close to 400 m.

Broadly speaking, the hydrostratigraphy encountered in this hole has been described previously, and is similar to expectations. The only major difference was the lithology of the Ettrick Formation. Brown and Stephenson (1991) described the formation as *mainly grey and green highly fossiliferous clay*, commonly described as marl. The Ettrick Formation at the site comprised fine calcareous sandy silt from 212–222 m bgl, and fine, poorly sorted calcareous sand from 222–260 m bgl. There was no evidence of fossiliferous material in this hole.

The deeper Warina Sand aquifer is 53 m thick and is composed of poorly sorted, sub-rounded medium to coarse sand. This aquifer is artesian with the head of water after well construction and completion 11.24 m above ground level. This equates to a pressure head of 32.40 m AHD, given an estimated ground elevation of 21.16 m from the Chowilla Digital Elevation Model (DEM). There is potential for upward groundwater movement from the Warina Sands into the Olney Formation.

Preliminary estimates of hydraulic conductivity were made using the grain-size analysis and a short-term flow test. The particle size analysis derived values between 0.01788–0.5576 cm/s. Particle size information will be useful in well screen design for future wells drilled on the Chowilla Floodplain.

The main sources of error during the collection of sample cuttings was the wide aperture of the shale shaker screen, which resulted in a significant portion of the fine sands and silts being lost during the collection process. This may explain why hydraulic conductivities calculated using the particle size gave a wider range of values (0.17–0.56 cm/s) when compared with estimates from the 90 minute flow test (0.0185–0.022 cm/s). It can be concluded that estimating the hydraulic conductivity of the aquifer in terms of grading characteristics of samples can lead to underestimation or overestimation unless the appropriate method is used. It is recommended that a long-term aquifer test using an air-lifting/recovery method be conducted on WARINA 1 to refine the aquifer hydraulic properties. The results from this test will help to determine the capacity of the aquifer to accept injected water, and will reduce some of the risks associated with the proposed Injection trial.

The relatively small diameter of the screen (75 mm) and FRP casing (100 mm) may have contributed to problems encountered during development, and did place limitations on aquifer pump testing information that could be collected from the well. Larger diameter screens and casing should be considered for future wells constructed to similar depths.

Analysis of water flow data during development indicated that the Warina Sand aquifer was flowing at 8 L/s. Preliminary estimates of well production focused on the upper 30 m of the aquifer (the production interval of the well). Preliminary flow data suggests the aquifer is capable of receiving greater than 10 L/s. Future planning for a salt interception scheme at Chowilla involving deep aquifer disposal will involve multiple injection wells, each sourcing recharge water from several shallow production wells. Any injection well drilled must be able to satisfy the demand of the shallow production wells for a salt interception scheme to be viable.

The value of development was shown by the well yield prior to and after development. Before jetting, the well yielded 2.5 L/s. The post development yield of 8 L/s confirmed that a non-development scenario would have been unacceptable, and without such, the integrity of the information collected would have been doubtful.

Groundwater chemistry sampling of WARINA 1 and four shallow Monomon Sands observation wells was undertaken by DWLBC and used by CSIRO in clogging studies and a geochemical model. Chemistry information from three Monomon Sands sampled in 2005 wells were also used in these studies (see Fig. 1). Results show physical clogging from suspended sediment and oxidation of available iron (Fe) are the principal threats for project viability. These threats can be reduced to acceptable levels by settling of the water, filtration (if economical), and limiting the exposure of the recharge water to free air prior to injection.

Seismic analysis by Environmental Systems and Services suggest that there is a low chance of disposal related seismicity at the target depth, given the porous properties of the Warina Sands and the relatively shallow depth. Overseas examples of induced/disposal related activity are at depths greater than 5 km and into basement rock, which is quite different from the Chowilla scenerio.

Given the sparse seismic information in the Chowilla Region, a precautionary approach to injection should be adopted which incorporates the establishment of a seismic monitoring network of up to six monitoring stations (including within boreholes).

10. RECOMMENDATIONS FOR PHASE III

- Refine hydrogeologic parameters by performing a staged pump/recovery test on WARINA 1. This should occur by airlifting the well at staged stress intervals and analysing recovery data.
- Conduct a targeted literature review of Aquifer Storage and Recovery (ASR) projects in Australia and overseas, in consultation with industry leaders to select appropriate infrastructure and treatment facilities for a Phase III injection trial.
- Confirm the site for the Phase III injection trial which will complement major project works on the Chowilla Floodplain.
- Finalise injection well design specifications.
- Call for tender, award and finalise a drilling contract to construct a wide diameter injection well into the Warina Formation, and construct four to five shallow production wells into the Monomon Formation close to the trial site.
- Perform long term pumping tests on the injection well to refine hydraulic parameters and record long term water quality changes. Use WARINA 1 as an observation well during pump testing.
- Update the regional groundwater model with newly obtained data from Phase II and Phase III studies.
- Outlay a seismic monitoring network to record baseline seismic data and continue to monitor during an injection operation.
- Adopt a strategic operational plan should seismic activity occur.

APPENDICES

1. TENDER PURCHASE RECOMMENDATION

MINUTES *forming* ENCLOSURE *to* DWLBC 0136/06

TO: APU

FROM: Senior Hydrogeologist

SUBJECT: Deep Aquifer Disposal Renmark Group – Assessment of drilling Tender – Purchase Recommendation

DATE: 17 May 2006

THROUGH: Executive Director Natural Resources Management (PII)

Director Knowledge and Information

Group Manager Resource Knowledge and Science

A/Manager River Murray SIS Investigations

ISSUE

Assessment of the responses to the Renmark Group Construction of Observation Well tender for the Deep Aquifer Disposal - Renmark Group project.

This project drilling tender and acquisition plan (refer Attachment ‘A’) were endorsed by the APU at the November 2005 meeting (refer Attachment ‘B’).

The tender called for the drilling and construction of one (1) 550 m deep investigation drillhole to be completed as an observation well. The data gained from this work will be used in investigations into the feasibility of deep aquifer disposal of saline groundwater to be pumped from the proposed Chowilla Salt Interception Scheme (SIS).

The tender also called for the cost estimates for the drilling and construction of a 550 m deep injection well, that may be constructed following satisfactory results from the preliminary investigations. This well would be the subject of a separate tender.

THE TENDER

DAIS Contract Services handled the tender. The tender was advertised in the Advertiser (28/02/2006) and Australian (04/03/2006) with a closing date of 22 March 2006. The tender was also included on the DAIS website: http://www.tenders.sa.gov.au.

The tender closing date was extended due to the fact that K H Adams & Sons Pty Ltd could not provide a response in the required timeframe. DAIS extended the closing date to 29 March 2006 by emailing anyone who had accessed the website (and in the case of Adams, by telephone advice due to problems with their computer system).

Only three (3) tenders were received, all from Victorian drilling contractors with the following estimated costs for the observation well and injection well:

Drilling contractor	Estimated cost of observation well inc GST	Estimated cost of alternative observation well inc GST	Estimated cost of injection well inc GST
Sides	**$365 000**	**$376 000**	$562 000
Drilltec	**$294 000**		$444 000
Adams	**$345 000**		$1 022 000

OVERVIEW OF TENDER SUBMISSIONS

7. Sides Engineering Pty Ltd (Sides). This tender arrived on time and was comprehensive in that it addressed all of the issues raised in the tender. The tender questioned the proposed well design and offered an alternative, which indicated that Sides had critically evaluated the proposed Work. Sides made telephone contact to discuss the issue. This tender included a statement of conformity that detailed several minor non-conforming issues:

   a. Not registered with InSkill SA. Note that this would not necessarily be expected of any non-South Australian company and can be arranged.

   b. Not provided a Works Method Statement for the injection well, but will provide after award of contract.

   c. Have appropriately licensed Level-3 drillers but they do not have a South Australian Class 3 licence. Note that this would not necessarily be expected of any non-South Australian drilling contractor. South Australian licensing can be arranged.

   d. Sides do not have $25m public liability insurance ($20m only), but this is deemed acceptable, considering the remote location of the Work. Sides do not carry works insurance, but make individual arrangements for particular jobs. This will need to be discussed further with Sides. The cost of Works insurance is likely to be around $5000.

   e. Only an example table of contents of the Health Safety Environment Management Plan was provided as Sides stated that it would be site-specific. Some further information was sought and provided. These details have been reviewed by the departmental OHS&W Coordinator, and were deemed satisfactory. Further site-specific material may be sought prior to signing of any contract.

   Sides tender provided the following evidence of their capacity to undertake the Work:

   a. A detailed Works Method Statement and critical analysis of the proposed observation well construction that resulted in them proposing an alternative design. This clearly indicated that the Work had been carefully considered, the proposed alternative design would overcome any potential risks with the final completion of the well.

b. A track record of deep drilling.
c. An offer to provide a driller with 45 years experience who has an extensive track record of difficult jobs (note that this is someone with the same standing as our retired Drilling Superintendant Mike Brennan).
d. Quality management systems for Quality, Safety and Environment.
e. Specific details of OHS&W history over the past 10 years, which indicates that over the past five years the injury rate is low (in 2005 only 10 man hours were lost and two medically reportable injuries occurred during 63 000 man hours worked).
f. Referees who spoke highly of Sides work. These persons had also been involved with work undertaken by Drilltec, who they rated as good, but not quite as good as Sides.
g. A financial capacity and stability statement from a Certified Practising Accountant that gave full financial details of the company. This statement was considered acceptable by S Patriarca.

8. Drilltec Pty Ltd (Drilltec). This tender arrived late, and only on request for information from the company after the tender closing date. This tender was non-conforming in that some of the information requested in the tender document was not provided, and what was provided was less detailed, in particular:

    a. The Works Method Statement was less detailed than Sides, and although there was a general comment stating that the grouting of the well needed to be further discussed, there was no detail of any concerns regarding the well construction (and no telephone contact was made to discuss the Work), although it may be that they were satisfied with the proposed design. The suggestion that the proposed well should be jetted for development may indicate that little thought had been given to the Work, as this is not an acceptable method for slotted casing.
    b. No costing or Works Method Statement was provided for the injection well, however upon further request a costing was provided.
    c. Drilltec is a new company and as such do not have a significant track record of difficult work (in comparison to Sides).
    d. No resumes were provided, however upon further request these were provided.
    e. A quality management system is held for Quality, but not for Safety or Environment (as is the case for Sides).
    f. Specific details of OHS&W history were not provided, stating only that their WorkCover levy is significantly below the industry standard (although some information for the past three years was gleaned from an OHS&W questionnaire that was mistakenly sent to this department, which indicated that the record of the last three years was good, i.e. no lost work days). This is in contrast to Sides, which gave full details of their OHS&W record and analysis for the past 10 years.
    g. The only insurance held by the company is public liability matching that required by this department, however no works insurance is held.
    h. The financial capacity and stability statement that was provided was examined by S Patriarca who concluded that it was unsatisfactory.

9. K H Adams & Sons Pty Ltd (Adams). This tender arrived late (7 April 2006) due to being posted in country Victoria the day before tender closing. This tender was non-conforming in that the bulk of the information requested in the tender was not provided.

TENDER ASSESSMENT AND RECOMMENDATION

The tenders were assessed by the evaluation panel on 4 May 2006 (S Howles, T Hodgkin, D Sartoretto, A MacIntyre) against the evaluation criteria in the acquisition plan. It was noted that an accurate final cost would not be achieved until negotiations were entered into with a selected drilling contractor.

The committee made the following recommendations:

1. That the Sides tender with its minor non-conforming issues be accepted as conforming. Note that all outstanding issues will be clarified and finalised before signing of any contract.
2. That the remaining late tenders with more significant deficiencies be considered non-conforming and these tenderers be written to advising them that they were not successful.
3. There was no need to undertake scoring against the evaluation criteria as there was only one conforming tender, however Sides were assessed to meet the criteria sufficiently to be considered suitable for the Works. The other two companies were not able to demonstrate that they had the capability to perform the Work.
4. That the prudent course of action, based on the research and information provided, was to initiate further negotiations with Sides regarding the outstanding technical and administrative arrangements for the completion the proposed observation well.

The tender placed less emphasis on the cost of the Work, and more emphasis on the technical ability of the drilling contractor to be able to complete the Work. In view of the experience gained by Knowledge and Information Division during the tendering and contracting of the $1.2m Loxton horizontal drainage well, experience should be selected over a lower price.

RECOMMENDATION

That the APU:

1. Note that only three tenders were received for the *Renmark Group Construction of Observation Well* tender.
2. Endorse contract negotiations with Sides regarding the outstanding technical and administrative arrangements for the completion the proposed observation well, and if agreement can be reached, to award contract, subject to the funding being approved by the SIS Steering Committee.

Stephen Howles

SENIOR HYDROGEOLOGIST

2. CONSTRUCTION TIMELINE; CHOWILLA OBSERVATION WELL

Construction timeline – Chowilla 1 Observation well	Activity
Jan 8	Earthmoving: construction of holding dam, mud pits, preparation of site for drill rig.
Jan 9	Earthmoving: Continued and completed by 15:00 hrs.
Jan 10	Mobilisation: first delivery trucks arrive with drilling equipment, pumps. JMA cranes arrive to unload pumps. Drill rig arrived in early afternoon.
Jan 11	Mobilisation continued. Water truck hired to cart water from campsite 15 to holding dam for mud mixture. Rigging up.
Jan 12	Rigging up: Installation of 450 mm stabilisation collar to 3 m.
Jan 13	Rigging up: Setup of drill platform, shale shaker. Mud mixture prepared in preparation for drilling.
Jan 14	Rigging up/mixing mud: Equipment tested in preparation for drilling, lights set up for 24 hr shift. Backup crew arrived. Drilling commenced 3 pm, stopped at 28 m in Monomon Sands.
Jan 15	Drilling continued/night shift begins: drilled to 104 into Murray Group Limestone. Installation of 203 mm PVC casing to 104 m. Pull out of hole in preparation for grout mixture to arrive (cementing).
Jan 16	Cement PVC casing/drilling: Cement truck arrived at 09:45, grout was pumped around annulus. Waited 12 hours for grout to set. Drilling continued from 00:00 through Murray Group Limestone.
Jan 17	Drilling continued: drilling through Murray Group Limestone.
Jan 18	Drilling continued: Drilled through Murray Group Limestone, into Ettrick formation (202 m); and Olney Formation (~230 m). Added barites to mud early in morning to increase viscosity of mud. Continued to drill throughout the day through Olney formation to over 300 m BGL.
Jan 19	Drilling continued: Drilling through Olney Formation (variations of sands, silts, clays and lignites). Target aquifer (Warina Sands) struck at ~370 m later in evening.
Jan 20	Drilling continued: Showers and heavy rain fell overnight. Drilled through Warina Sands Formation and into pre-Tertiary Clay material. Target depth reached. Warina Sands formation found between 370–460 m. Continued drilling to 537 m. Stopped drilling and shut down rig at ~11 am due to heavy rain.
Jan 21	Standby: Heavy rain forced site abandonment for all of Sunday 21st Jan.
Jan 22	Geophysical Logging/placement of plug: Don Freebairn (Geophysical Services) logged hole to total depth 537 m. Initial placement of plug at 442–448 m, and 454–460 m after discussion with Stephen Howles, Kwadwo Osei-Bonsu, Adrian Costar, Paul Magarey and Peter Freeman. Set to screen between 410–440 m.
Jan 23	Initial plug failed: Mud contaminated with cement and curdled. Thinning agent added. Second attempt to set plug.
Jan 24	Second plug located/running of FRP casing. Second plug found at 449 m. FRP casing run to 398 m, (screen interval aimed for 410–440 m – see screen design attached). FRP found to be short of O'Rings, Peter Freeman drove to Waikerie to obtain.
Jan 25	Finish running casing/cement FRP. O'Rings obtained and FRP casing run and completed to 398 m. Truck arrived and FRP casing cemented. Wait for grout to set.
Jan 26	Preparation and running of screen assembly/prepare for jetting: Screen prepared (welded) for lowering into formation. Stainless steel used from 398–410 m, and 440–447 m, with 2 m sump from 447–449 m (see screen design). Jetting tool lowered into hole, had trouble entering past "J-latch."

Construction timeline – Chowilla 1 Observation well	Activity
Jan 27	Problem entering screen: Galvinised jetting tool had parted early hours of morning. Pipe recovered and drill string removed from hole. Pipe repaired and entered back into hole. Could not enter past J-Latch at ~410 m.
Jan 28	Downhole Camera inspection: Downhole Camera (Vic Freschi) inspected damage to J-latch. J-latch found to be bent.
Jan 29	Tool attached to drill string to fix J-latch problem. Entered back into hole, and pushed J-Latch down.
Jan 30	Vic Freschi arrived back with downhole camera. Confirmed that J-Latch problem had been suitably rectified. Jetting tool welded together and initial development occurred into top of screen.
Jan 31	Development of bore: Jetting through screen and sump. Collection of water sample and fine sand sample for CSIRO. Completion and hand over of bore to DWLBC.

3. SIDES CONTRACTORS PTY LTD DRILLING REPORT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 855 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE: D W L B C
Project: OBSERVATION WELL
Location: LOCK 6 SA

Rig No. CD 2500
DATE OF REPORT 10-1-07
DRILL REPORT # 1
BORE HOLE # P/N123479
SHIFT DAY/~~NIGHT~~

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit			DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cememting,Access,Waiting on decisions, Breakdown,etc	DELAY HOURS
7⁰⁰	7³⁰										TRAVEL	
7³⁰											RIG + EQUIPMENT ON SITE UNLOAD TRUCKS WITH CRANE	
	4³⁰										SETTING UP RIG + EQUIPMENT	
4³⁰	5⁰⁰										TRAVEL	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	N HAMILTON		
Offsider	B MACINTOSH		
	L BERNALDO		
	S CONSTANTINE		

Comments:-

VERY HOT DAY 42°C

	Name	Signature
Supervisor/Driller	P FREEMAN	P Freeman
Client's Authorised Representative:-	[signature] PAUL MAGAREY.	
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 855 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE: DWLBC
Projec.: OBSERVATION WELL
Location: LOCK 6 SA.

Rig No. CD 2500
DATE OF REPORT: 11-1-07
DRILL REPORT #: 2
~~BORE HOLE~~ #: P/N 123479
SHIFT: DAY/~~NIGHT~~

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit			DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cememting, Access, Waiting on decisions, Breakdown, etc	DELAY HOURS
7.00	7.30										TRAVEL	
7.30	5.00										Rigging up Rig + Equipment	
											WATER TRUCK ON SITE CARTING TO STORAGE DAM	
5.00	6.00										TRAVEL	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	M HAMILTON		
Offsider	B MACINTOSH		
	L BERNALDO		
	S CONSTANTINE		

Comments:-

	Name	Signature
Supervisor/Driller	P FREEMAN	P Freeman
Client's Authorised Representative:-	PAUL MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 855 248
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE: DWLBC
Proje..: OBSERVATION WELL
Location: LOCK 6 SA

Rig No. GD 25
DATE OF REPORT 12-1-07
DRILL REPORT # 3
P/N ~~BORE HOLE~~ # 123479
SHIFT DAY/~~NIGHT~~

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cementing,Access,Waiting on decisions, Breakdown,etc	DELAY HOURS
7:00	7:30								TRAVEL	
7:30									UNLOAD TRUCK FROM MILLS	
									CONT RIGGING UP	
									UNLOAD MUD OFF SEMI	
	5:00								CONT FILLING STORAGE DAM	
									SET IN CONDUCTOR	
5:00	5:30								TRAVEL	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
$2\frac{1}{2}$ m x $13\frac{3}{8}$ STEEL	CASING
8 BAGS x 20KG	CEMENT

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	N HAMILTON		
Offsider	B McINTOSH		
	L BERRALDO		
	S CONSTANTINE		

Comments:-

	Name	Signature
Supervisor/Driller	P FREEMAN	PF
Client's Authorised Representative:-	PAUL MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 305 855 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468855 Fax (03) 95468599

DRILLING REPORT

CLIE: DWLBC
Proje.: OBSERVATION WELL
Location: LOCK 6 SA.

Rig No. GD 2500
DATE OF REPORT 13-2-07
DRILL REPORT # 4
P/N ~~BORE HOLE~~ # 123479
SHIFT DAY/~~NIGHT~~

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit			DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cememting,Access,Waiting on decisions, Breakdown,etc	DELAY HOURS
7⁰⁰	7³⁰										TRAVEL	
7³⁰											SET UP FLOW LINE + SHAKER	
											MIXING MUD	
											SETTING GUY WIRES	
											SET WORK DECK	
	6⁰⁰										HAVE ELEC POWER HOOKED UP TO GEN	
6⁰⁰	6³⁰										TRAVEL	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
AUS-GEL	16 x 25 KG BAGS
SODA-ASH	1 BAG

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	N HAMILTON		
Offsider	B McINTOSH		
	L BERNARDO		
	S CONSTANTINE		

Comments:-

	Name	Signature
Supervisor/Driller	P FREEMAN	PF
Client's Authorised Representative:-	PAUL MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 866 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE: DWLBC
Proje.: OBSERVATION WELL
Location: LOCK 6 SA.

Rig No. GD 2500
DATE OF REPORT 14-1-07
DRILL REPORT # 5
P/H ~~BORE HOLE~~ # 123479
SHIFT DAY/~~NIGHT~~

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	MUD VIS	MUD WT	DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cementing, Access, Waiting on decisions, Breakdown, etc	DELAY HOURS
7.00	7.30								38	8.5	TRAVEL	
7.30											CONT SETTING UP TO DRILL	
											SET LIGHTS	
											FINISH MIXING MUD	
	3.00										RUN + TEST ALL EQUIPMENT	
3.00	6.00	1.5	3.0	SILTY CLAY		12¼" R/R					DRILL	
		3.0	28	SANDS								
6.00	6.15										PULL UP HOLE	
6.15											MIX MUD + FUEL UP	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
AUS GEL	63 X 25 KG BAGS
SODA-ASH	4 BAGS
PAC-R	1 BAG

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	N HAMILTON		
Offsider	B MCINTOSH		
	L BERNALDO		
	S CONSTANTINE		
	ANDREW		
	RAY		
	ANDREW		

Comments:-

	Name	Signature
Supervisor/Driller	P FREEMAN	PF
Client's Authorised Representative:-	PAUL MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 895 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE' DWLBC
Projs. OBSERVATION WELL
Location LOCK 6 SA

Rig No. GD 2500
DATE OF REPORT 15-1-07
DRILL REPORT # 6
P/H BORE HOLE # 123479
SHIFT DAY/~~NIGHT~~

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per TIME	VIS	WT	DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cementing, Access, Waiting on decisions, Breakdown, etc	DELAY HOURS
7⁰⁰	7³⁰				CK 2337	12¼"		9³⁰	38	8·6	TRAVEL	
7³⁰	7⁴⁵							10³⁰	37	8·6	SERVICE	
7⁴⁵	8¹⁵							11³⁰	38	8·6	RUN BACK TO BOTTOM, COND MUD	
8¹⁵	5⁴⁵	28	30	SANDS				1³⁰	36	8·6	DRILL 28–104	
5⁴⁵	6⁰⁰	30	34	CLAYEY SAND				3⁰⁰	37	8·7	CIRC HOLE CLEAN	
6⁰⁰	7⁰⁰	34	36	SANDS				5³⁰	37	8·9	PULL BACK FOR WIPER RUN	
		36	69	SILTY CLAYS VERY PUGGY								
7⁰⁰	7³⁰	69	92	LIMESTONE CLAYEY							TRAVEL	
		92	104	LIMESTONE WITH HARD SANDS								

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
½ Bag Pac-R	12½ KG

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	N HAMILTON		
Offsider	B MCINTOSH		
Offsider	A MARTYN		
	A LAMBERT		

Comments:-

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	[signature] PAUL MAGAREY	
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 855 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE: DWLBC
Proje: OBSERVATION WELL
Location: LOCK 6 SA

Rig No. GD 2500
DATE OF REPORT 15 16-1-07
DRILL REPORT # 7
P/H BORE HOLE # 123479
SHIFT ~~DAY~~NIGHT

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit			DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cementing,Access,Waiting on decisions, Breakdown,etc	DELAY HOURS
630	730										TRAVEL	
700	745										RIH WIPER RUN	
745											CIRC HOLE CLEAN	
	930										PREPARE CASING + GEAR	
930	1015										P O H.	
1015											RUN PVC CASING + HYDRIL PIPE	
	115										BREAK CIRC	
115											PREPARE GROUT GEAR	
											HYDRATE BENTONITE	
	7PM										GENERAL WORK AROUND RIG	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
PVC	17X 6-01 JOINTS
"	1 FLANGE JOINT
CENTRALIZERS	5 SETS
BENTONITE	3 X 25 KG BAGS
S/STEEL SCREWS	70 X 12" X 3/4

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	S CONSTANTINE		
Offsider	L BERNALDO		
	RAY A		

Comments:-

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 005 855 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE' DWLBC
Proj. OBSERVATION WELL
Location LOCK 6 S.A.

Rig No. CD2500
DATE OF REPORT 16-1-07
DRILL REPORT # 8
P/N BORE HOLE # 123479
SHIFT DAY/[redacted]

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit			DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cementing,Access,Waiting on decisions, Breakdown,etc	DELAY HOURS
6^30	7^00										TRAVEL	
7^00	7^30										CAL CEMENT VOL REQUIRED	
7^30	9^45										ORDER CEMENT + WAIT FOR CEMENT	
9^45	10^30										PUMP CEMENT TO SURFACE	
10^30	1^30										CLEAN UP GEAR WAIT ON CEMENT SET	
1^30		WAIT ON CEMENT SET									RELEASE PRESS + PULL OUT CEMENTING PIPE. FILL UP ANNULUS BETWEEN 13 3/8 + PVC CASING WITH HAND MIXED CEMENT REMOVE 12¼ BIT + SUBS	
	7^00										GENERAL SITE WORK	
7^00	7^30										TRAVEL	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
CEMENT	11 x 20 KG BAGS

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	H HAMILTON		
Offsider	B McINTOSH		
Offsider	A MARTYN		
	A LAMBERT		

Comments:-
2 SAMPLES TAKEN
WT 1·44 SG
USED 3000 KG CEMENT
WATER 2420
BENTONITE 960LT 3% VOL
TOTAL CEMENT VOL 4340 LT

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD
ABN 21 905 955 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE' DWLBC
Proj. OBSERVATION WELL
Location LOCK 6 SA.

Rig No. GD 2500
DATE OF REPORT 16-17-1-07
DRILL REPORT # 9
P/H ~~BOREHOLE~~ # 123479
SHIFT ~~DAY~~/NIGHT

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	VIS	WT	DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cementing, Access, Waiting on decisions, Breakdown, etc	DELAY HOURS
6.30	7.00					7 7/8 NR		1.00	35	8.9	TRAVEL	
7.00								2.00	35	8.9	WAIT ON CEMENT TO SET	
	10.30							3.00	35	8.9	MAKE UP RISER + T PIECE / FLOW LINE	
10.30	12.00							4.00	34	8.9	RIH CLEAN OUT TO 104 mt	
12.00	7.00	104		LIMESTONE HARD BANDS				5.00	35	8.9	DRILL 104 - 141	
7.00	7.30							6.30	35	8.9	TRAVEL	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	L BERNALDO		
Offsider	S CONSTANTINE		
	Ray		

Comments:-

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD
ABN 21 005 855 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE*: D W L B C
Proj.: OBSERVATION WELL
Location: LOCK 6 S.A.

Rig No. GD 2500
DATE OF REPORT: 17-1-07
DRILL REPORT #: 10
P/H ~~BORE HOLE~~ #: 123479
SHIFT: DAY/~~NIGHT~~

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	WT	W/S	DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cementing, Access, Waiting on decisions, Breakdown, etc	DELAY HOURS
6.30	7.00							8.30	9.1	35	TRAVEL	
7.00	7.30	141	184	LIMESTONE/HARD BANDS				11.30	9.1	35	DRILL 141-184	
								1.30	9.0	51		
7.00	7.30							4.00	9.1	39	TRAVEL	
								5.30	9.2	42		
					LK8958 ER5016	7 7/8"						

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
SODA-ASH	3 KG
AUSGEL	8 x 25 KG Bags
PAC-R	1 x 25 KG Bag

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	M HAMILTON		
Offsider	B McINTOSH		
Offsider	A MARTYN		
	A LAMBERT		

Comments:-

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 855 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE' DWL BC
Proj. OBSERVATION WELL
Location LOCK 6 SW.

Rig No. GD 2500
DATE OF REPORT 17/10-107
DRILL REPORT # 11
P/H BORE HOLE # 123479
SHIFT DAY/NIGHT

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	WT	VIS	DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cememting,Access,Waiting on decisions, Breakdown,etc	DELAY HOURS
6^30	7^30							7^15	9.1	40	TRAVEL	
7^30	4^30	184	212	LIMESTONE				8^30	9.1	43	DRILL 184-231	
4^30	7^00	212	231	SILTY CLAYS				10^30	9.1	37	WEIGHT UP MUD WITH BARITES	
7^00	7^30							12^15	9.1	35	TRAVEL	
								1^00	9.1	37		
								3^00	9.2	40		
								4^00	9.1	39		

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
SODA-ASH	1½ KG
AUS-GEL	4 X 25KG BAGS
PAC R	12½ KG
BARITES	110 ~~X~~ 25KG BAGS

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	L BERNALDO		
Offsider	S CONSTANTINE		
	RAY 14		

Comments:-

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 855 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE' DWLBC
Proj. OBSSERVATION WELL
Location LOCK 6 S.W.

Rig No. GD2500
DATE OF REPORT 18-1-07
DRILL REPORT # 12
P/H BORE HOLE # 123479
SHIFT DAY

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	WT	VIS
6:30	7:00							7:00	9.3	41
7:00	8:30							8:45	9.6	40
8:30		231	232	SILTY CLAYS				8:30	9.6	41
	7:00	232	258	CLAYEY SILT + FINE SAND				9:45	9.5	39
7:45	7:30	258	263	LIGNITES				11:45	9.6	38
		263	276	SILTY CLAYS				12:45	9.6	39
		276	286	SAND				2:45	9.5	38
		286	289	LIGNITES				3:45	9.6	42
								4:45	9.6	42
								5:45	9.6	39
								6:45	9.6	40
								6:45	9.6	42

DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) — Logging, Cementing, Access, Waiting on decisions, Breakdown, etc | **DELAY HOURS**

TRAVEL
WEIGHT UP MUD WITH BARYTES
DRILL 231-289
MIX MUD + BARYTES
TRAVEL

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
BARYTES	80 x 25KG BAGS
AUSGEL	8 x 25KG BAGS
SODA ASH	3KG
PAC-R	3/4 BAG

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	N HAMILTON		
Offsider	B McINTOSH		
Offsider	A MARTYN		
	A LAMBERT		

Comments:-
SAMPLE LAG TIME FROM 250m 7 MINS

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P HAGARTY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 855 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE' DW L B C
Proj. OBSERVATION WELL
Location LOCK 6 S.A.

Rig No. GD2500
DATE OF REPORT 19/9/07
DRILL REPORT # 13
BORE HOLE # P/N 12347
SHIFT [redacted]/NIGHT

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	WT	VIS
6.30	7.00							7.30	9.4	44
7.00	7.00	289	330	LIGNITES				3.30	9.4	40
7.00	7.30	330	351	SILTY SANDY CLAY				11.30	9.4	42
								1.30	9.5	40
								3.30	9.6	38
								5.30	9.6	39
								6.30	9.6	40

DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cementing, Access, Waiting on decisions, Breakdown, etc	DELAY HOURS
TRAVEL	
DRILL 289 - 351 (ADJUST ROTARY CLUTCH)	
TRAVEL	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
SODA ASH	3 KG
AUS-GEL	8 X 25KG BAGS

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	L BERNALDO		
Offsider	S CONSTANTINE		
	R LOOBY		

Comments:-

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 855 249

25 Garden Rd Clayton Vic 3168

Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE' DWLBC

Proj. OBSERVATION WELL

Location LOCK 6 S4

Rig No. GD2500

DATE OF REPORT 19-1-07

DRILL REPORT # 14

P/H BORE HOLE # 123479

SHIFT DAY/~~NIGHT~~

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	WT	VIS	DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cementing, Access, Waiting on decisions, Breakdown, etc	DELAY HOURS
6 30	7 30							7 30	9-6	40	TRAVEL	
7 00	8 45	351	353	SILTY SANDY CLAY				8 30	9-6	48	DRILL 351-354	
8 45	9 45	353	368	STICKY CLAYS				1 45	9-6	42	CIRC HOLE CLEAN, SET UP TO POOH	
9 45	10 30	368	370	CLAYEY SAND				2 00	9 6	42	POOH FOR BIT INSPECTION	
10 30		370	386	SAND				3 00	9-6	45	SERVICE ALL EQUIPMENT	
	11 30	386	389	SANDY CLAY				4 00	9-6	45	MIX MUD	
11 30	12 30							6 00	9-7	42	RIH	
12 30	7 00							7 00	9.7	44	DRILL 354 - 389	
7 00	7 30										TRAVEL	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
PIAC-R	3/4 BAG
BARYTES	30 x 25 KG BAGS

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	N HAMILTON		
Offsider	B MCINTOSH		
Offsider	A MARTYN		
	A LAMBERT		

Comments:-

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P HAGARET	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 655 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE' DWLBC
Proje. OBSERVATION WELL
Location LOCK 6 SA.

Rig No. GD 2500
DATE OF REPORT 19/20-1-07
DRILL REPORT # 15
P/N ~~BORE HOLE~~ # 123479
SHIFT ~~DAY~~NIGHT

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	WT	VIS
6:30	7:00							8:00	9.7	42
7:00	7:00	389	398	SANDY CLAY				9:00	9.7	45
7:00	7:30	398	403	GRAVELY CLAY				10:00	9.7	44
		403	410	SANDY CLAY				11:00	9.7	42
		410	462	SANDS				12:00	9.7	42
		462	506	CLAYS				1:00	9.7	43
								2:00	9.8	45
								3:55	9.6	44
								5:00	9.8	44
								6:00	9.7	43
								7:00	9.6	44

DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) — Logging, Cementing,Access,Waiting on decisions, Breakdown,etc

Description	Delay Hours
TRAVEL	
DRILL 389 - 506	
TRAVEL	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
SODA ASH	6 KG
AUS GEL	16 x 25KG BAGS
PAC- R	3/4 BAG
BARYTES	30 x 25KG BAGS

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	L BERNALDO		
Offsider	S CONSTANTINE		
	R LOOBY		

Comments:- (LIGHT RAIN ALL NIGHT)

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 005 855 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE' DWLBC
Proj. OBSERVATION WELL
Location LOCK 6 SA.

Rig No. GD2500
DATE OF REPORT 20-1-07
DRILL REPORT # 16
P/N BORE HOLE # 123479
SHIFT DAY/~~NIGHT~~

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	WT	VIS	DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cementing,Access,Waiting on decisions, Breakdown,etc	DELAY HOURS
6:30	7:00										TRAVEL	
7:00	10:30	506	537	CLAYS							DRILL 506-537	
10:30											SITE BECOMING TO WET	
											PULL OUT HOLE + MAKE	
	12:00										SECURE SHUT DOWN	
12:00											TRAVEL	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	N HAMILTON		
Offsider	B McINTOSH		
Offsider	A MARTYN		
	A LAMBERT		

Comments:- HEAVY RAIN

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	I MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD	DRILLING REPORT	Rig No. CD 2500
ABN 21 005 855 249	CLIE' DWLBC	DATE OF REPORT 22-1-07
25 Garden Rd Clayton Vic 3168	Proj. OBSERVATION WELL	DRILL REPORT # 17
Tel (03)95468655 Fax (03) 95468599	Location LOCK 6 SA.	P/N BORE HOLE # 123479
		SHIFT DAY

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	WT	VIS	DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cementing,Access,Waiting on decisions, Breakdown,etc	DELAY HOURS
7^{00}	7^{30}							8^{00}	9-6	44	TRAVEL	
7^{30}	9^{00}							10^{00}	9.5	41	SERVICE RIG + EQUIPMENT	
9^{00}								11^{00}	9-7	40	RIH + CLEAN OUT TO BOTTOM	
	2^{45}										FOR LOGGING	
2^{45}	3^{15}										CIRC HOLE CLEAN	
3^{15}	4^{45}										POOH FOR LOGGING	
4^{45}	5^{30}										SET UP LOGGER	
5^{00}	7^{00}										LOGGING	
7^{00}	7^{30}										TRAVEL	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	N HAMILTON		
Offsider	B MCINTOSH		
Offsider	A MARTYN		
	A LAMBERT		

Comments:-

	Name	Signature
Supervisor/Driller	T FREEMAN	[signature]
Client's Authorised Representative:-	P McGARRY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 855 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE': DWLBC
Proj: OBSERVATION WELL
Location: LOCK 6 SA.

Rig No. GD2500
DATE OF REPORT 22/23/2007
DRILL REPORT # 18
BORE HOLE # P/H 123479
SHIFT NIGHT

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cememting,Access,Waiting on decisions, Breakdown,etc	DELAY HOURS
6³⁰	7⁰⁰								TRAVEL	
7⁰⁰	11³⁰								LOG HOLE	
11³⁰									RIH 3½ D/P CIRC MUD	
									MUD VERY THICK	
									MIX 9 X 20 KG BAGS CEMENT	
									200 LTR MIX 13-LB. CHASE GROUT	
									1758 LTS MUD. PULL BACK 4 mts	
									CIRC MUD. MUD CURDLED IN PIPE	
									MIX 9x20 KG CEMENT, UNABLE TO	
									PLACE DUMP GROUT. PULL BACK	
									2 SINGLES, FIT KELLY & CIRCULATE	
	7⁰⁰								POOH CLEAN UP/GEAR	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
CEMENT	18 x 20 KG BAGS CEMENT

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	L BERNALDO		
Offsider	S CONSTANTINE		
	R LOOBY		

Comments:-

	Name	Signature
Supervisor/Driller	P Freeman	[signature]
Client's Authorised Representative:-	P MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 885 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE': DWLBC
Proj.: OBSERVATION WELL
Location: LOCK 6 SR.

Rig No. BD250C
DATE OF REPORT 23-1-07
DRILL REPORT # 19
BORE HOLE # 123479 7/N
SHIFT DAY/~~NIGHT~~

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	WT	VIS	DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cementing, Access, Waiting on decisions, Breakdown, etc	DELAY HOURS
6:30	7:30										TRAVEL	
7:30											RING AMC RE MUD. WAIT THINNING MATERIAL FROM ADEL RUN D/Cs. UNLOAD FRP CASING + S/STEEL PIPE CONT RUNNING IN HOLE STOPPED 230 m HOLE CAVED IN CLEAN OUT TO 280 RUN + CIRC PIPE DOWN TO 463 NO PLUG MUD CONTAMINATED WITH CEMENT. COND MUD	
	4:25										P.O.O.H STAND BACK D/Cs	
4:25	6:00											
6:00	7:00										RUN OPEN END PIPE FOR PLUGS	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
SODIUM BI-CARB	2 X 25 KG
LIQUI-SPERSE	2 X 25 KG
SODA ASH	3 KG
AUS-GEL	8 X 25 KG
PAC-R	$\frac{3}{4}$ BAG

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	N HAMILTON		
Offsider	B MCINTOSH		
Offsider	A MARTYN		
	A LAMBERT		

Comments:-

	Name	Signature
Supervisor/Driller	P FREEMAN	PF
Client's Authorised Representative:-	P MAGAREY	P Magarey
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 855 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE' DWLBC.
Proje. OBSERVATION WELL
Location LOCK 6 SA

Rig No. GD 25c
DATE OF REPORT 23/24-1-07
DRILL REPORT # 20
BORE HOLE # 123479
SHIFT ~~DAY~~NIGHT

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	WT	U/S
6:30	7:30							8:30	9-6	43
7:30	9:00							10:30	9-5	52
9:00								1:15	9-4	43
								4:15	9-4	45
								6:00	9.6	45
	7:00									

DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS)
Logging, Cememting Access,Waiting on decisions, Breakdown,etc

DELAY HOURS

TRAVEL
CIRC SET UP GROUT GEAR
MIX GROUT FOR PLUG 12.8LBS
PLACE GROUT IN D/PIPE + CHASE TO
BOTTOM. PULL PIPE BACK WHILE PUMPING
CHASER FLUID. LAY OUT 2 SINGLES
MIX 2ND PLUG UNABLE TO GET FLUID
TO RUN DOWN PIPE. PULL UP 2 RODS
FIT KELLY CIRC 1HR AT 430 ft
PULL OUT D/PIPE. RUN BACK TO 200 ft
WITH D/CS + BIT. WAIT ON GROUT SET

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
LIQUI-SPERSE	2KG
SOD/BICARB	3 KG
CEMENT	12 x 20 KG BAGS

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	L BERNALDO		
Offsider	S CONSTANTINE		
	R LOOBY		

Comments:-

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 895 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE' DWLBC
Proje OBSERVATION WELL
Location LOCH 6 S.A.

Rig No. GD 2500
DATE OF REPORT 24-1-07
DRILL REPORT # 21
P/H BORE HOLE # 123479
SHIFT DAY

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	WT	VIS	DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cementing, Access, Waiting on decisions, Breakdown, etc	DELAY HOURS
6:30	7:30							9.50	9.5	41	TRAVEL	
7:30	9:15							10.50	9.5	42	RUN TO BOTTOM, CHECK PLUG	
9:15											PLUG AT 449 mtr	
	10:00										COND MUD	
10:30	12:00										POOH + LAY DOWN D/C's	
12:00	1:00										RIH OPEN END PIPE	
1:00	1:45										CIRC HOLE. CLEAN OUT MUD TANKS	
1:45											PULL OUT D/P + LAY DOWN	
											LAY DOWN KELLY (MIX MUD)	
	6:00										SET UP TO RUN FRP	
6:00	7:00										RUNNING FRP	
7:00	7:30										TRAVEL	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
AUS-GEL	14 X 25KG Bags
LIQUI-SPERSE	2 X 25KG

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	N HAMILTON		
Offsider	B MCINTOSH		
Offsider	A MARTYN		
	A LAMBERT		

Comments:-

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 005 055 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468855 Fax (03) 95468599

DRILLING REPORT

CLIE' DWLBC
Proje OBSERVATION WELL
Location LOCK 6 SA.

Rig No. CD 2500
DATE OF REPORT 24/25·1·07
DRILL REPORT # 22
P/H BORE HOLE # 123479
SHIFT ~~DAY~~NIGHT

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit			DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cementing,Access,Waiting on decisions, Breakdown,etc	DELAY HOURS
0 30	7 30										TRAVEL	
7 30	12 30										RUNNING FRP CASING	
12 30	2 15										WAIT FOR SMALLER DIAM O RINGS	
2 15											FINISH RUNNING CASING + WELD	
											FLANGE + FIT ~~[illegible]~~ RISER TUBE	
											PREPARE + RUN HYDRIL PIPE	
	7 00										STING INTO SHOE + BREAK CIRC	
7 30	2 30										TRAVEL	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
CENTR KWIK-ZIP	20 X 3 SETS
FRP CASING	1 X 1 mt + FLOAT SHOE
	66 X 6 CASING
	1 X 1 mt TOP + FLANGE
	TOTAL 398 mts

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	L BERNALDO		
Offsider	S CONTANTINE		
	R LOOBY		

Comments:-

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P HAGAREY	
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 005 855 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE' DW LBC
Proj. OBSERVATION WELL
Location LOCK 6 SA.

Rig No. GD2500
DATE OF REPORT 25-1-07
DRILL REPORT # 23
BORE HOLE # 123479
SHIFT DAY/~~NIGHT~~

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	WT	U/S	DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cememting, Access, Waiting on decisions, Breakdown, etc	DELAY HOURS
6:30	7:30							7:30	9.6	52	TRAVEL	
7:30	8:00							9:00	9.5	41	PREPARE FOR CEMENTING	
8:00								11:30	9.5	40	WAIT FOR CEMENT TRUCKS	
											GENERAL SITE WORK	
	12:15										CIRC HOLE + COND MUD	
12:15											CEMENT TRUCKS ON SITE ADD	
											HYDRATED BENTONITE + PUMP DOWN	
	1:45										AROUND FRP CASING	
1:45											CLEANING UP GEAR RELEASE STINGER	
	2:30										CIRC HOLE	
2:30											WAIT ON CEMENT SET	
	7:30										PULL PIPE. GENERAL WORK	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
LIQUI-SPERSE	4X 25 KG

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	N HAMILTON		
Offsider	B MC INTOSH		
Offsider	A MARTYN		
	A LAMBERT		

Comments:- CEMENT VOL. PER TRUCK

2760 KG CEMENT
1725 LT WATER
2052 LT HYDRATED BENTONITE

X 2

GOOD RETURNS TO SURFACE
4 SAMPLES TAKEN

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 855 248
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE' DWLBC
Proje OBSERVATION WELL
Location LOCK 6 SA.

Rig No. GD1500
DATE OF REPORT 25 26-1-07
DRILL REPORT # 24
BORE HOLE # 123479
SHIFT ~~DAY~~NIGHT

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	WT	VIS	DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cememting,Access,Waiting on decisions, Breakdown,etc	DELAY HOURS
6 30	7 00							5 90	9.4	41	TRAVEL	
7 00					B24806	3 7/8		6 00	9.5	51	WAIT ON GROUT SET	
	2 30										PREPARE SCREEN ASSEMBLY	
2 30	4 30										MAKE UP 3 7/8 BIT + SUB RIH	
4 30											DRILL OUT SHOE + CLEAN OUT	
	7 00										TO 431	
7 00	7 30										TRAVEL	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	L BERNALDO		
Offsider	S CONSTANTINE		
	R LOOBY		

Comments:-

FIT 100mm S/STEEL GATE VALVE TO FRP CASING

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 009 855 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE' DWLBC
Proj. OBSERVATION WELL
Location LOCK 6 SA

Rig No. CD250C
DATE OF REPORT 26-1-07
DRILL REPORT # 25
P/H BORE HOLE # 123479
SHIFT DAY/~~NIGHT~~

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit	WT	VIS	DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cementing, Access, Waiting on decisions, Breakdown, etc	DELAY HOURS
6:30	7:00							8:30	9.5	48	TRAVEL	
7:00								10:30	9.4	41	CLEAN OUT HOLE 431-449	
	9:00										COND MUD	
9:00	10:30										P.O.O.H.	
10:30											WELDING & RUNNING SCREEN ASSEMBLY & LOWER TO BOTTOM WITH HYDRIL	
	3:00										& RELEASE	
3:00	3:15										PULL 5 STDS & FLUSH MUD FROM	
3:15	3:45										HOLE (HOLE STARTED FLOWING)	
3:45	5:00										POOH	
5:00											PREPARE SETTING TOOL STRING	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
SOD/BICARB	1 X 25 KG
LIQUI-SPERSE	1 X 25 KG

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	H HAMILTON		
Offsider	B McINTOSH		
Offsider	A MARTYN		
	A LAMBERT		

Comments:-
TOP OF SCREEN ASSEMBLY
390-3
BOTTOM IS AT 449

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P MABARKEY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 855 248
25 Garden Rd Clayton Vic 3168
Tel (03)95468855 Fax (03) 95468599

DRILLING REPORT

CLIE DWLBC
Proj. OBSERVATION WELL
Location LOCK 6 SA

Rig No. GD 250C
DATE OF REPORT 26/27/1/07
DRILL REPORT # 26
BORE HOLE # 123479
SHIFT ~~DAY~~NIGHT

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit			DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cememting,Access,Waiting on decisions, Breakdown,etc	DELAY HOURS
630	750										TRAVEL	
750											RIH WITH JETTING STRING	
											TROUBLE ENTERING INTO J LATCH	
	930										SCREEN ASSEMBLY	
930	145										JETTING. TIGHT ROTATION	
145											POOH GAL PIPE HAD PARTED	
											+ CAUGHT ON HYDRIL + CAME	
											TO SURFACE IN TWO SECTIONS	
	415										RECOVER ALL PIPE	
415	700										GENERAL WORK STRIPPING GEAR	
700	730										TRAVEL	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	L BERNARDO		
Offsider	G CONSTANTINE		
	R LOOBY		

Comments:-
BORE FLOWING
1/2 LT PER SEC

JETTING STRING HAD NOT ENTERED SCREEN ASSEMBLY

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD	DRILLING REPORT	Rig No. GD2500
ABN 21 005 656 249	CLIE: DWLBC	DATE OF REPORT: 27-1-07
25 Garden Rd Clayton Vic 3168	Proj.: OBSERVATION WELL	DRILL REPORT #: 27
Tel (03)95468655 Fax (03) 95468599	Location: LOCK 6 S.W.	BORE HOLE #: 123479
		SHIFT: DAY/~~NIGHT~~

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit			DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cememting,Access,Waiting on decisions, Breakdown,etc	DELAY HOURS
6 30	7 00										TRAVEL	
7 00	10 50										To BERRI + PICK UP 4 JOINTS GAL PIPE	
10 50	1 30										PREPARE + RAN GAL PIPE + HYDRIL	
1 30	2 00										TRY TO ENTER & LATCH NO GOOD	
2 00	3 30										POOH	
3 30	4 30										PACK UP GEAR + SHUT DOWN	
4 30	5 00										TRAVEL	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	N HAMILTON		
Offsider	B MCINTOSH		
Offsider	M MARTYN		
	L LAMBERT		

Comments:-

WAITING FURTHER INSTRUCTIONS

{BORE FLOWING 2-5 LT PER SEC}

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P HAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 905 855 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE: DWLBC
Proje.: OBSERVATION WELL
Location: LOCK 6 SA

Rig No. ED 2500
DATE OF REPORT: 28.1.07
DRILL REPORT #: 28
P/H BORE HOLE #: 123479
SHIFT: DAY

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit			DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cememting,Access,Waiting on decisions, Breakdown,etc	DELAY HOURS
7:00	7:30										TRAVEL	
7:30											OPEN BORE TO RUN CAMERA	
	9:00										WAIT FOR OPERATOR	
9:00	12:45										RUN CAMERA TO J LATCH +	
12:45	2:30										INSPECT DAMAGE	
											CLEAN OUT + FILL ANNULAR	
											BETWEEN FRP + PVC WITH	
											CEMENT	
2:30	3:00										PACK UP GEAR + SHUT DOWN	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied
CEMENT	9 x 20 KG Bags

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	N HAMILTON		
Offsider	L BERNALDO		
	A MARTYN		

Comments:-

DAMAGE TO J LATCH FOLDED OVER ACROSS HOLE

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 005 855 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE: DWLBC
Proje.: OBSERVATION WELL
Location: LOCK 6 SA

Rig No. GD2500
DATE OF REPORT: 29-1-07
DRILL REPORT #: 29
BORE HOLE #: P/N 123479
SHIFT: DAY

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit			DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cememting, Access, Waiting on decisions, Breakdown, etc	DELAY HOURS
7.00	10.30										WAIT INSTRUCTIONS	
10.30	11.00										TRAVEL	
11.00	12.00										MODIFIED J LATCH TOOL +	
12.00	1.30										R.I.H.	
1.30	2.15										ATTEMPT TO ENTER J LATCH	
											P.O.O.H	
											INSPECT TOOL. SHOWED SIGNS	
											IT HAD ENTER J LATCH	
2.15											SHUT DOWN WAIT FOR	
	3.00										CLAMERA.	

HSE Stats	Today	Total	Task	Today	Total
Pre-start			Meetings (hrs)		
JSA's			Drilling (m)		
Hazards Reported			Grouting (m3)		
FAC			Redrill of Grout (m)		
MTC			Coring of Steel (hr)		
LTI			Working with Compressors (h)		
Safety Meetings			Working without Compressors/Standby (h)		
Toolbox Meetings					
Other Incidents					

Consumables: | **Quantity Used/Supplied**

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	H HAMILTON		
Offsider	L BERNALDO		
	A MARTYN		

Comments:-

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 005 855 246

25 Garden Rd Clayton Vic 3168

Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIE: DWLBC.

Proje..: OBSERVATION WELL

Location: LOCK 6 SA.

Rig No. GD 2500

DATE OF REPORT 30-1-07

DRILL REPORT # 30

P/N BORE HOLE # 123479

SHIFT DAY/~~NIGHT~~

Time from	Time to	Metres from	Metres to	Strata	Bit No	Bit Diameter Start	Bit Diameter Pullout	Metre per bit			DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cememting,Access,Waiting on decisions, Breakdown,etc	DELAY HOURS
7:00	7:30										TRAVEL	
7:30	9:00										MAKE UP 3/4 JETTING STRING WHILE WAITING FOR CAMERA	
9:00	11:45										RUN CAMERA	
11:45	1:00										RUN NEW JETTING STRING	
1:00	6:00										DEVELOP BORE BY JETTING	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	H HAMILTON		
Offsider	L BERNALDO		
	A MARTYN		

Comments:-

	Name	Signature
Supervisor/Driller	P FREEMAN	[signature]
Client's Authorised Representative:-	P MAGAREY	[signature]
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

059

SIDES DRILLING CONTRACTORSPTY LTD

ABN 21 005 855 249
25 Garden Rd Clayton Vic 3168
Tel (03)95468655 Fax (03) 95468599

DRILLING REPORT

CLIEN: DWLBC
Projec: OBSERVATION WELL
Location: LOCK 6 SA.

Rig No. ED250C
DATE OF REPORT 31-1-07
DRILL REPORT # 31
P/N BORE HOLE # 123479
SHIFT DAY/~~NIGHT~~

Time from	Time to	Metres from	Metres to	Strata	Bit No.	Bit Diameter Start	Bit Diameter Pullout	Metre per bit			DESCRIPTION (OPERATION, DELAY AND CAUSE OF DELAYS) Logging, Cememting,Access,Waiting on decisions, Breakdown,etc	DELAY HOURS
7:00	7:30										TRAVEL	
7:30	12:30										DEVELOP BORE BY JETTING CLEAN OUT SUMP + JET BACK UP	
12:30	2:00										PULL OUT JETTING STRING HAND WELL OVER + SHUT IN	
2:00											RIGGING DOWN	

HSE Stats	Today	Total
Pre-start		
JSA's		
Hazards Reported		
FAC		
MTC		
LTI		
Safety Meetings		
Toolbox Meetings		
Other Incidents		

Task	Today	Total
Meetings (hrs)		
Drilling (m)		
Grouting (m3)		
Redrill of Grout (m)		
Coring of Steel (hr)		
Working with Compressors (h)		
Working without Compressors/Standby (h)		

Consumables:	Quantity Used/Supplied

Survey Results

Hours Worked (HSE Statistics)

Position	Name	Daily total	Project Total
Supervisor	P FREEMAN		
Driller	J HAMILTON		
Offsider	M HAMILTON		
Offsider	L BERNALDO		
	A MARTYN		

Comments:-
BORE FLOWING
10 LTS PER SEC

	Name	Signature
Supervisor/Driller	P FREEMAN	
Client's Authorised Representative:-	P MAGAREM	
Date of Issue to Client/Superintendent :-		

THIS DOCUMENT SERVES AS NOTIFICATION OF DELAY PURSUANT TO THE CONTRACT

4. PHOTOS OF COLLECTED SAMPLES/CHIP TRAYS


0-40 m
42-80 m
82-120 m
122-160 m
162-200 m
202-240 m
242-280 m
282-320 m
322-360 m
362-400 m
402-440 m
442-480 m
482-508 m

5. LITHOLOGICAL LOG

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM

WATER WELL LOG

PROJECT: Renmark Group Observation Well – Chowilla Floodplain

PERMIT No. 123479

UNIT No. 7030-809

Near Werta Wert (Old Coach Road)

Coordinates: E N | El. Surface (m) | El. Ref. Point (m) | Datum: GDA 94

AQUIFER SUMMARY	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL (m)		SUPPLY			TOTAL DISSOLVED SOLIDS	
			From	To	L/sec	Test length	Method	mg/L	Analysis No.
	N/A	- 11 .6 (above ground level)	410	440	8	120 minutes	Flow test	14 711 (major cations/anions)	Job Number 108874 AWQC

DEPTH (m) From	DEPTH (m) To	GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING Dia (mm)	CASING From (m)	CASING To (m)
0	2		CLAY	CLAY, silty. Light yellow brown.	Coonambidgal				
2	4		CLAY	CLAY, silty. Light yellow grey. Minor gravel.	Coonambidgal				
4	6		SAND	SAND, mottled grey/white/orange, coarse 1–1.5 mm, sub-rounded. Opaque, clear, Fe stained quartz, minor biotite. Root fibres present.	Monomon				
6	8		SAND	SAND, mottled grey/white/orange, coarse 0.6–2.0 mm, poorly sorted, sub-angular, predominantly clear quartz with Fe staining.	Monomon				
8	10		SAND	SAND, As above, slightly cleaner, some charcoal.	Monomon				
10	12		SAND	SAND, clean, medium to coarse, 0.5–3.0 mm, sub-rounded. Orange/clear/white quartz, Fe stained.	Monomon				
12	14		SAND	SAND, coarse, grey/white, 1.0–2.5 mm. Gray quartz grains. Lignite present ~50%.	Monomon				
14	28		SAND	SAND, grey to light grey, very coarse, tending to gravel. Well sorted, clean.	Monomon				
28	30		SAND	SAND, coarse, silty, clayey, dark grey/brown, 1.0–2.0 mm, minor gravel.	Monomon				
30	34		SAND	SAND, fine sand, silty, with coarse component (~40 %), clayey. Grey to dark grey.	Monomon				
34	36		SAND	GRAVEL, light gray/white. 1.0–3.0 mm, sub -angular, clean.	Monomon				
36	38		CLAY	CLAY, sandy, silty, with minor gravel, brown. Coarse sands ~10 %.	Lower Loxton Clay				
38	54		CLAY	CLAY, silty, with minor sand, brownish grey.	Lower Loxton Clay				

REMARKS: Renmark Group Investigation/Observation Well. Constructed at Chowilla Floodplain by Sides Drilling Contractors. Driller: Peter Freeman. Wellsite Hydrogeologists: Paul Magarey and Adrian Costar (DWLBC). Well completed in Warina Formation (Renmark Group) from 410–440 m. Artesian Flow at 8 L/s. Full chemical analysis conducted by Australian Water Quality Centre (SA Water). NB, The shale shaker used had a coarse aperture so significant fines were lost in the samples obtained. It is unclear as to the percentage of fines in the sand and gravel lenses particularly in the deeper Olney and Warina Formation Aquifers.

DRILL TYPE: Rotary	COMPLETED: 410–440 m
DRILL FLUID: Mud (Aus Gel).	LOGGED BY: Paul Magarey
DATE: 31/1/2007	SHEET 1 OF 3

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM

WATER WELL LOG

CONTINUATION SHEET

PROJECT: Renmark Group Observation Well – Chowilla Floodplain

PERMIT No. 123479

UNIT No. 7030-809

Near Werta Wert (Old Coach Road)

DEPTH (m) From	DEPTH (m) To	GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING Dia (mm)	CASING From (m)	CASING To (m)
54	64		CLAY	CLAY, silty, brown. Grading into Bookpurnong Formation at 64 m (fizzes HCL at 64 m).	Lower Loxton Clay				
64	84		CLAY	CLAY, olive with shell fragments. Fizzes HCl	Bookpurnong				
84	100		MARL	MARL, Grey marly limestone/clay, becoming gritty. Strong fizz with HCL.	Winnambool				
100	104		LIMESTONE	LIMESTONE, grey/white, shelly. Component of marly clay present.	Murray Group Limestone				
104	126		LIMESTONE	LIMESTONE, grey/white marly, minor shell fragments.	Murray Group Limestone				
126	202		LIMESTONE	LIMESTONE, Grey to light grey, hard at 126 m, becoming rocky with hard bands at depth.	Murray Group Limestone				
202	212		LIMESTONE	LIMESTONE/MARL, whitish grey with minor olive. Warm.	Murray Group Limestone				
212	222		SILT	SILT/SAND, fine to medium sand silt/silty sand, poorly sorted. Olive green tending to grey brown. Minor quartz.	Ettrick				
222	256		SAND	SAND, grey fine/medium, minor coarse component, poorly sorted, 0.06–0.3 mm.	Ettrick (Yanac Member)				
256	260		SAND	SAND, clayey, with minor lignite. Grey brown, transition into Olney Formation.	Ettrick				
260	264		LIGNITE	LIGNITE, heavy peaty lignite, becoming consolidated.	Olney				
264	268		CLAY	CLAY, heavy, with silt/lignite.	Olney				
268	270		SAND	SAND, fine-medium, minor clay. Brown.	Olney				
270	273		CLAY	CLAY, silty, brown, minor quartz sand.	Olney				
273	285		SAND/ GRAVEL	SAND, greyish brown, coarse tending to gravel, 1.0–5.0 mm, unclean. Clay/silt particles stuck to sand grains.	Olney				

The Department of Water, Land and Biodiversity Conservation

GROUNDWATER PROGRAM
WATER WELL LOG
CONTINUATION SHEET

PROJECT: Renmark Group Observation Well – Chowilla Floodplain

PERMIT No. 123479

UNIT No. 7030-809

Near Werta Wert (Old Coach Road)

DEPTH (m)		GRAPHIC LOG	ROCK/SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION/AGE	Depth Core Sample	CASING		
From	To						Dia (mm)	From (m)	To (m)
285	328		CLAY/SILT	CLAY/SILT, dark brown, minor coarse sand (<5%).	Olney				
328	340		SAND	SAND, coarse (~60%), with fine-medium component. Lignitice, brown, dark brown.	Olney				
340	349		SAND	SAND, fine to medium, minor coarse component (~30%). Brown	Olney				
349	362		CLAY	CLAY, brown, minor sand, <5%.	Olney				
362	380		SAND	SAND, coarse, poorly sorted, 1.0–2.0 mm, some gravel, predominantly clear quartz, some opaque ~25 %.	Olney				
380	407		CLAY	CLAY, sandy, light brown.	Olney				
407	460		SAND	SAND, coarse, with gravel 1.0–3.0 mm, poorly sorted, sub-rounded, opaque and clear quartz.	Warina				
460	468		CLAY	CLAY, light grey, minor coarse sand.	Coombool Member				
468	470		CLAY	CLAY, light grey, coarse sand ~10%.	Coombool Member				
470	508		CLAY	CLAY, light grey, tending to brown.	Coombool Member				
				END OF LOG.					
				NB: END OF HOLE at 537 m.					

6. CONTRACTUAL ISSUES/DEBRIEFING LETTER TO SIDES DRILLING

There were few contractual issues that arose during well construction. Below is a debriefing letter to Sides Drilling outlining the main deficiencies in the contract and areas where the contract could be improved for similar projects.

Contractual issues that arose were related to:

1. Sides Project Management Plan that had not been sufficiently updated prior to commencement of drilling.

This was seen as a minor issue, however recommendations were made to ensure that the *Techical Specifications* developed during the course of contract negotiations be the primary Technical document used.

2. Risk sharing arrangements when there is limited data available outlining the final depth of the hole.

This problem arose because the final depth of the hole was less than anticipated, and casing, mobilisation and materials had been ordered based on a 602 m hole, not 537 m. This problem should be reduced for any Phase 3 Injection Trial due to improved baseline data, however this issue may be important for future drilling projects where there is limited hydrogeological information for a particular site.

3. The *lost hole* clause. This could have been implemented if the problem with the J-latch had not been rectified.
4. The *Force Majeure* Clause relating to standby rate payments/non-payments.

Our Ref: DWLBC 0951/06

28 February 2007

Mr Graham Van Damme
Contracts Manager
Sides Drilling Contractors Pty. Ltd.
25 Garden Road
Clayton 3168

Dear Sir

RE: FEEDBACK AND DEBRIEFING ON RENMARK GROUP OBSERVATION WELL

I refer to the recent drilling and construction of the Renmark Group observation well at Chowilla in the South Australian Riverland that was completed in January 2007. The well was completed on time, within the estimated cost (including Agency contingencies), and overall we are satisfied with the manner in which the project has been managed.

Sides drillers showed a high level of technical skill in the drilling and construction of the observation well, acted in a professional manner at all times while on site, and provided assistance to the Wellsite Hydrogeologists. This professional behaviour resulted in a good working relationship which was most appreciated by our hydrogeologists.

Debriefing on a number of contractual issues that arose during the course of the project:

1. During the development of the *Drilling Contract,* a clear *Technical Specification* was developed. Sides transferred some of this material into its *Quality Management Plan* for the project during the tender phase, but this was not updated and the final version contained a significant number of errors in relation to key depths and materials. It is suggested that the *Technical Specification* developed during the course of contract negotiations clearly detail the requirements of the Work and be used as the primary document.

2. During planning for the Renmark Group observation well, the limited available data was used to determine the expected total depth of the well, which was anticipated to be 602 m. During the drilling of the well, the geology resulted in termination of drilling at a depth of 537 m (rather than the original estimated depth of 602 m), and setting of casing at 410 m (rather than the original estimated depth of 570 m).

   The issue of the final well depth is obviously very important to all drilling projects, but critical to a contract involving a single expensive well as opposed to those involving multiple wells (especially when those wells are shallow and variations likely to be small). The question arises as to what is an equitable sharing of the risk on this matter. Your views on this issue would be appreciated.

3. There was a risk that the Renmark Group observation well would not have been completed due to the problem encountered with the J-latch. Sides managed to rectify this problem and the well was completed in a satisfactory manner. Had the well not been able to be completed and developed, the Lost Wells clause would have been applicable. This raises the question of whether there are actions that could be taken in future to minimise this risk.

4. Sides requested the inclusion of the *Force Majeure* clause in the *Drilling Contract*. While there was some negotiation in relation to the wording of this clause, and a limitation of 5% of the contract price was accepted, this Agency still had concerns in relation to the inclusion of the term *Act of God*. This term may need to be clarified in future, as it appears to be in conflict with the *Schedule of Prices Contract* which states that:- *Waiting time will not be paid for delays to the Work resulting from inclement weather preventing access to the site, or ability to work on the site*. Your views on this issue would be appreciated.

You are invited to comment of these matters, or any other issues that you may have had with the project. This will assist us to manage our projects more effectively and to deal with our drilling contractors in a constructive and cooperative manner. Please contact Stephen Howles on 8204 8510 if have any queries in relation to the matters discussed in this letter. This Agency looks forward to working with Sides on future projects.

Yours sincerely

MICHAEL DEERING

A/DIRECTOR

KNOWLEDGE AND INFORMATION DIVISION

7. RESULTS, PARTICLE SIZE ANALYSIS

The Department of Water, Land and Biodiversity Conservation

Form E

Grain Size Analysis Sheet

The Department of Water, Land and Biodiversity Conservation

Record Number: 156

Form Type: E

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 19/01/2007

Permit Number: 123479

Observation Number: 8B

Unit Number:

Sample Depth From: 410 m

Sample Depth To: 410 m

Driller:

Bore Serial Number:

Method of Sampling: (Outcrop, Core, Tube, Bailer, Jetted etc)

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start: Stop: Duration:

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	86.7	17.34%	17.34%
1.4	1400	115.35	23.07%	40.41%
0.85	850	109.98	22.00%	62.41%
0.5	500	91.82	18.36%	80.77%
0.3	300	56.47	11.29%	92.06%
0.25	250	8	1.60%	93.66%
0.212	212	7.9	1.58%	95.24%
0.18	180	4.81	0.96%	96.21%
0.15	150	4.47	0.89%	97.10%
0.125	125	4.56	0.91%	98.01%
0.09	90	6.66	1.33%	99.34%
Retainer Dish		3.28	0.66%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 15/05/2007

Recommended Screen:

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The Department of Water, Land and Biodiversity Conservation

Form E Grain Size Analysis Sheet

Form Type: E

Record Number: 155

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 19/01/2007

Permit Number: 123479

Observation Number: 7B

Unit Number:

Sample Depth From: 412 m

Sample Depth To: 412 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	43.84	8.77%	8.77%
1.4	1400	88.97	17.79%	26.56%
0.85	850	232.31	46.46%	73.02%
0.5	500	74.04	14.81%	87.83%
0.3	300	20.69	4.14%	91.97%
0.25	250	6.39	1.28%	93.25%
0.212	212	6.43	1.29%	94.53%
0.18	180	2.83	0.57%	95.10%
0.15	150	6.34	1.27%	96.37%
0.125	125	4.29	0.86%	97.23%
0.09	90	9.26	1.85%	99.08%
Retainer Dish		4.61	0.92%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 15/05/2007

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The Department of Water, Land and Biodiversity Conservation

The Department of Water, Land and Biodiversity Conservation

Form E

Grain Size Analysis Sheet

Form Type: E

Record Number: 151

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 19/01/2007

Permit Number: 123479

Observation Number: 3B

Unit Number:

Sample Depth From: 414 m

Sample Depth To: 414 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	36.94	7.39%	7.39%
1.4	1400	98.73	19.75%	27.13%
0.85	850	296.64	59.33%	86.46%
0.5	500	38.01	7.60%	94.06%
0.3	300	8.82	1.76%	95.83%
0.25	250	2.6	0.52%	96.35%
0.212	212	2.63	0.53%	96.87%
0.18	180	1.53	0.31%	97.18%
0.15	150	2.04	0.41%	97.59%
0.125	125	1.21	0.24%	97.83%
0.09	90	2.41	0.48%	98.31%
Retainer Dish		8.44	1.69%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 15/05/2007

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Form E

Grain Size Analysis Sheet

The Department of Water, Land and Biodiversity Conservation

Form Type: E

Record Number: 157

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 19/01/2007

Permit Number: 123479

Observation Number: 9B

Unit Number:

Sample Depth From: 416 m

Sample Depth To: 416 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	65.84	13.17%	13.17%
1.4	1400	94.87	18.97%	32.14%
0.85	850	252.8	50.56%	82.70%
0.5	500	47.81	9.56%	92.26%
0.3	300	13.68	2.74%	95.00%
0.25	250	4.32	0.86%	95.86%
0.212	212	3.78	0.76%	96.62%
0.18	180	2.49	0.50%	97.12%
0.15	150	3.54	0.71%	97.83%
0.125	125	2.53	0.51%	98.33%
0.09	90	3.9	0.78%	99.11%
Retainer Dish		4.44	0.89%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 15/05/2007

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The Department of Water, Land and Biodiversity Conservation

Form E

Grain Size Analysis Sheet

The Department of Water, Land and Biodiversity Conservation

Record Number: 152

Form Type: E

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 19/01/2007

Permit Number: 123479

Observation Number: 4B

Unit Number:

Sample Depth From: 418 m

Sample Depth To: 418 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	59.06	11.81%	11.81%
1.4	1400	100.46	20.09%	31.90%
0.85	850	233.09	46.62%	78.52%
0.5	500	78.6	15.72%	94.24%
0.3	300	8.73	1.75%	95.99%
0.25	250	1.96	0.39%	96.38%
0.212	212	1.36	0.27%	96.65%
0.18	180	0.7	0.14%	96.79%
0.15	150	1.25	0.25%	97.04%
0.125	125	1.37	0.27%	97.32%
0.09	90	1.83	0.37%	97.68%
Retainer Dish		11.59	2.32%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 15/05/2007

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Form E — Grain Size Analysis Sheet

The Department of Water, Land and Biodiversity Conservation

Form Type: E

Record Number: 154

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 19/01/2007

Permit Number: 123479

Observation Number: 6B

Unit Number:

Sample Depth From: 422 m

Sample Depth To: 422 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	38.76	7.75%	7.75%
1.4	1400	79.39	15.88%	23.63%
0.85	850	266.35	53.27%	76.90%
0.5	500	104.34	20.87%	97.77%
0.3	300	6.53	1.31%	99.07%
0.25	250	1.21	0.24%	99.32%
0.212	212	0.77	0.15%	99.47%
0.18	180	0.42	0.08%	99.55%
0.15	150	0.69	0.14%	99.69%
0.125	125	0.32	0.06%	99.76%
0.09	90	0.9	0.18%	99.94%
Retainer Dish		0.32	0.06%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 15/05/2007

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Form E

Grain Size Analysis Sheet

The Department of Water, Land and Biodiversity Conservation

Record Number: 153

Form Type: E

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 19/01/2007

Permit Number: 123479

Observation Number: 5B

Unit Number:

Sample Depth From: 424 m

Sample Depth To: 424 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	37.46	7.49%	7.49%
1.4	1400	96.27	19.25%	26.75%
0.85	850	306.41	61.28%	88.03%
0.5	500	50.84	10.17%	98.20%
0.3	300	3.34	0.67%	98.86%
0.25	250	0.89	0.18%	99.04%
0.212	212	0.82	0.16%	99.21%
0.18	180	0.55	0.11%	99.32%
0.15	150	0.39	0.08%	99.39%
0.125	125	0.49	0.10%	99.49%
0.09	90	0.58	0.12%	99.61%
Retainer Dish		1.96	0.39%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 15/05/2007

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Form E Grain Size Analysis Sheet

The Department of Water, Land and Biodiversity Conservation

Form Type: E

Record Number: 159

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 19/01/2007

Permit Number: 123479

Observation Number: 1A

Unit Number:

Sample Depth From: 426 m

Sample Depth To: 426 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	86.26	17.25%	17.25%
1.4	1400	95.32	19.06%	36.32%
0.85	850	244.24	48.85%	85.16%
0.5	500	56.56	11.31%	96.48%
0.3	300	7.23	1.45%	97.92%
0.25	250	2.01	0.40%	98.32%
0.212	212	1.62	0.32%	98.65%
0.18	180	0.76	0.15%	98.80%
0.15	150	1.9	0.38%	99.18%
0.125	125	1.15	0.23%	99.41%
0.09	90	1.64	0.33%	99.74%
Retainer Dish		1.31	0.26%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 15/05/2007

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Form E Grain Size Analysis Sheet

The Department of Water, Land and Biodiversity Conservation

Record Number: 150

Form Type: E

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 19/01/2007

Permit Number: 123479

Observation Number: 2B

Unit Number:

Sample Depth From: 428 m

Sample Depth To: 428 m

Driller:

Bore Serial Number:

Method of Sampling: (Outcrop, Core, Tube, Bailer, Jetted etc)

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	54.21	10.84%	10.84%
1.4	1400	116.83	23.37%	34.21%
0.85	850	256.15	51.23%	85.44%
0.5	500	52.74	10.55%	95.99%
0.3	300	6.15	1.23%	97.22%
0.25	250	1.41	0.28%	97.50%
0.212	212	1.22	0.24%	97.74%
0.18	180	0.69	0.14%	97.88%
0.15	150	1.15	0.23%	98.11%
0.125	125	0.96	0.19%	98.30%
0.09	90	1.02	0.20%	98.51%
Retainer Dish		7.47	1.49%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 15/05/2007

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The Department of Water, Land and Biodiversity Conservation

Form E

Grain Size Analysis Sheet

The Department of Water, Land and Biodiversity Conservation

Record Number: 168

Form Type: E

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 19/01/2007

Permit Number: 123479

Observation Number: 10A

Unit Number:

Sample Depth From: 430 m

Sample Depth To: 430 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams   Agitation: Start   Stop   Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	37.29	7.46%	7.46%
1.4	1400	85.69	17.14%	24.60%
0.85	850	244.53	48.91%	73.50%
0.5	500	102.92	20.58%	94.09%
0.3	300	11.51	2.30%	96.39%
0.25	250	1.52	0.30%	96.69%
0.212	212	1.51	0.30%	96.99%
0.18	180	1.25	0.25%	97.24%
0.15	150	1.32	0.26%	97.51%
0.125	125	1.36	0.27%	97.78%
0.09	90	1.85	0.37%	98.15%
Retainer Dish		9.25	1.85%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 21/05/2007

Recommended Screen:

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The Department of Water, Land and Biodiversity Conservation

Form E

Grain Size Analysis Sheet

Form Type: E

Record Number: 171

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 19/01/2007

Permit Number: 123479

Observation Number: 13A

Unit Number:

Sample Depth From: 432 m

Sample Depth To: 432 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	28.38	5.68%	5.68%
1.4	1400	58.03	11.61%	17.28%
0.85	850	264.62	52.92%	70.21%
0.5	500	125.33	25.07%	95.27%
0.3	300	8.74	1.75%	97.02%
0.25	250	1.47	0.29%	97.31%
0.212	212	1.63	0.33%	97.64%
0.18	180	1.11	0.22%	97.86%
0.15	150	1.77	0.35%	98.22%
0.125	125	1.26	0.25%	98.47%
0.09	90	2.27	0.45%	98.92%
Retainer Dish		5.39	1.08%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 21/05/2007

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Form E

Grain Size Analysis Sheet

The Department of Water, Land and Biodiversity Conservation

Record Number: 161

Form Type: E

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 19/01/2007

Permit Number: 123479

Observation Number: 3A

Unit Number:

Sample Depth From: 434 m

Sample Depth To: 434 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	44.08	8.82%	8.82%
1.4	1400	88.58	17.72%	26.53%
0.85	850	283.13	56.63%	83.16%
0.5	500	57.45	11.49%	94.65%
0.3	300	9.06	1.81%	96.46%
0.25	250	2	0.40%	96.86%
0.212	212	1.97	0.39%	97.25%
0.18	180	0.98	0.20%	97.45%
0.15	150	1.5	0.30%	97.75%
0.125	125	1.13	0.23%	97.98%
0.09	90	1.72	0.34%	98.32%
Retainer Dish		8.4	1.68%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 15/05/2007

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Form E

Grain Size Analysis Sheet

The Department of Water, Land and Biodiversity Conservation

Form Type: E

Record Number: 173

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 19/01/2007

Permit Number: 123479

Observation Number: 15A

Unit Number:

Sample Depth From: 436 m

Sample Depth To: 436 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	38.96	7.79%	7.79%
1.4	1400	80.02	16.00%	23.80%
0.85	850	291.05	58.21%	82.01%
0.5	500	67.4	13.48%	95.49%
0.3	300	6.31	1.26%	96.75%
0.25	250	1.56	0.31%	97.06%
0.212	212	1.62	0.32%	97.38%
0.18	180	1.11	0.22%	97.61%
0.15	150	1.56	0.31%	97.92%
0.125	125	1.08	0.22%	98.13%
0.09	90	1.67	0.33%	98.47%
Retainer Dish		7.66	1.53%	100.00%
Total Sieved:		499.9999	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 21/05/2007

Recommended Screen:

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The Department of Water, Land and Biodiversity Conservation

Form E

Grain Size Analysis Sheet

The Department of Water, Land and Biodiversity Conservation

Record Number: 172

Form Type: E

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 19/01/2007

Permit Number: 123479

Observation Number: 14A

Unit Number:

Sample Depth From: 438 m

Sample Depth To: 438 m

Driller:

Bore Serial Number:

Method of Sampling: (Outcrop, Core, Tube, Bailer, Jetted etc)

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start: Stop: Duration:

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	36.8	7.36%	7.36%
1.4	1400	87.41	17.48%	24.84%
0.85	850	242.44	48.49%	73.33%
0.5	500	79.06	15.81%	89.14%
0.3	300	24.1	4.82%	93.96%
0.25	250	3.88	0.78%	94.74%
0.212	212	3.46	0.69%	95.43%
0.18	180	2.89	0.58%	96.01%
0.15	150	2.15	0.43%	96.44%
0.125	125	1.87	0.37%	96.81%
0.09	90	3.32	0.66%	97.48%
Retainer Dish		12.62	2.52%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 21/05/2007

Recommended Screen:

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The Department of Water, Land and Biodiversity Conservation

Form E

Grain Size Analysis Sheet

The Department of Water, Land and Biodiversity Conservation

Record Number: 164

Form Type: E

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 19/01/2007

Permit Number: 123479

Observation Number: 6A

Unit Number:

Sample Depth From: 440 m

Sample Depth To: 440 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	64.38	12.88%	12.88%
1.4	1400	86.19	17.24%	30.11%
0.85	850	220.88	44.18%	74.29%
0.5	500	80.11	16.02%	90.31%
0.3	300	21	4.20%	94.51%
0.25	250	3.32	0.66%	95.18%
0.212	212	3.11	0.62%	95.80%
0.18	180	2.69	0.54%	96.34%
0.15	150	2.07	0.41%	96.75%
0.125	125	2.43	0.49%	97.24%
0.09	90	3.25	0.65%	97.89%
Retainer Dish		10.57	2.11%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 15/05/2007

Recommended Screen:

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The Department of Water, Land and Biodiversity Conservation

The Department of Water, Land and Biodiversity Conservation

Form E

Grain Size Analysis Sheet

Form Type: E

Record Number: 162

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 20/01/2007

Permit Number: 123479

Observation Number: 4A

Unit Number:

Sample Depth From: 442 m

Sample Depth To: 442 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	32.63	6.53%	6.53%
1.4	1400	89.76	17.95%	24.48%
0.85	850	240.41	48.08%	72.56%
0.5	500	60.88	12.18%	84.74%
0.3	300	29.72	5.94%	90.68%
0.25	250	9.57	1.91%	92.59%
0.212	212	8.45	1.69%	94.28%
0.18	180	4.23	0.85%	95.13%
0.15	150	6.93	1.39%	96.52%
0.125	125	3.91	0.78%	97.30%
0.09	90	6.83	1.37%	98.66%
Retainer Dish		6.68	1.34%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 15/05/2007

Recommended Screen:

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Form E

Grain Size Analysis Sheet

The Department of Water, Land and Biodiversity Conservation

Record Number: 163

Form Type: E

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 20/01/2007

Permit Number: 123479

Observation Number: 5A

Unit Number:

Sample Depth From: 444 m

Sample Depth To: 444 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	32.63	6.53%	6.53%
1.4	1400	89.76	17.95%	24.48%
0.85	850	240.41	48.08%	72.56%
0.5	500	60.88	12.18%	84.74%
0.3	300	29.72	5.94%	90.68%
0.25	250	9.57	1.91%	92.59%
0.212	212	8.45	1.69%	94.28%
0.18	180	4.23	0.85%	95.13%
0.15	150	6.93	1.39%	96.52%
0.125	125	3.91	0.78%	97.30%
0.09	90	6.83	1.37%	98.66%
Retainer Dish		6.68	1.34%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 15/05/2007

Recommended Screen:

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The Department of Water, Land and Biodiversity Conservation

Form E

Grain Size Analysis Sheet

Record Number: 169

Form Type: E

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 20/01/2007

Permit Number: 123479

Observation Number: 11A

Unit Number:

Sample Depth From: 446 m

Sample Depth To: 446 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	42.32	8.46%	8.46%
1.4	1400	84.36	16.87%	25.34%
0.85	850	224	44.80%	70.14%
0.5	500	71.14	14.23%	84.36%
0.3	300	33.16	6.63%	91.00%
0.25	250	10.11	2.02%	93.02%
0.212	212	9.42	1.88%	94.90%
0.18	180	3.29	0.66%	95.56%
0.15	150	6.36	1.27%	96.83%
0.125	125	3.76	0.75%	97.58%
0.09	90	5.36	1.07%	98.66%
Retainer Dish		6.72	1.34%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 21/05/2007

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The Department of Water, Land and Biodiversity Conservation

Form E — Grain Size Analysis Sheet

Record Number: 148

Form Type: E

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 20/01/2007

Permit Number: 123479

Observation Number: 1B

Unit Number:

Sample Depth From: 448 m

Sample Depth To: 448 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams   Agitation: Start   Stop   Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	25.61	5.12%	5.12%
1.4	1400	72.01	14.40%	19.52%
0.85	850	226.07	45.21%	64.74%
0.5	500	64.65	12.93%	77.67%
0.3	300	40.07	8.01%	85.68%
0.25	250	12.2	2.44%	88.12%
0.212	212	12.94	2.59%	90.71%
0.18	180	8.9	1.78%	92.49%
0.15	150	6.19	1.24%	93.73%
0.125	125	6.65	1.33%	95.06%
0.09	90	8.04	1.61%	96.67%
Retainer Dish		16.67	3.33%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 15/05/2007

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Form E

Grain Size Analysis Sheet

The Department of Water, Land and Biodiversity Conservation

Record Number: 160

Form Type: E

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 20/01/2007

Permit Number: 123479

Observation Number: 2A

Unit Number:

Sample Depth From: 450 m

Sample Depth To: 450 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	28.27	5.65%	5.65%
1.4	1400	86.43	17.29%	22.94%
0.85	850	233.18	46.64%	69.58%
0.5	500	65.28	13.06%	82.63%
0.3	300	33.99	6.80%	89.43%
0.25	250	9.13	1.83%	91.26%
0.212	212	10.02	2.00%	93.26%
0.18	180	7.73	1.55%	94.81%
0.15	150	4.16	0.83%	95.64%
0.125	125	5.77	1.15%	96.79%
0.09	90	5.13	1.03%	97.82%
Retainer Dish		10.91	2.18%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 15/05/2007

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The Department of Water, Land and Biodiversity Conservation

Form E

Grain Size Analysis Sheet

Form Type: E

Record Number: 170

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 20/01/2007

Permit Number: 123479

Observation Number: 12A

Unit Number:

Sample Depth From: 452 m

Sample Depth To: 452 m

Driller:

Bore Serial Number:

Method of Sampling: (Outcrop, Core, Tube, Bailer, Jetted etc)

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start / Stop / Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	37.67	7.53%	7.53%
1.4	1400	92.37	18.47%	26.01%
0.85	850	249.47	49.89%	75.90%
0.5	500	69.74	13.95%	89.85%
0.3	300	18.88	3.78%	93.63%
0.25	250	3.84	0.77%	94.39%
0.212	212	3.52	0.70%	95.10%
0.18	180	3.11	0.62%	95.72%
0.15	150	2.33	0.47%	96.19%
0.125	125	2.74	0.55%	96.73%
0.09	90	3.73	0.75%	97.48%
Retainer Dish		12.6	2.52%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 21/05/2007

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Form E

Grain Size Analysis Sheet

Form Type: E

Record Number: 165

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 20/01/2007

Permit Number: 123479

Observation Number: 7A

Unit Number:

Sample Depth From: 454 m

Sample Depth To: 454 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	39.93	7.99%	7.99%
1.4	1400	102.08	20.42%	28.40%
0.85	850	283.91	56.78%	85.18%
0.5	500	44.02	8.80%	93.99%
0.3	300	5.57	1.11%	95.10%
0.25	250	2.91	0.58%	95.68%
0.212	212	2.58	0.52%	96.20%
0.18	180	2.1	0.42%	96.62%
0.15	150	2.89	0.58%	97.20%
0.125	125	1.81	0.36%	97.56%
0.09	90	2.79	0.56%	98.12%
Retainer Dish		9.41	1.88%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 21/05/2007

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The Department of Water, Land and Biodiversity Conservation

Form E

Grain Size Analysis Sheet

Record Number: 166

Form Type	E
Project	
Name	PAUL MAGAREY
Address	DWLBC
Hundred	
Section	
Date Collected	20/01/2007
Permit Number	123479
Observation Number	8A
Unit Number	
Sample Depth From	456 m
Sample Depth To	456 m
Driller	
Bore Serial Number	

Method of Sampling: (Outcrop, Core, Tube, Bailer, Jetted etc)

Description of Sample: (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start: Stop: Duration:

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	35.66	7.13%	7.13%
1.4	1400	111.27	22.25%	29.39%
0.85	850	240	48.00%	77.39%
0.5	500	68.21	13.64%	91.03%
0.3	300	11.22	2.24%	93.27%
0.25	250	3.54	0.71%	93.98%
0.212	212	3.52	0.70%	94.68%
0.18	180	3.24	0.65%	95.33%
0.15	150	2.42	0.48%	95.82%
0.125	125	2.53	0.51%	96.32%
0.09	90	3.91	0.78%	97.10%
Retainer Dish		14.48	2.90%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 21/05/2007

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Form E Grain Size Analysis Sheet

Form Type: E

Record Number: 174

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 20/01/2007

Permit Number: 123479

Observation Number: 16A

Unit Number:

Sample Depth From: 458 m

Sample Depth To: 458 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	27.85	5.57%	5.57%
1.4	1400	84.25	16.85%	22.42%
0.85	850	261.7	52.34%	74.76%
0.5	500	87.14	17.43%	92.19%
0.3	300	13.46	2.69%	94.88%
0.25	250	3.47	0.69%	95.57%
0.212	212	3.42	0.68%	96.26%
0.18	180	2.24	0.45%	96.71%
0.15	150	1.8	0.36%	97.07%
0.125	125	1.9	0.38%	97.45%
0.09	90	2.79	0.56%	98.00%
Retainer Dish		9.98	2.00%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 21/05/2007

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Form E — Grain Size Analysis Sheet

The Department of Water, Land and Biodiversity Conservation

Record Number: 167

Form Type: E

Project:

Name: PAUL MAGAREY

Address: DWLBC

Hundred:

Section:

Date Collected: 20/01/2007

Permit Number: 123479

Observation Number: 9A

Unit Number:

Sample Depth From: 460 m

Sample Depth To: 460 m

Driller:

Bore Serial Number:

Method of Sampling: Outcrop, Core, Tube, Bailer, Jetted etc

Description of Sample:

Description of Sample (including degree of consolidation, well, poorly, partially, unconsolidated)

Analysis Number:

Weight Taken: 500 grams

Agitation: Start Stop Duration

BS Screen Gauge	BS Opening Microns	Retained (Grams)	Retained (%)	Cumulative (%)
2	2000	8.04	1.61%	1.61%
1.4	1400	58.57	11.71%	13.32%
0.85	850	237.51	47.50%	60.82%
0.5	500	100.33	20.07%	80.89%
0.3	300	35.19	7.04%	87.93%
0.25	250	8.45	1.69%	89.62%
0.212	212	7.37	1.47%	91.09%
0.18	180	4.04	0.81%	91.90%
0.15	150	9.27	1.85%	93.75%
0.125	125	8.27	1.65%	95.41%
0.09	90	10.44	2.09%	97.50%
Retainer Dish		12.52	2.50%	100.00%
Total Sieved:		500	100.00%	

Remarks: Angularity, sphericity etc and washing detail

Staff Name: Steve Sincock

Date: 21/05/2007

Recommended Screen:

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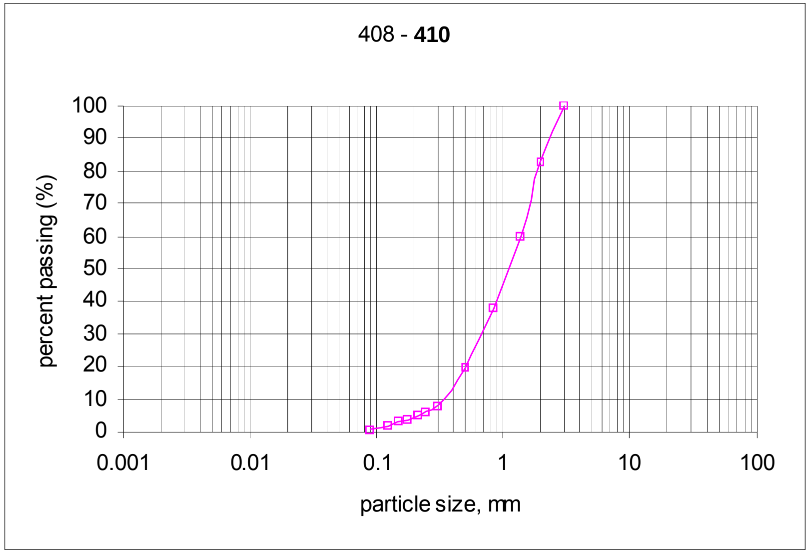
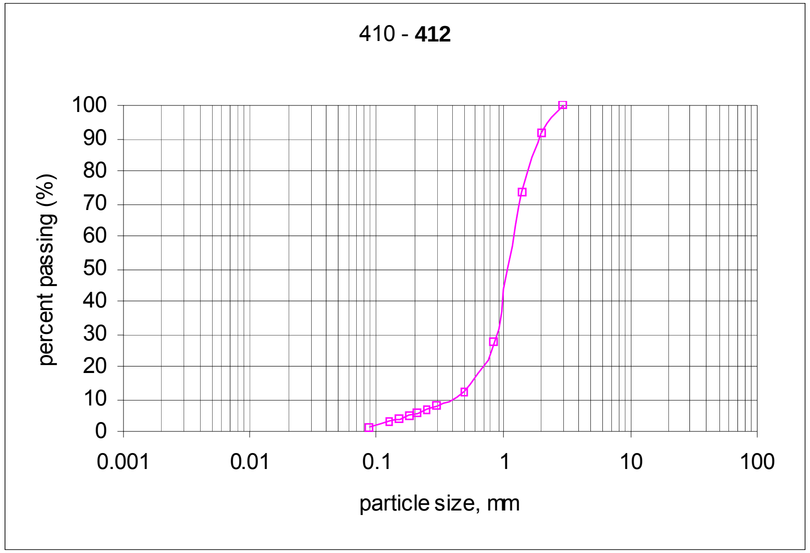
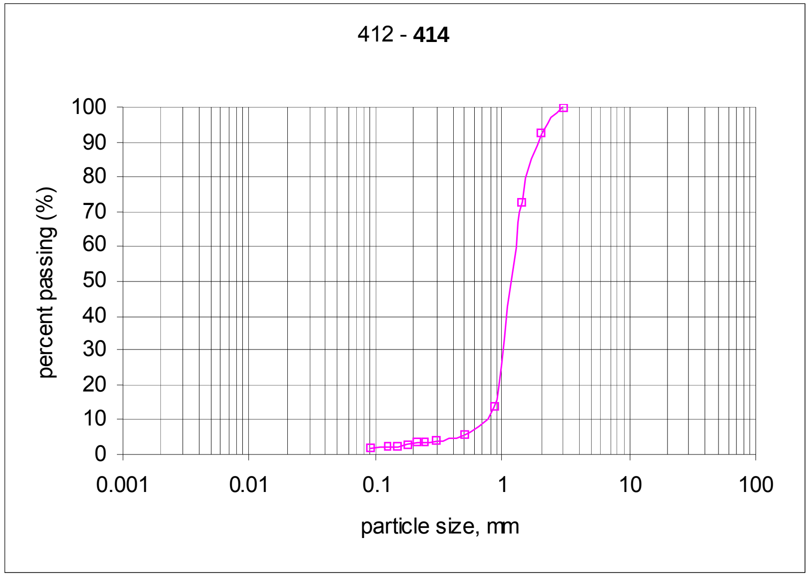
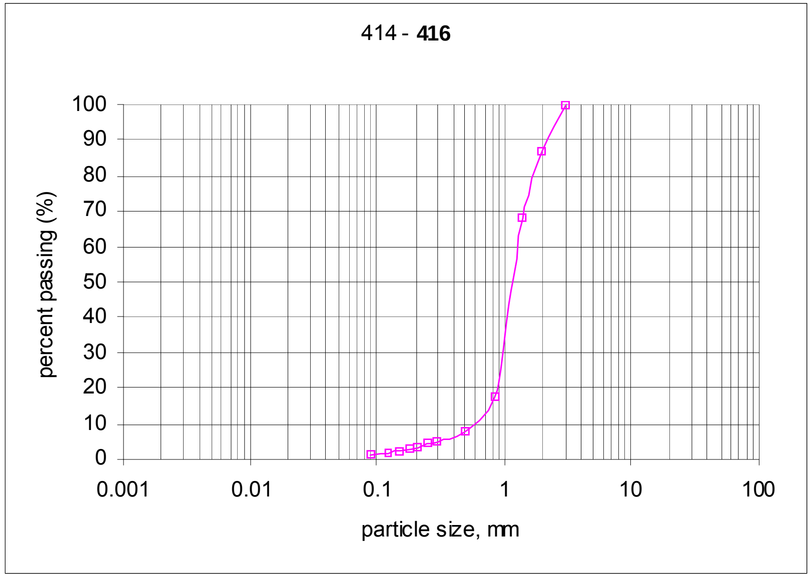
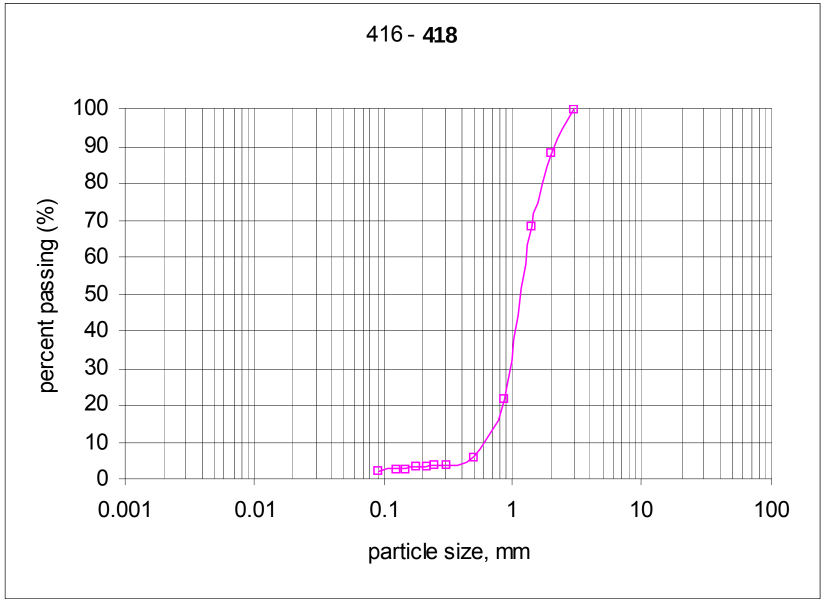
8. PARTICLE SIZE DISTRIBUTION AT VARIOUS SAMPLE DEPTHS (WARINA FORMATION)

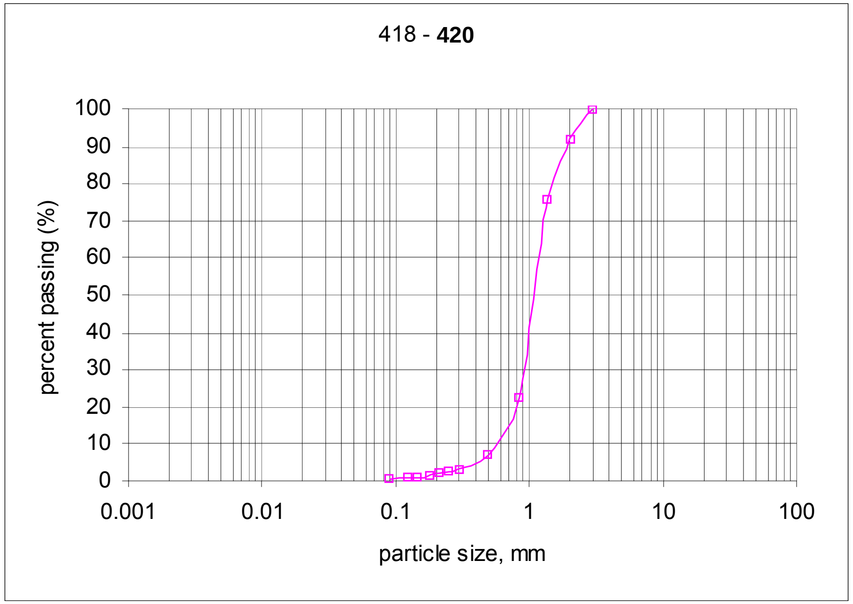


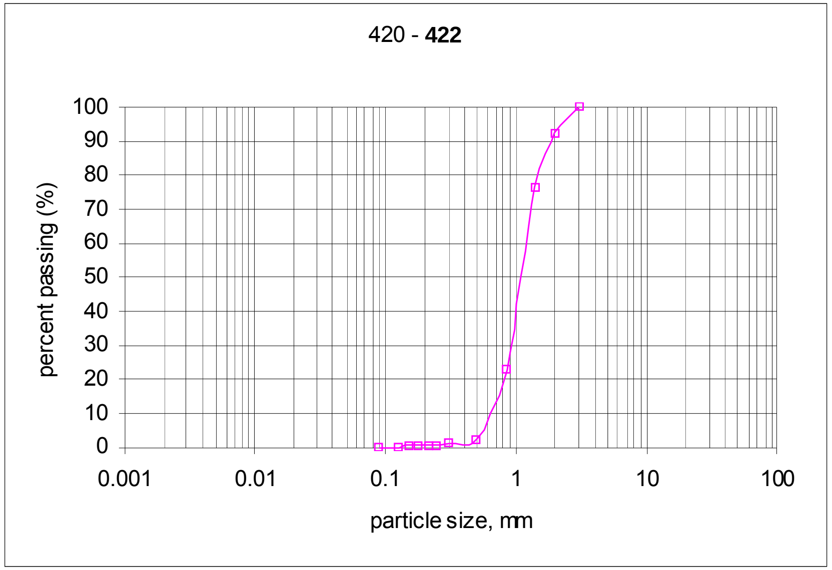


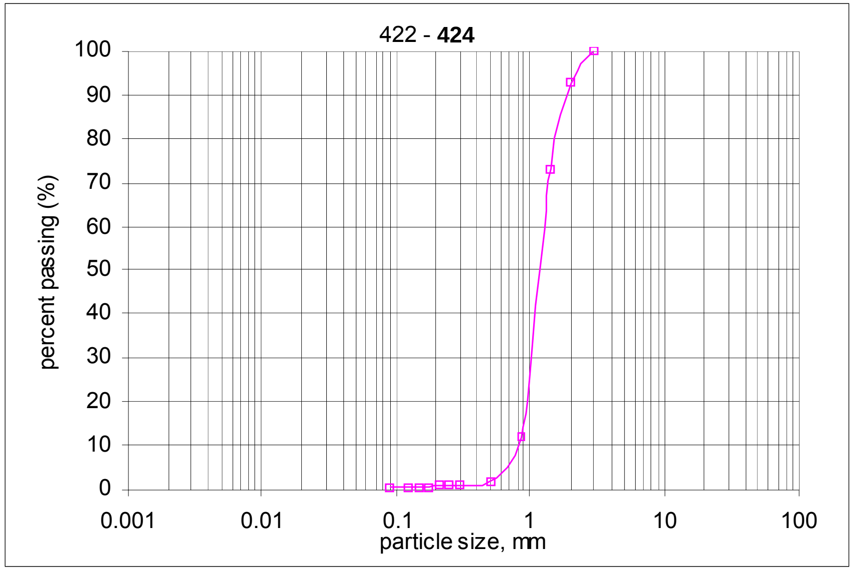

412 - **414**
percent passing (%)
particle size, mm
0.001
0.01
0.1
1
10
100

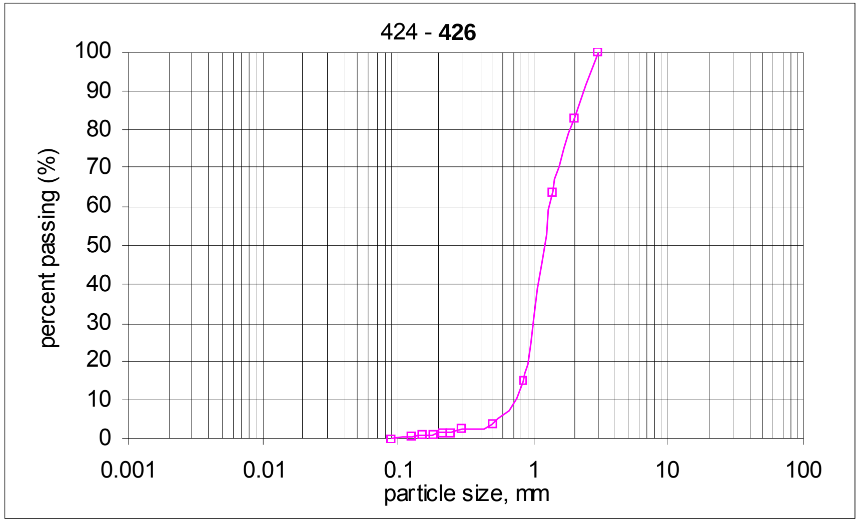

414 - **416**
percent passing (%)
particle size, mm
0.001
0.01
0.1
1
10
100

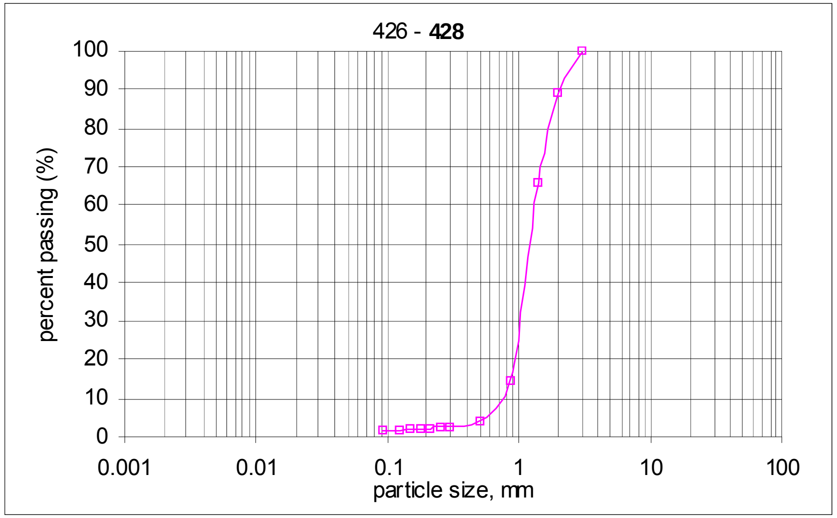

416 - **418**
percent passing (%)
particle size, mm
0.001
0.01
0.1
1
10
100

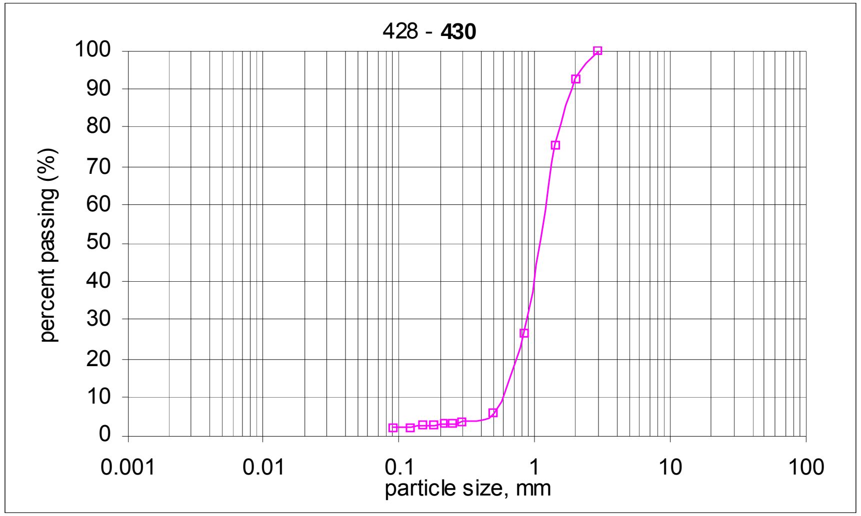

418 - **420**
percent passing (%)
particle size, mm
0.001
0.01
0.1
1
10
100

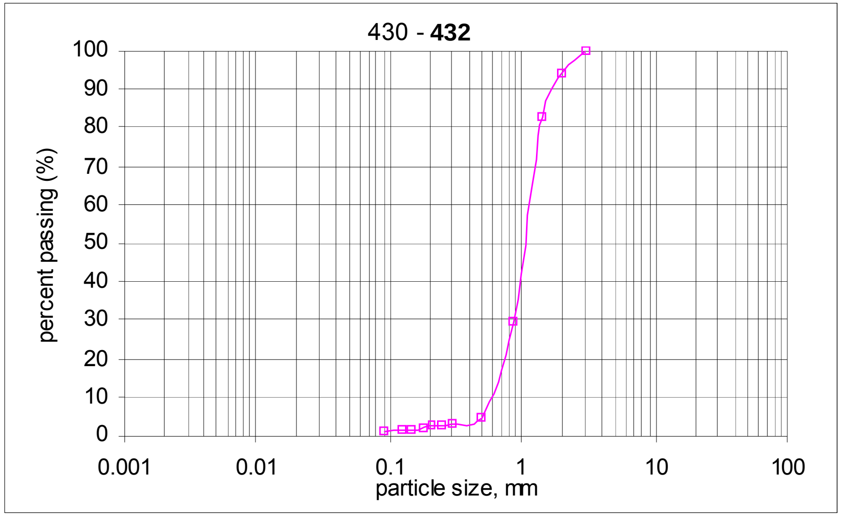

420 - **422**
percent passing (%)
particle size, mm
0.001
0.01
0.1
1
10
100

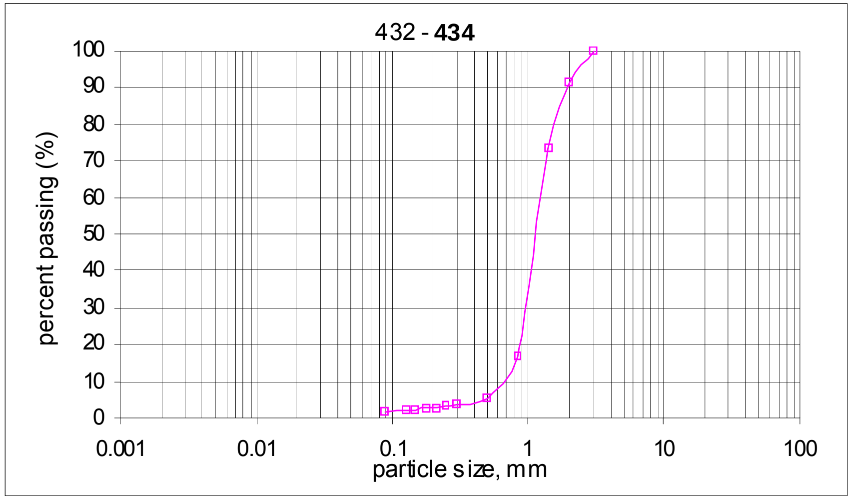

422 - **424**
percent passing (%)
particle size, mm

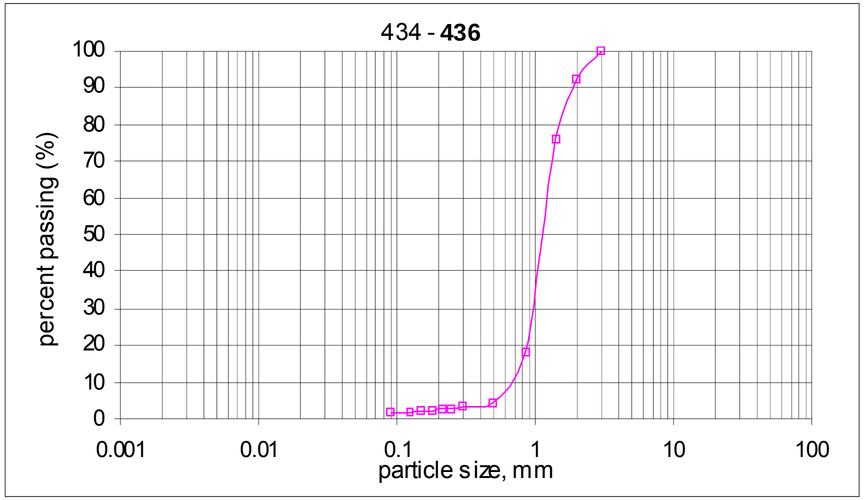

424 - **426**
percent passing (%)
particle size, mm

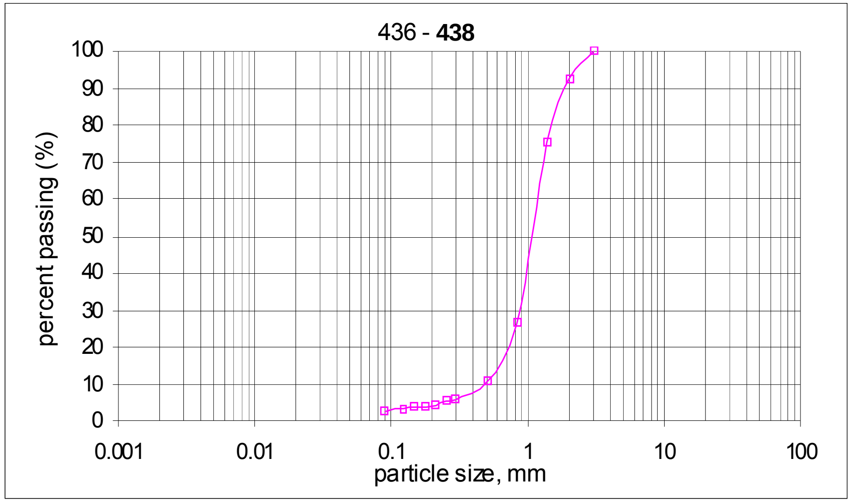

426 - **428**
percent passing (%)
particle size, mm

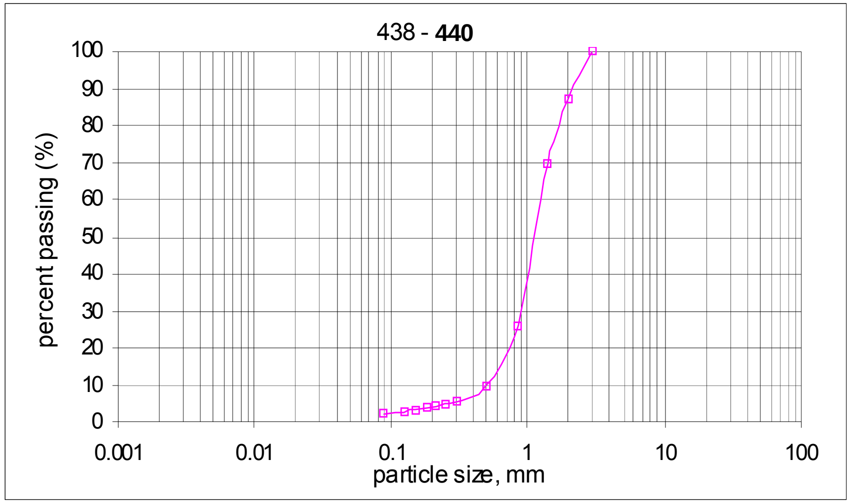

428 - **430**
percent passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.01
0.1
1
10
100
particle size, mm

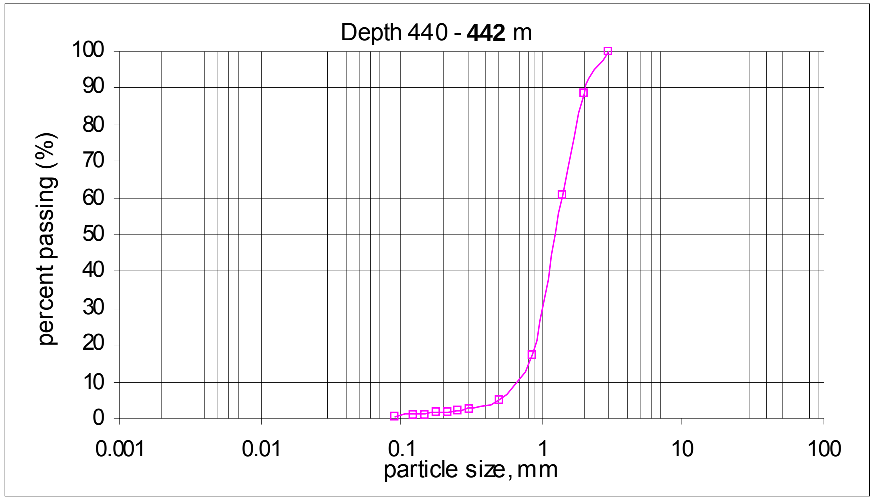

430 - **432**
percent passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.01
0.1
1
10
100
particle size, mm

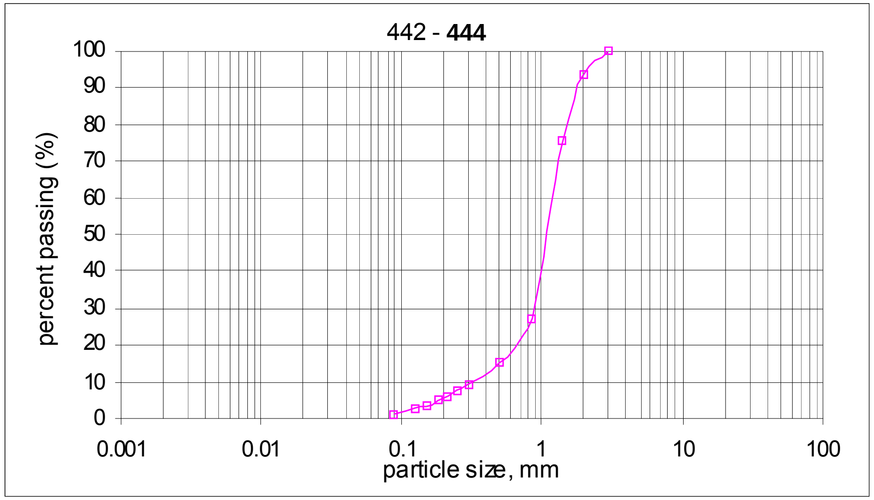

432 - **434**
percent passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.01
0.1
1
10
100
particle size, mm

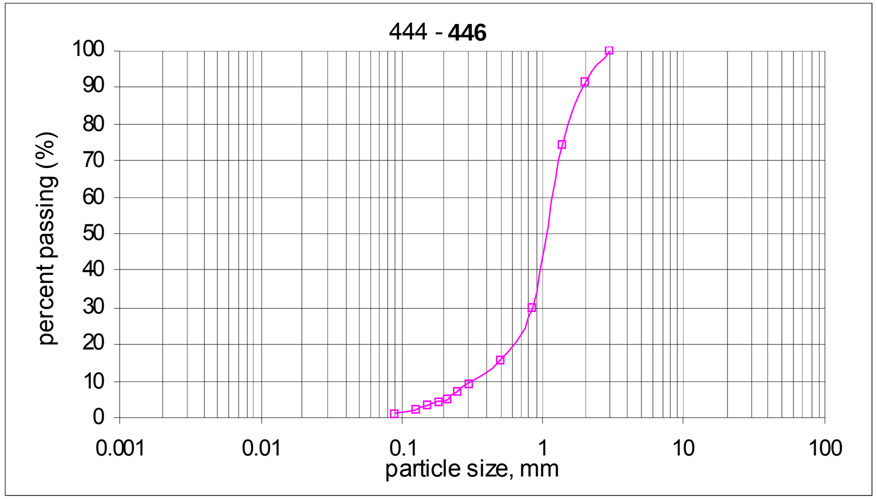

434 - **436**
percent passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.01
0.1
1
10
100
particle size, mm

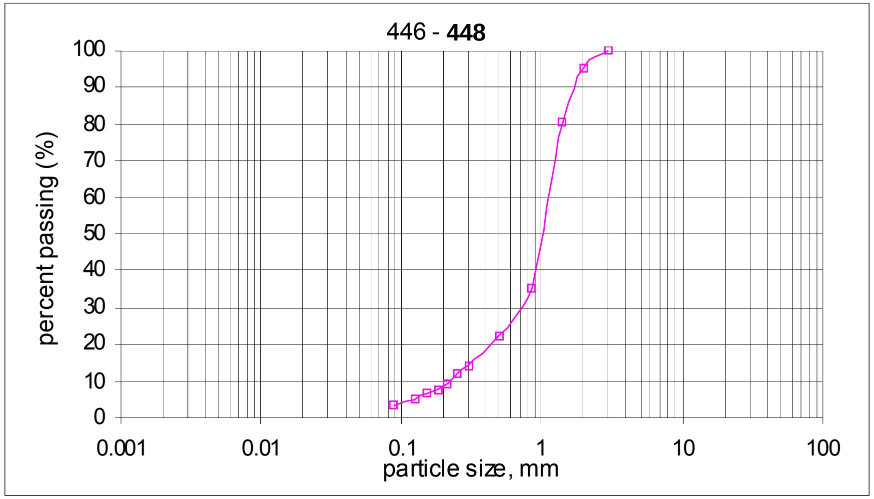

436 - **438**
percent passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.01
0.1
1
10
100
particle size, mm

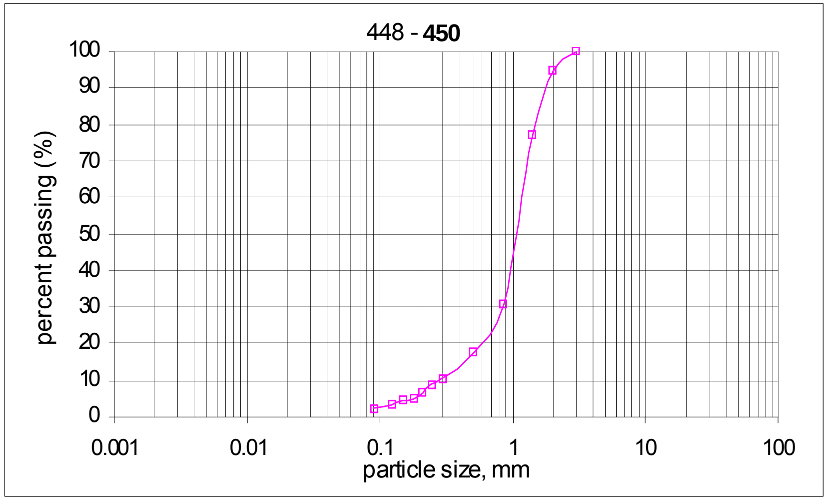

438 - **440**
percent passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.01
0.1
1
10
100
particle size, mm

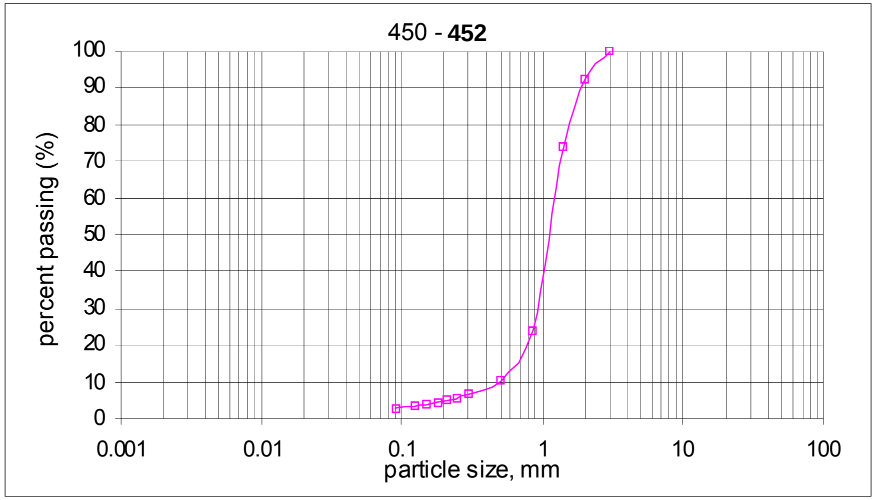

Depth 440 - **442** m
percent passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.01
0.1
1
10
100
particle size, mm

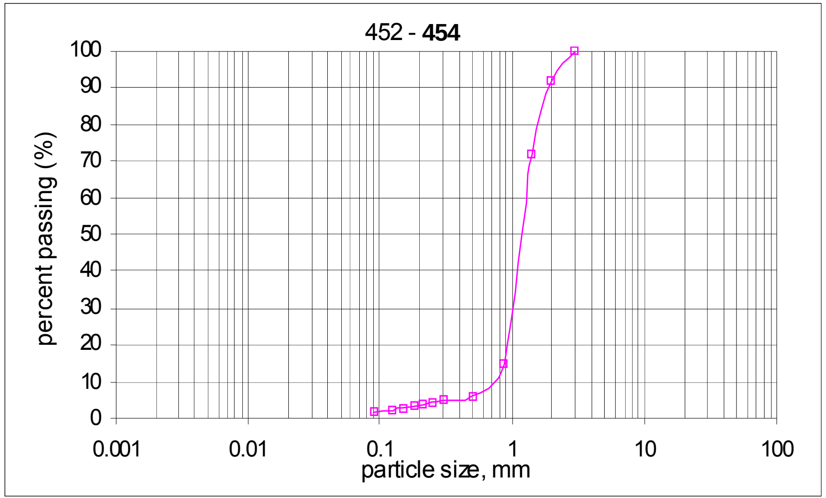

442 - **444**
percent passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.01
0.1
1
10
100
particle size, mm

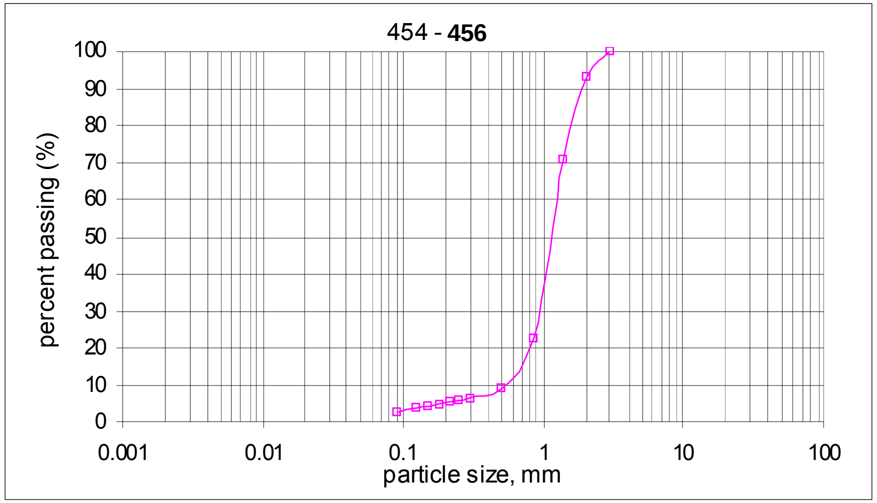

444 - 446
percent passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.01
0.1
1
10
100
particle size, mm

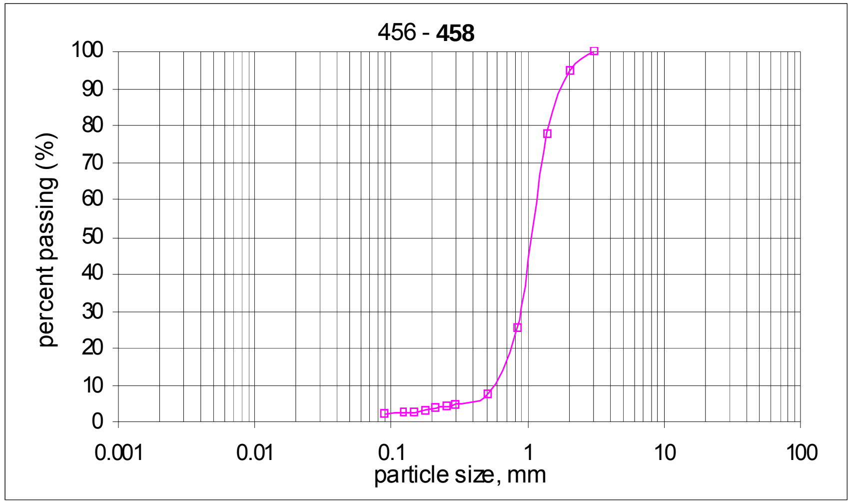

446 - 448
percent passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.01
0.1
1
10
100
particle size, mm

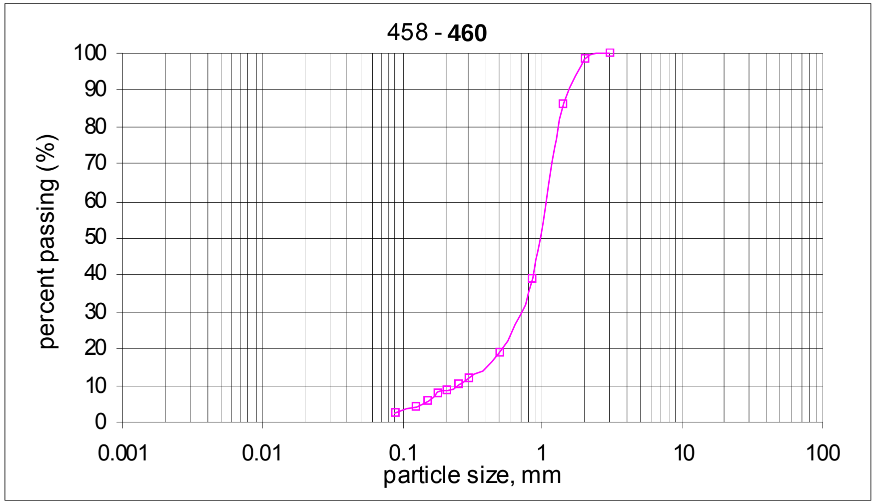

448 - 450
percent passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.01
0.1
1
10
100
particle size, mm


450 - 452
percent passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.01
0.1
1
10
100
particle size, mm


452 - 454
percent passing (%)
particle size, mm


454 - 456
percent passing (%)
particle size, mm


456 - 458
percent passing (%)
particle size, mm


458 - 460
percent passing (%)
particle size, mm

9. FULL CHEMICAL ANALYSIS AND GROUNDWATER SAMPLING RESULTS

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Australian Water Quality Centre

DWLBC
ATTN: Paul Magarey
Leve 11 25 Grenfell St
Adelaide
SA 5000 AUSTRALIA

10/05/2007

Dear Paul

Please find attached the Final Analytical Report for

Customer Service Request: 108874-2007-CSR-5
Account: 108874
Project: AWQC-12320 DWLBC - Paul Magarey - 06/07

Sample Date Range: 10-April-2007 to 16-April-2007

Yours sincerely,

Sam Loveder
Senior Customer Service Officer
Sam.Loveder@sawater.com.au
(08) 8259 0259

NATA WORLD RECOGNISED ACCREDITATION

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Australian Water Quality Centre

FINAL REPORT: 21421

This report supercedes the following issued reports: 20531, 20569

Report Information

Project Name	AWQC-12320
Customer	DWLBC
CSR_ID	108874-2007-CSR-5

Analytical Results

Customer Sample Description	CH-1
Sampling Point	11438-DWLBC - GENERAL
Sampled Date	10/04/2007 12:00:00AM
Sample Received Date	12/04/2007 12:57:00PM
Sample ID	*2007-002-4505
Status	Endorsed
Collection Type	Customer Collected

Inorganic Chemistry - Metals	LOR	Result
Aluminium - Total TIC-004 W09-023		
Aluminium - Total	0.010	<0.01 mg/L
Calcium TIC-001 W09-023		
Calcium	0.1	529 mg/L
Iron - Total TIC-004 W09-023		
Iron - Total	0.005	0.271 mg/L
Magnesium TIC-001 W09-023		
Magnesium	0.3	578 mg/L
Manganese - Total TIC-001 W09-023		
Manganese - Total	0.001	0.764 mg/L
Manganese - Total TIC-003 W09-023		
Manganese - Total	0.0005	0.5694 mg/L
Potassium TIC-001 W09-023		
Potassium	1.0	75.1 mg/L
Sodium TIC-001 W09-023		
Sodium	0.5	6530 mg/L
Sulphur TIC-001 W09-023		
Sulphate	1.5	2120 mg/L

Inorganic Chemistry - Nutrients	LOR	Result
Ammonia as N T0100-01 W09-023		
Ammonia as N	0.005	4.338 mg/L
Bromide W09-023		
Bromide	0.10	<0.1 mg/L
Chloride T0104-02 W09-023		
Chloride	4.0	4860 mg/L
Nitrate + Nitrite as N T0161-01 W09-023		
Nitrate + Nitrite as N	0.005	<0.005 mg/L
Nitrate as N W09-023		
Nitrate as Nitrogen	0	0.000 mg/L
Nitrite as N T0107-01 W09-023		

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FINAL REPORT: 21421

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Analytical Results

Customer Sample Description	CH-1
Sampling Point	11438-DWLBC - GENERAL
Sampled Date	10/04/2007 12:00:00AM
Sample Received Date	12/04/2007 12:57:00PM
Sample ID	*2007-002-4505
Status	Endorsed
Collection Type	Customer Collected

	LOR	Result
Nitrite as N T0107-01 W09-023		
Nitrite as Nitrogen	0.005	<0.005 mg/L
Nitrogen - Total W09-023		
Nitrogen - Total	0.05	4.62 mg/L
Phosphorus - Total T0109-01 W09-023		
Phosphorus - Total	0.005	0.169 mg/L
Silica - Reactive T0111-01 W09-023		
Silica - Reactive	1	14 mg/L
TKN as N T0112-01 W09-023		
TKN as Nitrogen	0.05	4.61 mg/L

Organic Chemistry	LOR	Result
Dissolved Organic Carbon T0158-09 W09-023		
Dissolved Organic Carbon	0.3	2.3 mg/L
Total Organic Carbon W09-023		
Total Organic Carbon	0.3	2.1 mg/L

Inorganic Chemistry - Physical	LOR	Result
Alkalinity, Carbonate, Bicarbonate and Hydroxide T0101-01 W09-023		
Alkalinity as Calcium Carbonate		351 mg/L
Bicarbonate		428 mg/L
Carbonate		0 mg/L
Hydroxide		0 mg/L
Turbidity T0018-01 W09-023		
Turbidity	0.1	1.3 NTU

Inorganic Chemistry - Waste Water	LOR	Result
Suspended Solids T0160-01 W09-023		
Suspended Solids	1.0	6 mg/L
Volatile Suspended Solids W09-023		
Volatile Suspended Solids	1	2 mg/L

Notes
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FINAL REPORT: 21421

This report supercedes the following issued reports: 20531, 20569

Analytical Results

Customer Sample Description	CH-3
Sampling Point	11438-DWLBC - GENERAL
Sampled Date	11/04/2007 10:30:00AM
Sample Received Date	12/04/2007 12:57:23PM
Sample ID	*2007-002-4506
Status	Endorsed
Collection Type	Customer Collected

Bacteriology	LOR	Result
Colony Count at 20 C T0083-01 WMZ-500		
Colony Count (20C) Aerobic		210 /mL
Colony Count at 35 C T0084-11 WMZ-500		
Colony Count (35C) Aerobic		220 /mL
Iron Bacteria - Heterotrophic T460-01 WMZ-500		
Iron Bacteria - Heterotrophic	10	10 /mL
Iron Bacteria - Heterotrophic T460-05 WMZ-500		
Iron Bacteria - Microscopic examination		Microscopical examination of the sample showed low numbers of filamentous iron associated microroganisms

Inorganic Chemistry - Metals	LOR	Result
Aluminium - Total TIC-004 W09-023		
Aluminium - Total	0.010	<0.01 mg/L
Calcium TIC-001 W09-023		
Calcium	0.1	627 mg/L
Iron - Total TIC-004 W09-023		
Iron - Total	0.005	2.97 mg/L
Magnesium TIC-001 W09-023		
Magnesium	0.3	2040 mg/L
Manganese - Total TIC-001 W09-023		
Manganese - Total	0.001	0.056 mg/L
Manganese - Total TIC-003 W09-023		
Manganese - Total	0.0005	0.0320 mg/L
Potassium TIC-001 W09-023		
Potassium	1.0	213 mg/L
Sodium TIC-001 W09-023		
Sodium	0.5	16200 mg/L
Sulphur TIC-001 W09-023		
Sulphate	1.5	9480 mg/L

Inorganic Chemistry - Nutrients	LOR	Result
Ammonia as N T0100-01 W09-023		
Ammonia as N	0.005	0.069 mg/L
Bromide W09-023		
Bromide	0.10	<0.1 mg/L
Chloride T0104-02 W09-023		

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FINAL REPORT: 21421

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Analytical Results

Customer Sample Description	CH-3
Sampling Point	11438-DWLBC - GENERAL
Sampled Date	11/04/2007 10:30:00AM
Sample Received Date	12/04/2007 12:57:23PM
Sample ID	*2007-002-4506
Status	Endorsed
Collection Type	Customer Collected

	LOR	Result
Chloride T0104-02 W09-023		
Chloride	4.0	26500 mg/L
Nitrate + Nitrite as N T0161-01 W09-023		
Nitrate + Nitrite as N	0.005	<0.005 mg/L
Nitrate as N W09-023		
Nitrate as Nitrogen	0	0.000 mg/L
Nitrite as N T0107-01 W09-023		
Nitrite as Nitrogen	0.005	<0.005 mg/L
Nitrogen - Total W09-023		
Nitrogen - Total	0.05	1.10 mg/L
Phosphorus - Total T0109-01 W09-023		
Phosphorus - Total	0.005	0.198 mg/L
Silica - Reactive T0111-01 W09-023		
Silica - Reactive	1	13 mg/L
TKN as N T0112-01 W09-023		
TKN as Nitrogen	0.05	1.10 mg/L

Organic Chemistry	LOR	Result
Dissolved Organic Carbon T0158-09 W09-023		
Dissolved Organic Carbon	0.3	1.1 mg/L
Total Organic Carbon W09-023		
Total Organic Carbon	0.3	1.2 mg/L

Inorganic Chemistry - Physical	LOR	Result
Alkalinity, Carbonate, Bicarbonate and Hydroxide T0101-01 W09-023		
Alkalinity as Calcium Carbonate		263 mg/L
Bicarbonate		321 mg/L
Carbonate		0 mg/L
Hydroxide		0 mg/L
Turbidity T0018-01 W09-023		
Turbidity	0.1	41 NTU

Inorganic Chemistry - Waste Water	LOR	Result
Suspended Solids T0160-01 W09-023		
Suspended Solids	1.0	30 mg/L
Volatile Suspended Solids W09-023		
Volatile Suspended Solids	1	6 mg/L

Corporate Accreditation No.1115
Chemical and Biological Testing
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Notes
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FINAL REPORT: 21421

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Analytical Results

Customer Sample Description	CH-3
Sampling Point	11438-DWLBC - GENERAL
Sampled Date	11/04/2007 10:30:00AM
Sample Received Date	12/04/2007 12:57:23PM
Sample ID	*2007-002-4506
Status	Endorsed
Collection Type	Customer Collected

Water Treatment	LOR	Result
Dissolved Organic Carbon - Biodegradable W09-023		
# Dissolved Organic Carbon - Biodegradable	0.2	<0.2 mg/L

Notes
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Analytical Results

Customer Sample Description	CH-4
Sampling Point	11438-DWLBC - GENERAL
Sampled Date	11/04/2007 1:00:00PM
Sample Received Date	12/04/2007 12:57:43PM
Sample ID	*2007-002-4507
Status	Endorsed
Collection Type	Customer Collected

Bacteriology	LOR	Result
Colony Count at 20 C T0083-01 WMZ-500		
Colony Count (20C) Aerobic		3 /mL
Colony Count at 35 C T0084-11 WMZ-500		
Colony Count (35C) Aerobic		1 /mL
Iron Bacteria - Heterotrophic T460-01 WMZ-500		
Iron Bacteria - Heterotrophic	10	<10 /mL
Iron Bacteria - Heterotrophic T460-05 WMZ-500		
Iron Bacteria - Microscopic examination		Microscopical examination of the sample did not detect iron associated microorganisms

Inorganic Chemistry - Metals	LOR	Result
Aluminium - Total TIC-004 W09-023		
Aluminium - Total	0.010	<0.01 mg/L
Calcium TIC-001 W09-023		
Calcium	0.1	576 mg/L
Iron - Total TIC-004 W09-023		
Iron - Total	0.005	2.06 mg/L
Magnesium TIC-001 W09-023		
Magnesium	0.3	1460 mg/L
Manganese - Total TIC-001 W09-023		
Manganese - Total	0.001	0.081 mg/L
Manganese - Total TIC-003 W09-023		
Manganese - Total	0.0005	0.0557 mg/L
Potassium TIC-001 W09-023		
Potassium	1.0	145 mg/L
Sodium TIC-001 W09-023		
Sodium	0.5	11100 mg/L
Sulphur TIC-001 W09-023		
Sulphate	1.5	6390 mg/L

Inorganic Chemistry - Nutrients	LOR	Result
Ammonia as N T0100-01 W09-023		
Ammonia as N	0.005	0.095 mg/L
Bromide W09-023		
Bromide	0.10	52.1 mg/L
Chloride T0104-02 W09-023		

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Notes
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Analytical Results

Customer Sample Description	CH-4
Sampling Point	11438-DWLBC - GENERAL
Sampled Date	11/04/2007 1:00:00PM
Sample Received Date	12/04/2007 12:57:43PM
Sample ID	*2007-002-4507
Status	Endorsed
Collection Type	Customer Collected

	LOR	Result
Chloride T0104-02 W09-023		
Chloride	4.0	7600 mg/L
Nitrate + Nitrite as N T0161-01 W09-023		
Nitrate + Nitrite as N	0.005	<0.005 mg/L
Nitrate as N W09-023		
Nitrate as Nitrogen	0	0.000 mg/L
Nitrite as N T0107-01 W09-023		
Nitrite as Nitrogen	0.005	<0.005 mg/L
Nitrogen - Total W09-023		
Nitrogen - Total	0.05	2.30 mg/L
Phosphorus - Total T0109-01 W09-023		
Phosphorus - Total	0.005	0.078 mg/L
Silica - Reactive T0111-01 W09-023		
Silica - Reactive	1	16 mg/L
TKN as N T0112-01 W09-023		
TKN as Nitrogen	0.05	2.29 mg/L

Organic Chemistry	LOR	Result
Dissolved Organic Carbon T0158-09 W09-023		
Dissolved Organic Carbon	0.3	0.7 mg/L
Total Organic Carbon W09-023		
Total Organic Carbon	0.3	0.7 mg/L

Inorganic Chemistry - Physical	LOR	Result
Alkalinity, Carbonate, Bicarbonate and Hydroxide T0101-01 W09-023		
Alkalinity as Calcium Carbonate		284 mg/L
Bicarbonate		346 mg/L
Carbonate		0 mg/L
Hydroxide		0 mg/L
Turbidity T0018-01 W09-023		
Turbidity	0.1	27 NTU

Inorganic Chemistry - Waste Water	LOR	Result
Suspended Solids T0160-01 W09-023		
Suspended Solids	1.0	15 mg/L
Volatile Suspended Solids W09-023		
Volatile Suspended Solids	1	2 mg/L

Notes
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Analytical Results

Customer Sample Description	CH-4
Sampling Point	11438-DWLBC - GENERAL
Sampled Date	11/04/2007 1:00:00PM
Sample Received Date	12/04/2007 12:57:43PM
Sample ID	*2007-002-4507
Status	Endorsed
Collection Type	Customer Collected

Water Treatment	LOR	Result
Dissolved Organic Carbon - Biodegradable W09-023		
# Dissolved Organic Carbon - Biodegradable	0.2	<0.2 mg/L

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Notes
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FINAL REPORT: 21421

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Analytical Results

Customer Sample Description	CH-5
Sampling Point	11438-DWLBC - GENERAL
Sampled Date	11/04/2007 2:35:00PM
Sample Received Date	12/04/2007 12:58:06PM
Sample ID	*2007-002-4508
Status	Endorsed
Collection Type	Customer Collected

Bacteriology	LOR	Result
Colony Count at 20 C T0083-01 WMZ-500		
Colony Count (20C) Aerobic		34 /mL
Colony Count at 35 C T0084-11 WMZ-500		
Colony Count (35C) Aerobic		13 /mL
Iron Bacteria - Heterotrophic T460-01 WMZ-500		
Iron Bacteria - Heterotrophic	10	<10 /mL
Iron Bacteria - Heterotrophic T460-05 WMZ-500		
Iron Bacteria - Microscopic examination		Microscopical examination of the sample showed low numbers of iron associated microroganisms containing a mixture of filamentous and non-filamentous types

Inorganic Chemistry - Metals	LOR	Result
Aluminium - Total TIC-004 W09-023		
Aluminium - Total	0.010	0.012 mg/L
Calcium TIC-001 W09-023		
Calcium	0.1	492 mg/L
Iron - Total TIC-004 W09-023		
Iron - Total	0.005	9.88 mg/L
Magnesium TIC-001 W09-023		
Magnesium	0.3	1270 mg/L
Manganese - Total TIC-001 W09-023		
Manganese - Total	0.001	0.290 mg/L
Potassium TIC-001 W09-023		
Potassium	1.0	148 mg/L
Sodium TIC-001 W09-023		
Sodium	0.5	10700 mg/L
Sulphur TIC-001 W09-023		
Sulphate	1.5	5430 mg/L

Inorganic Chemistry - Nutrients	LOR	Result
Ammonia as N T0100-01 W09-023		
Ammonia as N	0.005	<0.005 mg/L
Bromide W09-023		
Bromide	0.10	51.5 mg/L
Chloride T0104-02 W09-023		
Chloride	4.0	7050 mg/L

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Australian Water Quality Centre

FINAL REPORT: 21421

This report supercedes the following issued reports: 20531, 20569

Analytical Results

Customer Sample Description	CH-5
Sampling Point	11438-DWLBC - GENERAL
Sampled Date	11/04/2007 2:35:00PM
Sample Received Date	12/04/2007 12:58:06PM
Sample ID	*2007-002-4508
Status	Endorsed
Collection Type	Customer Collected

	LOR	Result
Nitrate + Nitrite as N T0161-01 W09-023		
Nitrate + Nitrite as N	0.005	0.007 mg/L
Nitrate as N W09-023		
Nitrate as Nitrogen	0	0.002 mg/L
Nitrite as N T0107-01 W09-023		
Nitrite as Nitrogen	0.005	<0.005 mg/L
Nitrogen - Total W09-023		
Nitrogen - Total	0.05	1.84 mg/L
Phosphorus - Total T0109-01 W09-023		
Phosphorus - Total	0.005	0.660 mg/L
Silica - Reactive T0111-01 W09-023		
Silica - Reactive	1	13 mg/L
TKN as N T0112-01 W09-023		
TKN as Nitrogen	0.05	1.83 mg/L

Organic Chemistry	LOR	Result
Dissolved Organic Carbon T0158-09 W09-023		
Dissolved Organic Carbon	0.3	2.0 mg/L
Total Organic Carbon W09-023		
Total Organic Carbon	0.3	2.5 mg/L

Inorganic Chemistry - Physical	LOR	Result
Alkalinity, Carbonate, Bicarbonate and Hydroxide T0101-01 W09-023		
Alkalinity as Calcium Carbonate		551 mg/L
Bicarbonate		672 mg/L
Carbonate		0 mg/L
Hydroxide		0 mg/L
Turbidity T0018-01 W09-023		
Turbidity	0.1	140 NTU

Inorganic Chemistry - Waste Water	LOR	Result
Suspended Solids T0160-01 W09-023		
Suspended Solids	1.0	36 mg/L
Volatile Suspended Solids W09-023		
Volatile Suspended Solids	1	7 mg/L

Water Treatment	LOR	Result

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Sampled Date	11/04/2007 2:35:00PM
Sample Received Date	12/04/2007 12:58:06PM
Sample ID	*2007-002-4508
Status	Endorsed
Collection Type	Customer Collected

Dissolved Organic Carbon - Biodegradable W09-023

# Dissolved Organic Carbon - Biodegradable	0.2	<0.2 mg/L

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FINAL REPORT: 21421

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Analytical Results

Customer Sample Description	CH-2
Sampling Point	11438-DWLBC - GENERAL
Sampled Date	11/04/2007 3:30:00PM
Sample Received Date	12/04/2007 12:56:44PM
Sample ID	*2007-002-4504
Status	Endorsed
Collection Type	Customer Collected

Bacteriology	LOR	Result
Colony Count at 20 C T0083-01 WMZ-500		
Colony Count (20C) Aerobic		1 /mL
Colony Count at 35 C T0084-11 WMZ-500		
Colony Count (35C) Aerobic		5 /mL
Iron Bacteria - Heterotrophic T460-01 WMZ-500		
Iron Bacteria - Heterotrophic	10	<10 /mL
Iron Bacteria - Heterotrophic T460-05 WMZ-500		
Iron Bacteria - Microscopic examination		Microscopical examination of the sample did not detect iron associated microorganisms

Inorganic Chemistry - Metals	LOR	Result
Aluminium - Total TIC-004 W09-023		
Aluminium - Total	0.010	<0.01 mg/L
Calcium TIC-001 W09-023		
Calcium	0.1	596 mg/L
Iron - Total TIC-004 W09-023		
Iron - Total	0.005	1.41 mg/L
Magnesium TIC-001 W09-023		
Magnesium	0.3	1440 mg/L
Manganese - Total TIC-001 W09-023		
Manganese - Total	0.001	0.016 mg/L
Manganese - Total TIC-003 W09-023		
Manganese - Total	0.0005	0.0118 mg/L
Potassium TIC-001 W09-023		
Potassium	1.0	161 mg/L
Sodium TIC-001 W09-023		
Sodium	0.5	11200 mg/L
Sulphur TIC-001 W09-023		
Sulphate	1.5	6300 mg/L

Inorganic Chemistry - Nutrients	LOR	Result
Ammonia as N T0100-01 W09-023		
Ammonia as N	0.005	0.110 mg/L
Bromide W09-023		
Bromide	0.10	52.5 mg/L
Chloride T0104-02 W09-023		

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Sample Received Date	12/04/2007 12:56:44PM
Sample ID	*2007-002-4504
Status	Endorsed
Collection Type	Customer Collected

	LOR	Result
Chloride T0104-02 W09-023		
Chloride	4.0	18100 mg/L
Nitrate + Nitrite as N T0161-01 W09-023		
Nitrate + Nitrite as N	0.005	<0.005 mg/L
Nitrate as N W09-023		
Nitrate as Nitrogen	0	0.000 mg/L
Nitrite as N T0107-01 W09-023		
Nitrite as Nitrogen	0.005	<0.005 mg/L
Nitrogen - Total W09-023		
Nitrogen - Total	0.05	2.44 mg/L
Phosphorus - Total T0109-01 W09-023		
Phosphorus - Total	0.005	0.084 mg/L
Silica - Reactive T0111-01 W09-023		
Silica - Reactive	1	14 mg/L
TKN as N T0112-01 W09-023		
TKN as Nitrogen	0.05	2.44 mg/L

Organic Chemistry	LOR	Result
Dissolved Organic Carbon T0158-09 W09-023		
Dissolved Organic Carbon	0.3	0.5 mg/L
Total Organic Carbon W09-023		
Total Organic Carbon	0.3	0.5 mg/L

Inorganic Chemistry - Physical	LOR	Result
Alkalinity, Carbonate, Bicarbonate and Hydroxide T0101-01 W09-023		
Alkalinity as Calcium Carbonate		242 mg/L
Bicarbonate		296 mg/L
Carbonate		0 mg/L
Hydroxide		0 mg/L
Turbidity T0018-01 W09-023		
Turbidity	0.1	10 NTU

Inorganic Chemistry - Waste Water	LOR	Result
Suspended Solids T0160-01 W09-023		
Suspended Solids	1.0	16 mg/L
Volatile Suspended Solids W09-023		
Volatile Suspended Solids	1	4 mg/L

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Sample Received Date	12/04/2007 12:56:44PM
Sample ID	*2007-002-4504
Status	Endorsed
Collection Type	Customer Collected

Water Treatment	LOR	Result
Dissolved Organic Carbon - Biodegradable W09-023		
# Dissolved Organic Carbon - Biodegradable	0.2	<0.2 mg/L

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NATA Signatories


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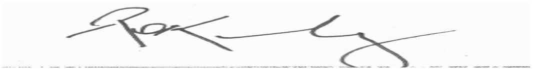
Chris Chow - Water Treatment Research Chemist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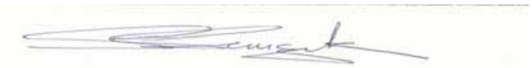
John Martini - Organic Chemistry Scientific Officer


Greg O'Neil - Inorganic Chemistry Team Leader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Incidents

Sample ID	S.Point	Description	Sampled Date	Analysis (where Applicable)	Incident Description
2007-002-4504	11438	CH-2	11/04/2007		No air gap in Bacteriology Sample bottle
2007-002-4505	11438	CH-1	10/04/2007	Dissolved Organic Carbon	DOC > TOC but within method uncertainty
2007-002-4506	11438	CH-3	11/04/2007		No air gap in Bacteriology Sample bottle
2007-002-4507	11438	CH-4	11/04/2007		No air gap in Bacteriology Sample bottle
2007-002-4508	11438	CH-5	11/04/2007		No air gap in Bacteriology Sample bottle

Analytical Method

Analytical Method Code	Description
T0018-01	Turbidity - Nephelometric Measurement
T0083-01	Colony Count (20C) Aerobic - Pour plate
T0084-11	Colony Count (35C) Aerobic - Pour plate
T0100-01	Ammonia/Ammonium - Automated Flow Colorimetry
T0101-01	Alkalinity - Automated Acidimetric Titration
T0104-02	Chloride - Automated Flow Colorimetry
T0107-01	Nitrite - Automated Flow Colorimetry
T0109-01	Total Phosphorus - Automated Flow Colorimetry
T0111-01	Reactive Silica - Automated Flow Coloimetry
T0112-01	TKN - Automated Flow Colorimetry
T0158-09	Total and Dissolved Organic Carbon (OI Analytical)
T0160-01	Suspended Solids
T0161-01	Nitrate + Nitrate (NOx) - Automated Flow Colorimetry
T460-01	Heterotrophic Iron Bacteria - Spread plate
T460-05	Heterotrophic Iron Bacteria - microscopic
TIC-001	Determination of Metals-ICP Spectrometry
TIC-003	Elemental Analaysis - ICP Mass Spectrometry
TIC-004	Determination of Metals - ICP Spectrometry by ICP2
W-052	Preparation of Samples for Metal Analysis

Sampling Method

Sampling Method Code	Description
W09-023	Sampling Method for Chemical Analyses

Laboratory Information

Laboratory	NATA accreditation ID
Bacteriology	1115
Inorganic Chemistry - Metals	1115
Inorganic Chemistry - Nutrients	1115
Organic Chemistry	1115
Inorganic Chemistry - Physical	1115
Inorganic Chemistry - Waste Water	1115
Water Treatment	1115

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10. CLOGGING AND GEOCHEMICAL MODELLING STUDIES, CSIRO

National Research FLAGSHIPS

CSIRO

Assessment of the Potential for Well Clogging Associated with Salt Water Interception and Deep Injection at Chowilla, SA

Paul Pavelic, Joanne Vanderzalm, Peter Dillon, Andrew Herczeg, Karen Barry, Kerry Levett, Joao Mimoso and Paul Magarey[*]

[*] Department of Water, Land and Biodiversity and Conservation

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Final Report to Department of Water, Land, Biodiversity and Conservation

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Cover Photograph:

Title: Backwaters along Chowilla Creek, upstream from Renmark, SA 1993
From: CSIRO Land and Water Image Gallery http://www.clw.csiro.au/ImageGallery/
File: PDC00411_006.jpg
Photographer: Willem van Aken

CONTENTS

EXECUTIVE SUMMARY

Interception of shallow saline groundwater from the Monoman Sands (MS) aquifer on the floodplain of the River Murray at Chowilla prior to it reaching the River Murray and then injecting it into the deeper Renmark Group (RG) aquifer is proposed as part of a major long-term initiative to control salinity levels in the river and lower the watertable beneath the floodplain.

This report addresses the feasibility of injecting MS groundwater into the RG aquifer from the viewpoint of assessing the risks from well clogging in proceeding with an injection pilot trial at Chowilla.

The quality of the groundwater in the MS aquifer was determined from sampling of three MS wells in 2005 and a further four wells in 2007 for a range of physico-chemical parameters. In January 2007 a 540 m deep well was drilled by the Department of Water, Land and Biodiversity and Conservation (DWLBC) into the RG aquifer and cutting samples collected at regular intervals during drilling. Following well development sampling was performed to determine the quality of the ambient groundwater. Geochemical modelling with PHREEQC using the water quality and mineralogical data enabled an assessment of the potential for geochemical reactions to impact on aquifer permeability.

The results demonstrate that injection into the RG would not be entirely without risk as a result of clogging due to physical, chemical or microbial processes. These risks in proceeding with a trial should be manageable to within acceptable limits by ensuring:

a) that the quality of the source water from the MS aquifer is improved by pre-treatment prior to injection to achieve low particulate levels (notionally <10 mg/L TSS)

b) that aeration of the MS source water during storage be prevented or at least minimized

c) redevelopment be performed before a 20% reduction in injection rate is observed and recovered water evaluated for composition of particulates present

d) the turbidity and oxygen status of the injectant as well as the injection rates and pressures should be carefully monitored during the trial to inform the operational performance and to enable fine-tuning in subsequent phases of project development

e) additional parameters should also be evaluated in the injectant and at observation wells directly influenced by breakthrough of recharge water. Parameters would include total and dissolved iron and manganese, electrical conductivity, pH, redox potential, dissolved oxygen, temperature, major ions, nitrogen species (nitrate, ammonium and total Kjeldahl Nitrogen), phosphorus (total and soluble reactive P) and dissolved organic carbon.

INTRODUCTION

A proposal to intercept shallow saline groundwater on the floodplain of the River Murray at Chowilla prior to it reaching the River Murray is part of a major long-term initiative to control salinity levels in the River. It is proposed that saline groundwater from the shallow unconfined Monoman Sands (MS) aquifer would be pumped from multiple wells situated close to the River and injected into the deep confined Renmark Group (RG) aquifer, thereby minimizing the footprint typically associated with surface basin disposal of more conventional Salt Interception Schemes (Rammers *et al,* 2005).

Virtually all well injection operations experience some degree of well clogging that can critically limit the quantity of water that is stored within the aquifer and/or lead to large increases in pressures within the well that may necessitate costly pre-treatment and maintenance procedures, or even project abandonment in extreme cases.

One of the key considerations for the success of the proposed project is the extent of clogging which could occur when the MS groundwater mixes with the RG groundwater as a result of the injection process. Risks associated with well clogging include:

- irrecoverable accumulation of particulate matter that is present within the MS source water
- precipitation of minerals due to chemical or bacterial processes
- swelling or dispersion of reactive clays that may be present in the aquifer
- production of bacterial biomass and polysaccharide ‘slime’ growth around the well due to nutrients present in the source water
- degassing during injection leading to gas binding

The objective of this study is to determine the feasibility of the proposed pilot injection trial on the Chowilla floodplain from a clogging perspective, taking into account each of the above-noted risks. The assessment consists of:

- a literature review on clogging issues associated with well injection of saline waters
- an evaluation of the physical, biological and geochemical clogging processes likely to occur due to mixing and water-matrix interactions at the Chowilla site

LITERATURE REVIEW

The injection of saline water into deeper saline groundwater aquifers for the purpose of intercepting and disposing of salt is not a common practice, however within the petroleum resources industry, this is relatively common. For example, in the USA, where large quantities of saline formation water are produced as a by-product of extracting hydrocarbons from deep reservoirs, around 8GL/day is reinjected into suitable formations.

Several international and national case studies were reviewed as summarized below. National studies are abstracted from previous work by Rammers *et al,* (2005):

International

In the Gulf Coast region of the USA, brine injection has been reported to cause the clogging of injection wells (Raber *et al*, 1981). Ultra-filtration methods were used to remove particulates and large organic molecules that led to reduced clogging potential. Multi-media filtration combined with chemical pre-treatment by coagulation produced a high quality feed water which also produced satisfactory results. Injection testing without any form of pre-treatment proved unsuccessful.

Saline injection operations in the Texas East and Permian Basins have experienced clogging problems due to chemical precipitation (so-called 'scaling'), clay mobilization and filter cake development which has placed an upper limit on the injection rate that may be sustained. Site-specific solutions have been found such as injecting acids to treat the scaling and providing pre-treatment such as the addition of chemicals to source waters to stabilize clays.

Also in Texas, proposals for the injection of brackish concentrate from desalination plants into depleted oil or gas reservoirs have considered clogging risks and demonstrated the concept is an environmentally and economically attractive option (Nicot and Chowdhury, 2005).

In the Tongonan Geothermal Well Field in the Philippines, a 50% reduction in injection rates within four months of operation was attributed to the presence of particulates within the source water composed of polymerized silica formed from the reaction between magnetite and silica. Improving the level of solids removal through bifurcation traps were shown to found to rectify the problem (Villa *et al*, 2004).

In the Zueta Well Field in Venezuala, clogging by high total suspended solids (TSS) and organics content (hydrocarbons at ppm levels) was identified from declines in injectivity. Initial trials with various chemicals added to the injectant produced only short-lived benefits. Horizontal wells were trialled, but did not prove useful. Further work on removing residual organics and drilling new wells that would allow injection above formation fracturing pressures has been proposed (Briceno *et al,* 2003).

National

A feasibility study to investigate the potential for deep aquifer disposal was undertaken at Noora Evaporation Basin (near Berri in the Murray Basin) in the 1970s (Forth and Reed, 1979). The aim of the study was to determine a target aquifer for deep aquifer disposal of 200,000 mg/L TDS brine at 1.5 ML/day or bitterns (brine following NaCl removal) at 0.8 ML/day over a period of at least 50 years. A field investigation into aquifer hydraulic properties supported by a study of the possible chemical reactions resulting from mixing of injected water with aquifer water was proposed to enable a design to be finalised. The project has yet to proceed.

Sinclair Knight Merz (SKM), on behalf of Goulburn-Murray Water, undertook investigations to assess the feasibility of deep groundwater injection into the Renmark Group aquifer as a means of brine disposal in the Kerang Lakes district of Victoria (SKM, 2003; 2004). A staged approach involving sampling of wells and lakes; investigation of the characteristics of the target aquifer; prediction of impacts, costing of conceptual design and pilot trials was proposed. The salinities of the Renmark Group in Kerang district are typically around 40,000 mg/L, which are about twice the observed values in the Chowilla region. PHREEQC modelling identified the potential for chemical clogging to occur when high calcium lake water combines with high iron groundwater in a reducing environment. Recommendations from the report included investigating potential of biological clogging, and assessing the hydraulic properties of the Loxton-Parilla Sands and Renmark Group formations and completing a more comprehensive sampling programme.

Australian Water Environments (AWE) were engaged by the Murray-Darling Basin Commission (MDBC) to explore the potential for deep injection into the Renmark Group at the Stockyard Plain Disposal Basin to address future disposal options required in the Woolpunda-Waikerie district. Investigations thus far have focussed on the identification of a suitable target aquifer (AWE, 2005).

Hydrogeology of the Target Aquifer

The target aquifer for injection is the Warina Formation that represents the lower zone of the Renmark Group. The Warina Formation comprises pale grey to pale brown, medium to coarse quartz sand with minor carbonaceous fine silt, clay and minor pebble conglomerate (Brown and Stephenson, 1991). The formation is weakly consolidated, loose and friable in places, occasionally lithified in part by siliceous cement, intergranular clay, carbonaceous material, and or quartz pyrite aggregates. In some bores these aggregates have been oxidised to form ferruginous cement. The formation is characterised by clean sand, high porosity, good permeability and is a high yielding confined aquifer.

In January a 540 m deep pilot well was drilled by DWLBC into the Warina Formation (Renmark Group) (CH1; Unit No. 7030-809) at the Chowilla study site. The Warina Formation contained layers of coarse, poorly sorted sand and gravel, grading to sandy clay. Although aquifer pumping tests are yet to be conducted in the test well, an ambient discharge rate of 8 L/sec was recorded by DWLBC during a 95 minute test due to an ambient artesian head of approximately 11m above ground surface (K. Osei-Bonsu, pers. comm.).

Sampling and Analysis Methods

The inherent spatial variations in the quality of the MS groundwater across the Chowilla floodplain required the sampling of multiple wells to gain reasonable insight of the quality likely to be injected in a pilot trial, whereby multiple MS wells would be expected to supply a single RG injection well.

Groundwater samples were collected in April 2007 by DWLBC personnel from CH1 well (Unit No. 7030-809) completed in the RG formation and from four nearby MS monitoring wells identified as wells CH2-CH5 (Unit Nos. 7030- 712, 756, 759 and 765) (**Figure 1**). Field parameters, temperature, pH, oxidation-reduction potential (ORP), electrical conductivity and dissolved oxygen were measured *in-situ* using a YSI 556 multi-parameter instrument. Additional physio-chemical and microbiological analyses (**Table 1**) were undertaken at the Australian Water Quality Centre (AWQC) and at CSIRO Land and Water laboratories according to standard methods (APHA, 1999).

An earlier investigation that targeted the Murray Group Limestone (overlying the Renmark Group) was undertaken in the Gum Flat area of Chowilla during 2005, which included drilling and coring of an injection well and subsequent aquifer testing. While this investigation found the Murray Group Limestone aquifer unsuitable for injection of MS groundwater, it gave additional useful information on source water quality from the MS. Groundwater data from MS observation wells (Unit Nos. 7030-577, 7030-695 and 7130-56) sampled in 2005 was also used in this assessment.

Cutting samples provided by DWLC from the recent drilling of RG well CH1 (Unit No. 7030-809) were examined and six representative subsamples were selected on the basis of the geological and geophysical log and particle size data in addition to one sample of drilling mud and one sample of fine material collected during well redevelopment for physico-chemical and mineralogical analyses (results in **Appendix A**).

Organic and inorganic carbon, exchangeable cations and cation exchange capacity (CEC) were determined by the analytical services group of CSIRO Land and Water, Adelaide using standard methods (**Appendix A**).

Mineralogical determinations on oven-dried and ground subsamples were performed by X-Ray Diffraction with a Philips PW1800 diffractometer by the mineralogical services group of CSIRO Land and Water, Adelaide. Subsamples were sieved to <200µm to enhance the detection of the non-quartz components.

Two of the MS groundwater samples collected in May 2005 were analysed for Membrane Filtration Index (MFI) at CSIRO Land and Water (Dillon *et al.*, 2001). The MFI is a measure of the potential for a particular water to clog wells by filtration and development of a filter cake. The test procedure involves measuring the reduction in the rate of flow through a 0.45µm filter at normalised temperature and operating pressure.

Particle size analysis was also undertaken on one of the 2005 samples (Unit No. 7030-577) by CSIRO Minerals.

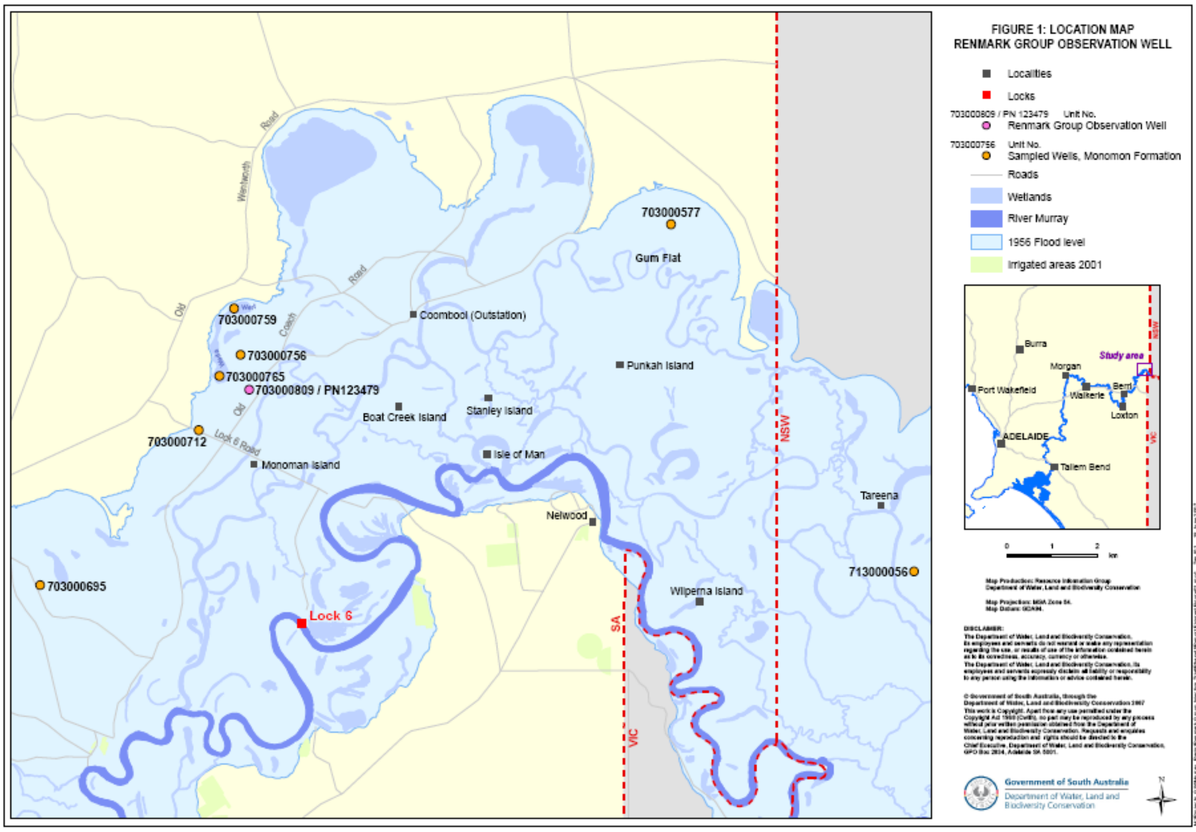

Figure 1. Location map of observation well 7030-809 (CH1) completed in the Renmark Group and wells 7030-712 (CH2), 7030-759 (CH3), 7030-765 (CH4) and 7030-756 (CH5) in the Monoman Sands. This assessment also used groundwater quality data from additional Monoman Sands observation wells 7030-577 (located at Gum Flat), 7030-695 and 7130-56. *Figure provided by DWLBC.*

Table 1. Groundwater quality data for the Renmark Group and the Monoman Sands

	RG and MS observation wells sampled in 2007					MS obs. wells sampled in 2005		
Aquifer	RG	MS	MS	MS	MS	MS	MS	MS
Well name/description	CH1	CH2	CH3	CH4	CH5	Gum Flat		
Unit No.	7030-809	7030-712	7030-759	7030-765	7030-756	7030-577	7030-695	7130-56
Date Sampled	10/04/07	10/04/07	11/04/07	11/04/07	11/04/07	3/05/05	05/05	2/05/05
Temp (°C)	36.08	21.6	19.5	20.15	23.26	20.3	21	22
pH (-)	6.83	6.29	6.46	6.39	6.75	6.6		6.7
DO (sat %)	0.8	1.9	1	0.9	1.9			
ORP (mV) †	-270.5	-62.4	-122.9	-157.4	-85.8			
TDS (g/L)	21.74	33.89	45.99	33.64	32.72			
Electrical Conductivity (mSiemens/cm)	40.53	48.75	63.31	46.95	48.66	75	42.9	48.2
Turbidity (NTU)	1.3	10	41	27	140	6.2	14	17
Suspended solids (mg/L)	6	16	30	15	36	73	55	56
Volatile suspended solids (mg/L)	2	4	6	2	7			
Alkalinity as $CaCO_3$ (mg/L)	351	242	263	284	551	200		
Calcium (mg/L)	529	596	627	576	492	469	630	501
Magnesium (mg/L)	578	1440	2040	1460	1270	2330	1560	1830
Potassium (mg/L)	75.1	161	213	145	148	213	177	121
Sodium (mg/L)	6530	11200	16200	11100	10700			
Bicarbonate (mg/L)	428	296	321	364	672	244	237	213
Chloride (mg/L)	4860	18100	26500	7600	7050	32900	20300	28200
Sulphate (mg/L)	2120	6300	9480	6390	5430	8950	6340	6570
Bromide (mg/L)	<0.1	52.5	<0.1	52.1	51.5			
Aluminium (mg/L)	<0.01	<0.01	<0.01	<0.01	0.012	0.021	0.518	0.178
Iron (mg/L)	0.271	1.4	2.97	2.06	9.88	3.61	8.15	5.23
Manganese (mg/L)	0.764	0.018	0.056	0.081	0.29	0.013	0.072	0.155
Manganese –soluble (mg/L)	0.569	0.016	0032	0.056				
Phosphorus (mg/L)	0.169	0.084	0.198	0.078	0.66	0.071	0.066	0.413
TKN as N (mg/L)	4.61	2.44	1.1	2.29	1.83	0.83	1.49	0.5
Ammonia as N (mg/L)	4.338	0.11	0.069	0.095	<0.005	0.331	0.867	0.102
Nitrate + Nitrite as N (mg/L)	<0.005	<0.005	<0.005	<0.005	0.007	<0.005	<0.005	0.006
Nitrate as N (mg/L)	<0.005	<0.005	<0.005	<0.005	0.002			
Nitrite as N (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005			
Silica – Reactive as SiO_2 (mg/L)	14	14	13	16	13	6	15	19
Total organic carbon (TOC) (mg/L)	2.1	0.5	1.2	0.7	2.5	0.5	0.7	0.7
Dissolved organic carbon (DOC) (mg/L)	2.3	0.5	1.1	0.7	2			
DOC – Biodegradable (mg/L)		<0.2	<0.2	<0.2	<0.2			
MFI (sec/L^2)						66.1		208.9
Aerobic colony count (20°C) (/mL)		1	210	3	34			
Aerobic colony count (35°C) (/mL)		5	220	1	13	210		
Heterotrophic Iron Bacteria (/mL)		<10	10	<10	<10	20	500	10
Radon-222 (Bq/L)	1.43±0.11	16.9±0.5	21.4±0.5	39.6±0.8	3.3±0.16			

† as measured in the field

Physical Clogging Assessment

The potential for the injection of MS water to lead to physical clogging can be assessed from examining the levels of indicator parameters such as MFI, total suspended solids (TSS), volatile suspended solids (VSS) and turbidity.

Turbidity, TSS and VSS data

Levels of particulate matter in the MS water, as characterized by the levels of turbidity, ranged from 10 to 140 NTU during the April 2007 sampling. This compares with values of 6 to 17 NTU in the previous (2005) sampling. TSS levels in the MS water ranged from 15 to 36 mg/L in 2007 and from 55 to 73 mg/L in 2005. The low VSS contribution to TSS indicates that only 10 to 30% of the particulate content is combustible at high temperature (ie. organic matter). By difference, the remaining 70 to 90% must be comprised of inorganic clay and silt-sized particles. The levels of all particulate indicators were lower in the deeper RG water than in the MS water.

MFI data

The Membrane Filtration Index (MFI) is an index of physical clogging potential that better accounts for the effect of particle size and composition than TSS or turbidity. MFI is a laboratory-based measure of the potential for physical clogging of a 0.45 µm membrane filter (Dillon *et al.,* 2001). The greater the retention of particles on the filter, the greater the MFI value (reported in units of sec/L^2) and hence also the rate of physical clogging. Note that chemically and biologically derived forms of clogging are not accounted for due to the nature and brevity of the test procedure.

MFI analyses conducted on two samples from the 2005 sampling were 66 and 209 sec/L^2 for turbidities of 6 and 17 NTU respectively. The estimated values for CH2-CH5 from 2007 sampling (using turbidity as the scaling factor) range from around 170 to 430 sec/L^2.

The values are high as compared to the range of 3-5 sec/L^2 generally accepted as an upper limit by Dutch water utilities for injection into fine-textured dune sands (Olsthoorn, 1982). By contrast, values of MFI as high as 400 to 4200 sec/L^2 were estimated to have been successfully injected into a sandy limestone aquifer with significant secondary porosity in the near-well zone during four successive years with routine backwash redevelopment every 40 ML (Pavelic *et al.,* 2006). These two examples illustrate that: a) the clogging potential of any given source water is highly dependent on the hydraulic characteristics of the target formation; and b) there is a trade off between the source water quality and the extent of clogging and hence the degree of redevelopment needed to sustain injection rates.

Particle size data

The particle size distribution curve was analyzed for one sample of MS water (2005 sample with MFI value of 66 sec/L^2). The size distribution curve given in **Appendix B** shows that particle sizes vary by almost two orders of magnitude, with a median size in the order of 22-26 microns. The majority of the size fraction is within the range that would be anticipated to be easily taken-out within settling tanks (Wegelin, 1996).

Biological Clogging Assessment

Microbial growth, defined as the collective increase in the number of bacterial cells and the extracellular polymeric materials (slimes) that they secrete, occurs where sufficient organic and inorganic substrates are present in the source water. In their own right, bacteria occupy little space at concentrations typically found in source waters and aquifers and it is only when they are given the opportunity to attach and grow on surfaces that they can cause significant practical problems. Bacteria reproduce by fission, and their rate of replication with time is exponential where the availability of substrate is not limiting. Unlike physical clogging, which is rapid, microbial clogging develops over time-scales of days to weeks (Rinck-Pfeiffer *et al*., 2000; Marsden, 2001).

In the absence of microbial inhibitors such as chemical disinfectants, the extent to which bioclogging of the well-screen and adjacent porous media can occur depends on the amount of organic matter or other key nutrients that are available to support bacterial metabolism.

The potential of the MS water to lead to microbial clogging can be determined by examining source water parameters including organic carbon, nitrogen and phosphorus. Levels of dissolved organic carbon (DOC) in the MS water were low and ranged from 0.5-2 mg/L. Levels of total nitrogen (1.1-2.4 mg/L) and total phosphorus (0.1-0.7 mg/L) were also low. Nutrient levels were higher in the ambient groundwater than the MS water in all cases apart from CH5 (Unit No. 7030-756). This well has the shallowest completion interval and may represent younger groundwater thereby limiting the time available for natural attenuation of reactive constituents.

Biodegradable organic carbon (BDOC) provides an indicator of the bio-availability of the organic carbon in water samples that may be analogous to microbial clogging of injection wells (Hijnen and van der Kooij, 1992; Pavelic *et al.*, 2007). BDOC concentrations in all MS wells were below detection (<0.2 mg/L). The data suggests that the MS groundwater is bio-stabilized, ie. offers little opportunity for growth of microbial slimes.

Microbially induced clogging may also occur due to the precipitation of iron hydroxides (Forward, 1994) or aluminium hydroxides (James-Smith *et al.,* 2005). Iron precipitates can occur if iron-bearing minerals such as pyrite present within the aquifer are oxidized by oxygen and nitrate. Levels of iron in the ambient groundwater were low and were not indicative of a potential issue, however higher levels are present in the source water. The presence of low numbers of filamentous and non-filamentous iron bacteria in some of the MS wells lend support that field trials would need to consider this as a possible issue. Clogging due to iron precipititaiton is further discussed below.

Geochemical Assessment

The potential for geochemical reactions resulting from the injection of saline groundwater from the Monoman Sands (MS) aquifer into the deeper Renmark Group (RG) formation on the Chowilla Floodplain was assessed using the PHREEQC code (Parkhurst and Appelo, 1999).

The assessment was based on groundwater samples collected from the RG well (CH1) and four nearby MS monitoring wells (CH2-5) (**Table 1**). Unfortunately the cutting samples collected from the RG well were contaminated by trace amounts of drilling mud and could not be used to indicate the nature of the reactive mineral phases in the storage zone.

The PHREEQC modelling was used to:

- Determine the mineral phases in equilibrium with the ambient groundwater from the RG and the source water from the MS
- Examine the potential for mineral precipitation or gas formation due to:
    - reaction between the source water and the mineral phases present in the storage zone using the EQUILIBRIUM PHASES subroutine
    - mixing between the injectant and the groundwater using the MIX subroutine
    - the warmer temperature in the storage zone
    - aeration of the source water during storage prior to injection using equilibration with oxygen and carbon dioxide at atmospheric partial pressures in the GAS PHASE subroutine
- Evaluate the potential for clay swelling due to changes in the surface site composition through ion exchange using the EQUILIBRIUM subroutine.

Electron activity (pe), calculated from Eh measurements, was used to describe the redox state of all solutions, according to Eh=0.059pe (Appelo and Postma, 1999). Eh (mV SHE) of samples was estimated by adding the theoretical value for the Zobell Solution to the reported oxidation-reduction potential (ORP) value (mV) and assumes the YSI556 Multiparameter ORP probe was operating within the acceptable error range. The sensitivity of modelling results to redox state was considered and is discussed later in the report. It is recommended that future ORP measurements included a calibration check with measurement of a calibration (Zobell) solution to allow reporting against the standard hydrogen electrode (SHE).

Mineral phases

The background water quality for the RG (based on one sample) is near equilibrium with respect to calcite, quartz, illite and montmorillonite; oversaturated with respect to dolomite, kaolinite and K-mica and undersaturated in K-feldspar, albite, iron hydroxides ($Fe(OH)_3$) and aluminium hydroxides ($Al(OH)_3$) (**Table 2**). Therefore, calcite, quartz, illite and montmorillonite appear to be the major mineral phases influencing groundwater quality in the proposed storage zone. The salinity of the source water is controlled by evapotranspiration during recharge processes.

Regionally, the Warina Formation of the RG consists of medium to coarse quartz sand with minor carbonaceous fine silt, clay and minor pebble conglomerates (Rammers *et al.*, 2005). While pyrite is also reported regionally (Rammers *et al.*, 2005), it was not calculated as an equilibrium phase due to the absence of sulphide in the input data, and not observed in the borehole log for RG well (CH1). The borehole log confirms the presence of quartz and clay but does not report any carbonaceous material in the Warina Formation.

Most samples of the source water from the MS indicate near equilibrium with quartz and albite; oversaturation with respect to illite, montmorillonite, kaolinite, K-mica and K-feldspar, and undersaturation in calcite, dolomite, $Fe(OH)_3$ and $Al(OH)_3$. The water quality sample from CH5 has higher alkalinity and iron concentrations than the other observation wells (CH2-CH4) indicating dissolution of calcite and $Fe(OH)_3$.

To test the sensitivity to uncertainty in redox estimates, mineral saturation index (SI) calculations were undertaken under varying redox states for two of the end-member samples (CH1 and CH2); from pe of -1.5 to 1.5 mV for CH1 (RG) and 0 to 4 mV for CH2 (MS). While the saturation index for $Fe(OH)_3$ was affected, this is not considered a major influence on groundwater quality locally. $Fe(OH)_3$ precipitation becomes important if the MS is exposed to aeration prior to injection and is discussed later in this report.

Table 2. Mineral saturation indices calculated from groundwater samples from the RG (CH1) and the MS (CH2-5)

Mineral Phase	Saturation Index				
	Groundwater (CH1)	Injectant (CH2)	Injectant (CH3)	Injectant (CH4)	Injectant (CH5)
Calcite	0.24	-0.70	-0.54	-0.58	0.05
Dolomite	0.99	-0.68	-0.25	-0.43	0.88
Quartz	0.25	0.50	0.55	0.58	0.43
Illite	-0.03	2.00	2.71	2.45	1.92
Ca-montmorillonite	0.24	2.55	3.05	2.97	2.12
Kaolinite	2.02	4.06	4.41	4.32	3.62
K-mica	5.58	8.19	8.97	8.62	7.99
K-feldspar	-0.76	0.35	0.87	0.66	0.44
Albite	-0.99	-0.13	0.43	0.21	-0.01
$Fe(OH)_{3\,(a)}$	-4.12	-1.63	-1.89	-2.70	0.22
$Al(OH)_{3\,(a)}$	-2.27	-1.61	-1.48	-1.56	-1.74

Aeration of the source water

If the groundwater from the MS were to be held within a balancing storage prior to injection, equilibration with the air would occur. As a result, the source water becomes oxygen-rich and the concentration of soluble iron decreases while the tendency for precipitation of $Fe(OH)_3$ increases (**Table 3**). Once the soluble Fe(II) present in the groundwater from the Monoman Sands aquifer is oxidised to Fe(III) it will precipitate as insoluble amorphous iron hydroxide. This precipitate should be removed prior to injection to minimise aquifer clogging. Removal can be achieved through natural settling and in-line filters prior to injection. Aeration also leads to loss of carbon dioxide through degassing, which marginally reduces the potential for calcite dissolution. Whist calcite was detected in all aquifer samples in small amounts, this was in part due to contamination from drilling muds.

Mixing and temperature changes

Mixing between the two end-member waters (RG and MS) was examined for the groundwater samples from CH2 (MS) and CH1 (RG) (**Table 4**) and does not suggest any reaction processes that will cause clogging. The temperature increases as the portion of groundwater increases or residence times increase (due to reestablishment of the native geothermal gradient), which reduces the solubility of carbon dioxide slightly. The effect of temperature on the source water can be seen when the CH2 groundwater sample normally at 22°C is placed under the warmer temperature of the storage zone (36°C) and the aqueous carbon dioxde concentration is reduced (**Table 3**). However, the increased pressure during storage will more than compensate for the effect of temperature on solubility.

Table 3. Comparison of MS source water (CH2-CH5) before and after aeration and also with elevated temperatures typical in the storage zone (CH2)

	CH2		CH3		CH4		CH5		CH2
	unaerated	aerated	unaerated	aerated	unaerated	aerated	unaerated	aerated	unaerated @36°C
pH	6.3	6.4	6.5	6.5	6.4	6.5	6.8	6.8	6.3
pe (mV)	2.9	14.7	1.9	14.7	1.4	14.7	2.5	14.2	2.9
Ca (mg/L)	619	619	664	664	592	592	505	505	619
Fe(II) (mg/L)	1.4	0	3.0	0	2.1	0	9.9	0	1.4
$CO_{2(aq)}$ (mg/L)	121	99	80	68	114	96	95	85	103
TIC (mg/L)	93	87	88	84	101	95	161	155	88
$SI_{Calcite}$	-0.70	-0.63	-0.54	-0.49	-0.58	-0.51	0.05	0.08	-0.52
SI_{Quartz}	0.50	0.50	0.55	0.55	0.58	0.58	0.43	0.43	0.30
$SI_{Fe(OH)3\ (a)}$	-1.63	2.51	-1.89	3.09	-2.70	2.82	0.22	3.60	-1.31

Table 4. Mixing between the MS source water (CH2) and groundwater (CH1)

	100% CH2 0% CH1	75% CH2 25% CH1	50% CH2 50% CH1	25% CH2 75% CH1	0% CH2 100% CH1
Temp (°C)	22	25	28	32	36
pH	6.3	6.4	6.5	6.6	6.8
pe (mV)	2.9	2.4	1.8	1.1	-0.9
Ca (mg/L)	619	599	578	558	537
Fe(II) (mg/L)	1.4	1.2	0.87	0.57	0.27
$CO_{2(aq)}$ (mg/L)	121	104	87	71	51
TIC (mg/L)	93	94	96	97	99
$SI_{Calcite}$	-0.70	-0.50	-0.29	-0.06	0.24
SI_{Quartz}	0.50	0.44	0.37	0.31	0.24
$SI_{Fe(OH)3\ (a)}$	-1.63	-1.83	-2.07	-2.44	-4.12

Reaction with minerals in the storage zone

As the MS source water is undersaturated in calcite, injection is expected to lead to dissolution of any calcite present. Silicate weathering is much slower and clay minerals are more likely to influence water quality through ion exchange than mineral dissolution and precipitation (Appelo and Postma, 1999). Calcite dissolution is not considered to present a risk to this project as it causes minimal increases to calcium concentrations (**Table 5**), can act to alleviate clogging and would not be likely to lead to stability concerns given calcite is a negligible or minor constituent of the target aquifer.

Injection of the oxygen-rich source water into the deeper Renmark Formation will also oxidise any Fe(II) present, either in the groundwater or within reduced minerals such as pyrite. The end result will be the formation of iron hydroxide flocs near the point of injection and aquifer clogging. There is approximately 0.3 mg/L reduced iron in the RG groundwater available for reaction with oxygen. However if pyrite is present there is a far greater pool of reduced iron in the sediments, and reaction of aerated MS source water with pyrite releases an average of approximately 18 mg/L iron (**Table 5**), which will precipitate under oxic conditions.

Pyrite oxidation can also release trace species such as arsenic into the groundwater, which would be of concern if the groundwater were to be recovered as a drinking water supply.

Similar geochemical evaluations have been undertaken for ASR sites at Warruwi in the Northern Territory for injection of shallow groundwater into a deeper sandstone aquifer (Pavelic *et al.*, 2001), and Rossdale in Melbourne for injection of urban stormwater into a fractured rock aquifer (Pavelic *et al.*, 2006). Both sites had iron in the ambient groundwater from 0.2-0.8 mg/L (*c.f.* 0.27 mg/L in RG), pyrite confirmed within the storage zone and identified iron oxide precipitation as the predominant clogging concern.

Table 5. Calcium and iron concentrations when MS groundwater (unaerated and aerated) is allowed to reach equilibrium with calcite and pyrite

mg/L	CH2		CH3		CH4		CH5	
	unaerated	aerated	unaerated	aerated	unaerated	aerated	unaerated	aerated
Ca	527	532	532	539	497	504	393	399
Fe(II) †	1.4	19	3.1	20	2.1	20	10.6	28

† Fe(II) expected to precipitate as Fe(III) under oxic conditions

Ion exchange

Clay swelling occurs when the diffuse double layer around the clay particles extends and can be caused by increasing the proportion of monovalent cations (eg Na^+) on the solid surface or by freshening the storage zone (Appelo and Postma, 1999), causing a deterioration in the hydraulic conductivity of the aquifer.

In this project, freshening is not expected as the MS source water (34-45 g/L TDS) is more saline than the groundwater in the RG (22 g/L TDS). The more saline MS injectant also has a higher sodium concentration than the RG groundwater.

In the absence of reliable measured data, the exchange site composition was estimated by assuming equilibrium with the groundwater (CH1). This indicated the exchange sites were dominated by sodium (49% based on charge), calcium (24% of charge) and magnesium (26% of charge), with a minor contribution from potassium. When this exchange composition reacts with the more saline MS source water, sodium from the source water displaces calcium from the exchange sites resulting in more calcium and less sodium in the MS water in storage (**Table 6**), which also alters the calcite saturation index slightly from -0.70 to -0.42.

Table 6. Cation concentrations in MS source water (CH2) before and after cation exchange

mg/L	Initial	After exchange
Na	11644	10789
Ca	619	1275
Mg	1496	1567
K	167	115

Following exchange there is a slight increase in sodium on the solid phase (4%) but this is not expected to lead to a clogging issue, especially if the content of clay minerals is low.

Management of Clogging

Upper limits on the levels of total suspended solids and turbidity in the MS injectant to minimize clogging risks are difficult to specify due to the dependence of physical properties of selected target aquifers. Whilst the hydraulic conductivity of the RG aquifer has yet to be determined by aquifer pump testing, preliminary estimates from the particle size distribution of the aquifer are suggestive high values, although it is recognised that the sampling method was preferentially biased towards the collection of coarser particles. Given the uncertainty in the actual particle size distribution in the aquifer, TSS values <10 mg/L should enable sustained operations that eliminates the need for an excessive degree of backwashing (Pérez-Paricio and Carrera, 1999).

Options for minimizing the risk of excessive clogging include:

- pre-treatment of the MS water to reduce particulate levels prior to injection
- implementing periodic redevelopment of the injection well when head buildup and/or injection rates reach unacceptable levels

Techniques to prevent clogging and to redevelop clogged wells are described in detail by Olsthoorn (1982), Driscoll, (1986); Cullimore (1993) and Pérez-Paricio and Carrera, (1999) and Segalen *et al,* (2005). Briefly, methods include hydraulic methods, such as pumping, surging and juttering; chemical methods such as chemical oxidants, such as adding chlorine and hydrogen peroxide, to reduce bioclogging and inactivate bacterial growth, and polyphosphates to reduce physical clogging by reducing the stability of retained particles, which enhances the efficiency of detachment.

The rate of clogging of injection and ASR wells in unconsolidated formations is highly dependent on the choice of drilling technique, the quality of the drilling, well design and completion, as well as redevelopment methods. For example, it is known that wells drilled with cable tool significantly outperform reverse circulation rotary; using biodegradable mud gives rise to less clogging than when bentonite-based mud is used; residual mud on or in the vicinity of the borehole wall severely limits recharge capacity; and completion with wire wrapped screens and natural gravel pack gives significantly higher performance than wells with slotted casing and emplaced gravel pack (Segalen *et al,* 2005).

If clogging is allowed to proceed then clogging layers can become compacted which limits the efficiency of the redevelopment. As a general 'rule of thumb' redevelopment should be initiated before a 20% reduction in injection rate is observed.

CONCLUSIONS

The untreated MS groundwater contains sufficient particulate matter to lead to some degree of physical clogging. Pre-treatment of source water using settling and/or filtration methods should be adequate. Note that during sustained pumping operations from MS wells it is likely that particulate levels would diverge from those measured during these investigations. Variations in the physical properties of the aquifer, the design and method of completion of the monitoring wells, the rate of pumping would affect particulate concentrations in the source water.

TSS values in the source water for injection of <10 mg/L should enable sustained operations that eliminates the need for an excessive degree of backwashing.

The nutrient status of the MS water is sufficiently low as to suggest a minimal risk of clogging from biofilm production.

Geochemical modelling shows that injection of cooler and more saline MS groundwater into the warmer RG aquifer will result in some degassing of carbon dioxide at higher temperature during injection, dissolution of calcite present in the storage zone and some ion exchange. The water quality changes resulting from calcite dissolution and ion exchange are not likely to inhibit injection rates.

Clay swelling may occur when sodium displaces calcium on exchange sites but this should not be a significant problem if clay minerals are a minor constituent of the aquifer. Similarly calcite dissolution would not be expected to lead to any instability concerns if present in small amounts. Due to the collection of cuttings rather than intact core samples, there is some uncertainty on the physico-chemical properties of the aquifer, and hence on the results from the geochemical modelling.

Effort should be taken to minimise degassing during injection as gas binding could result in clogging.

If the MS source water is to be retained within balancing/settling tanks prior to injection then care should be taken to prevent, or at least limit, exposure to atmospheric oxygen. Oxygenation would convert soluble Fe(II) in the source water to particulate Fe(III), which will need to be removed prior to injection by appropriate pre-treatment. In addition, adding oxygen to the storage zone will oxidise any Fe(II) present in the near well zone, leading to well clogging. This is expected to be manageable by regular backwashing of the injection well.

Any observed clogging should not be allowed to become too advanced before initiating well redevelopment.

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APPENDIX A. MINERALOGICAL AND CHEMICAL DATA FOR CUTTING SAMPLES COLLECTED FROM THE RG INJECTION WELL (CH1)

Table A.1 Physico-chemistry data for the 6 sub-samples from well CH1 (Unit No. 7030-809), 1 sample of fine fraction from well development and 1 sample of drilling mud.

Sample #	Corrected Depth [A]	Depth marked on samples [B]	Percent <0.09mm[E]	EC	pH	pH	Cl	TC	TOC	CO_3 as $CaCO_3$	Exch. Cations					CEC
				(1:5 soil:water)		(0.01M $CaCl_2$)					Ca	Mg	Na	K	Tot.	(NH_4)
	m	m		dS/m			mg/kg	%	%	%	cmol(+)/kg					cmol(+)/kg
1	406	410	0.7	0.83	8.9	8.1	591	1.7	1.6	1.3	1.7	1.7	2.4	0.24	6.0	6.2
2	418	422	0.1	0.58	9.6	8.6	336	0.76	0.5	2.4	1.0	0.75	1.5	0.25	3.5	2.4
3	422	426	0.3	0.71	9.6	8.5	430	1.1	0.8	2.2	1.2	0.85	1.6	0.29	4.0	2.9
4	432	436	1.5	0.60	9.6	8.6	350	0.65	0.4	2.1	1.0	0.62	1.1	0.21	2.9	1.9
5	444	448	3.3	0.80	9.3	8.3	440	2.2	1.9	2.2	2.2	1.9	3.0	0.45	7.5	6.5
6	456	460	2.5	0.60	9.3	8.5	399	1.0	0.9	0.9	1.8	1.3	1.8	0.27	5.1	4.6
7	Dev. [C]	NA	-	1.52	9.2	8.7	2040	0.38	0.2	1.6	0.9	0.70	0.94	0.14	2.7	2.1
8	Drill-Mud. [D]	NA	-	5.41	9.2	8.4	4810	3.8	1.5	19.9	4.5	0.69	29	1.1	35	26

[A] 4 m difference between the geophysical logs and lithologs (geophysics is 4 m less than the litholog)
[B] as marked on sample bags and from litholog (uncorrected for lag difference)
[C] silt sample collected during well development 31/1/07
[D] drilling mud
[E] from PSD data provided by SA DWLBC (P. Magarey, pers. comm.)

Table A.2 Elemental data for the 6 sub-samples from well CH1 (Unit No. 7030-809), 1 sample of fine fraction from well development and 1 sample of drilling mud.

Sample #	Al	As	B	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	P	Pb	S	Se	Zn
	(mg/kg)																		
1	18300	<20	<20	5140	<20	<20	24	18	5170	3700	1680	80	<20	1090	70	<20	3150	<20	27
2	4150	<20	<20	9020	<20	<20	<20	21	3200	586	1040	76	<20	865	34	<20	3600	<20	7
3	6240	<20	<20	11400	<20	<20	<20	25	4500	845	1330	100	<20	1160	46	<20	4600	<20	10
4	2940	<20	<20	6550	<20	<20	<20	15	2400	423	748	53	<20	641	27	<20	2650	<20	8
5	13800	<20	<20	14800	<20	<20	24	34	6190	1590	2050	142	<20	1800	70	<20	5870	<20	30
6	13400	<20	<20	3960	<20	<20	<20	15	2460	1360	808	55	<20	729	44	<20	2340	<20	14
7	3190	<20	<20	8040	<20	<20	<20	22	4890	655	1260	106	<20	1560	64	<20	3680	<20	61
8	29000	<20	34	64300	<20	<20	30	127	21900	4240	7820	537	<20	10900	409	<20	6400	<20	47

Table A.3 Mineralogy data for the 6 sub-samples from well CH1 (Unit No. 7030-809), 1 sample of fine fraction from well development and 1 sample of drilling mud.

Sample #	Quartz	Barite	Calcite	Kaolin	Mica	Albite	Orthoclase	Smectite	Percentage analysed ж (<200μm)
1	68	1	1	16	13	-	1	-	17%
2	55	7	11	8	6	2	2	8	4%
3	36	9	18	11	10	2	4	9	3%
4	41	9	17	9	7	2	4	10	3%
5	53	5	8	15	9	2	2	5	7%
6	59	2	2	26	10	<1	<1	-	16%
7	70	4	5	6	5	3	7	-	15%
8	24	10	16	11	11	4	7	17	100%

ж The quantitative analyses are reported on the <200μm fractions, with the exception of sample 8 which was analysed on the whole sample.

APPENDIX B. PARTICLE SIZE ANALYSIS OF MS GROUNDWATER

Analysis Report

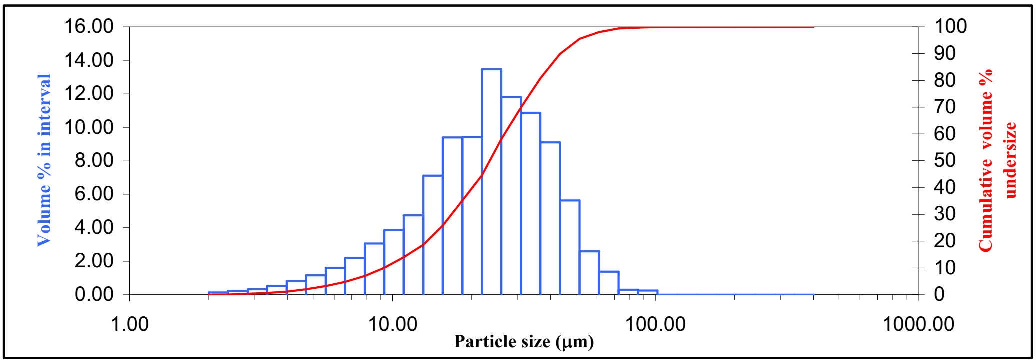
CSIRO

Division of Minerals
Particle Analysis Service

Client: Dept. Water, Land & Biodiversity Conservation
Sample: 1 Groundwater Sample
Batch No: R058829
PAS ID No: P47639

Analysis: Particle Counting by Hiac/Royco light extinction
Dispersant: Water
Additives: None
Sonication: None
Result units: Volume/Mass
Date: 31/08/07

Density: 2.65 g/cc (assumed value)
Calc. TSS : 3.64E+01 (mg/L, assuming spherical particles of homogeneous material)
Actual TSS: mg/L
Mass recovery: #DIV/0!



Min. size (µm)	Max. size (µm)	Volume % in interval	Min. size (µm)	Max. size (µm)	Volume % in interval	Min. size (µm)	Max. size (µm)	Volume % in interval
2.00	2.37	0.15	13.11	15.55	7.12	85.91	101.92	0.25
2.37	2.82	0.22	15.55	18.45	9.40	101.92	120.91	0.00
2.82	3.34	0.33	18.45	21.89	9.41	120.91	143.45	0.00
3.34	3.96	0.53	21.89	25.97	13.46	143.45	170.19	0.00
3.96	4.70	0.81	25.97	30.81	11.81	170.19	201.91	0.00
4.70	5.58	1.15	30.81	36.55	10.87	201.91	239.54	0.00
5.58	6.62	1.61	36.55	43.36	9.10	239.54	284.19	0.00
6.62	7.85	2.21	43.36	51.44	5.64	284.19	337.16	0.00
7.85	9.31	3.07	51.44	61.03	2.60	337.16	400.00	0.00
9.31	11.05	3.87	61.03	72.41	1.38			
11.05	13.11	4.74	72.41	85.91	0.30			

NOTE: This data is a calculated distribution based on the count distribution and the above assumptions.

Figure B.1 Particle size distribution of MS groundwater from well 7030-577.

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11. ASSESSMENT OF POTENTIAL INCREASE IN SEISMIC ACTIVITY RISK AND HAZARD, ASSOCIATED WITH INJECTION OF SALINE WATER INTO DEEP AQUIFERS AT CHOWILLA, SOUTH AUSTRALIA

Assessment of Potential Increase in Seismic Activity

Risk(s) and Hazard(s)

Associated with Injection of

Saline Water into Deep Aquifers at Chowilla, South Australia

seismology research centre
a division of
environmental systems and services

es&s
environmental systems & services

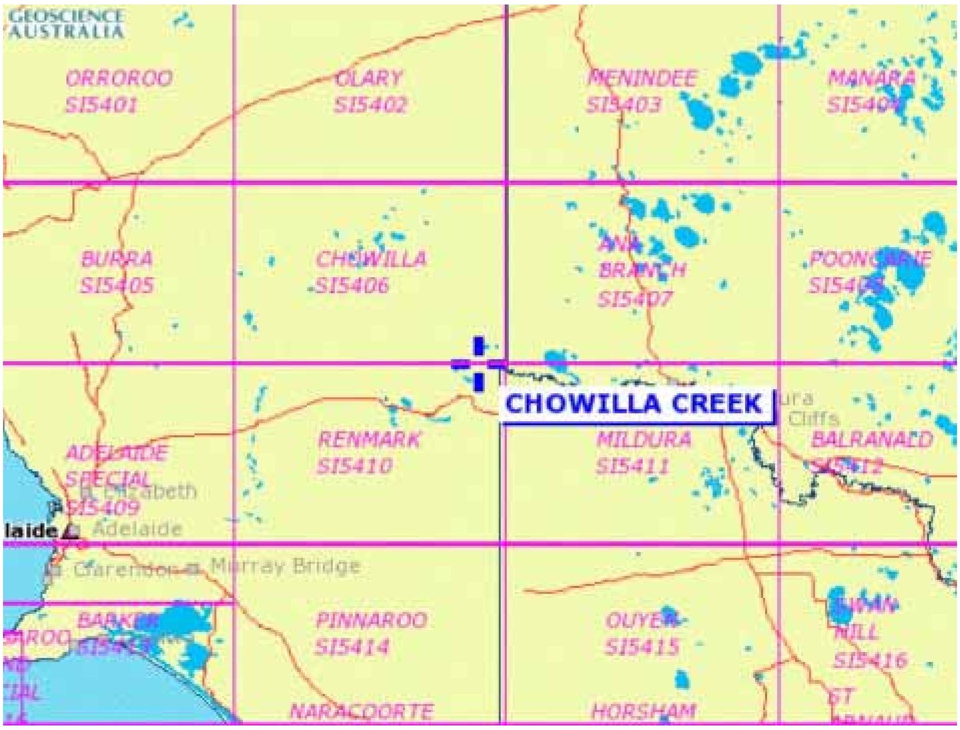
CONTENTS

Introduction

The Australian Seismological Centre's involvement in the project on Riverland seismicity risk was initiated in a phone conversation and follow-up email between Kwadwo Osei-Bonsu from the South Australian Department of Water, Land and Biodiversity Conservation and ASC on 17 January 2007.

The project was outlined as follows:

> The Department of Water, Land and Biodiversity Conservation (DWLBC), Adelaide, South Australia, wants to dispose saline groundwater from Salt Interception Scheme in Chowilla into deeper aquifer. The aquifer that has been considered is the basal Warina Sand member of the Renmark Group and is the oldest/lowest tertiary aged strata of the Murray basin. Major faults have been inferred in the region based on seismic surveys - the 2 closest would be the Chowilla Fault (perhaps less than a few km away) and the Hamley Fault (about 30 km away) - both these faults are not considered to extend to the current day surface.
>
> The project is to assess the risk(s) of induced seismicity associated with deep-well (about 600 m deep) injection in Chowilla, South Australia.



Location -34.01º 140.86º

Executive summary

• Tectonic earthquakes in Australia occur in an intraplate environment where seismic hazard and risk are low compared with interplate regions.

• The natural seismicity in the vicinity of Chowilla SA is low within this intraplate environment.

• As many as 7 earthquakes are known to have produced surface faulting in Australia in the last 50 years but in general, earthquakes in Australia and other intraplate areas such as Britain show no correlation with mapped faults so the proximity or otherwise of ancient faults should have no effect on the computed hazard or risk.

• Induced seismicity may occur when fluids are pumped deep underground depending on many factors such as the state of stress in the crust, the pumping pressure and volume, the depth of pumping and the permeability of the rock at the fluid injection depth. At Chowilla SA, none of these factors is critical.

• Australian and overseas experience of earthquakes induced by fluid injection indicates that they tend to be of small magnitude (able to be felt but not large enough to cause structural damage) and may be turned off and on again by controlling the fluid flow.

• Induced seismicity caused by fluid injection into rock has occurred in deep boreholes, at least several kilometres deep. The Chowilla injection will occur at a depth of only 600m into saturated confined sands above the basement interface.

• The Hamley Fault is too distant from the injection well to be considered a potential problem and unless fluid is pumped directly into the Chowilla Fault it too is very unlikely to be reactivated given that the brine will be pumped into the Warina Sand member at relatively shallow depth, the sand both porous and permeable.

• A 6-station monitoring network of seismographs and accelerographs should be installed to monitor any seismic activity in real time associated with fluid injection.

• Monitoring should begin now so that some record of pre-injection seismic activity can be made.

• A strategic operational plan should be set up so that the fluid injection pressure and volume can be quickly decreased or stopped should seismic activity be recorded, and resumed after the fluid pressure has dispersed.

Induced seismicity – what is it?

Induced seismicity refers to earthquakes that are caused by human activity that has changed the stresses and strains in the Earth's crust. A general conclusion drawn from numerous studies is that induced seismicity can be quantified in terms of at least one of the following mechanisms:

stress change
pore pressure change
volume change
application or removal of a load

The phenomenon of induced seismicity has been known for about 100 years and the first International Conference on Induced Seismicity was held in September 1975 at Banff, Alberta, Canada.

Examples of induced seismicity include:

Reservoir filling

An example of the application of a load is the weight of water in a reservoir that alters the pressure in the rock below, which can trigger earthquakes. Alternatively, water may also slowly percolate down to a nearby fault causing a change of stress that is sufficient to trigger earthquakes. Reservoir-induced seismic events can be relatively large compared to other forms of induced seismicity (Simpson, 1976). Earthquakes associated with the filling of Talbingo Dam in NSW or the Thompson Dam in Victoria are classic examples (Gibson and Wesson, 1979). The earthquakes under Thompson Dam ranged from near surface to a depth of 10 km, the largest event magnitude 5. The 1959 Eucumbene NSW earthquake (magnitude 5.2) has been attributed by some seismologists to the impounding of lake Eucumbene.

Mining

Mining produces voids that alter the effective stress in the rock. These voids may collapse or local faults move producing minor earthquakes. Many mining induced earthquakes have been observed and recorded in Western Australia at Kalgoorlie and in Tasmania at Beaconsfield, with events as large as magnitude 4.5.

Extraction of fossil fuel and groundwater

Subsidence caused by fossil fuel and groundwater extraction can generate minor earthquakes. Many seismic events in the Newcastle NSW area are attributed to the collapse of the hanging wall left by longwall coal mining. Such events have not exceed magnitude 3.5, though some researchers have recently claimed (incorrectly I believe) that the 1989 Newcastle earthquake, magnitude 5.6, was a result of mining in the area.

Fluid injection

Both accidental and deliberate seismicity has been induced by injection of fluid (mostly water) into the crust. Changes in stress caused by the increased pore pressure is considered the cause of the seismicity.

The pressure is normally just the weight of the water column per unit area at any particular location and depth. The deeper in the earth, the higher the natural pore pressure. If injection is into a fault or fracture, the fault will slip (i.e., an earthquake will occur) when the forces acting to cause slip are greater than the forces keeping the two sides of the fault together. The forces keeping them together are friction, the inherent strength of the rock, and the component of the forces acting perpendicular to the fault surface. An increase in pore pressure, such as that caused by nearby injection of fluid, facilitates slip by reducing friction and so reducing the net effect of the forces acting perpendicular to the direction of slip.

In a very porous, permeable material, the injected fluid will disperse easily, and any pressure buildup will be small. This appears to be a good description of the Warina sand member. In other cases, where the rock is less porous and less permeable, a substantial amount of pressure may be required to inject fluids, causing a large pore-pressure buildup.

The size, rate, and manner of seismicity is controlled by the rate and amount of fluid injected in the subsurface, the orientation of the stress field relative to the pore pressure increase, how extensive the local fault system is, and, last (but not least), the deviatoric stress field in the subsurface, i.e., how much excess stress there is available to cause an earthquake (Cornet et al., 1992, Cornet and Scotti, 1992, Cornet and Julian, 1993, Cornet and Jianmin, 1995, Brune and Thatcher, 2002).

At Innaminka SA in 2003, thousands of microearthquakes resulted from the deliberate hydro-fracture of rock from an injection well that bottomed at a depth of more than 4,400 m (750 m into granite below the sediments of the Cooper Basin). The observed earthquakes were up to magnitude 3.5 (14 November 2003) and extended on a near horizontal plane out to about 7 km from the injection well. Asanuma et al. (2005) recorded 32,000 events and accurately located more than 11,000 of these on site during the stimulations thanks to a dedicated monitoring network of at least 6 stations, two of which were at depth in boreholes ie not all of them were at the surface.

The first and best known case of accidentally induced seismicity was that associated with the Rocky Mountain Arsenal fluid disposal operations at Denver, Colorado USA (many events over a 10 year period, the largest with a magnitude of 5.3). Injection depth was 3.67 km and rates were up to 0.8 million litres per day between 1962 and 1965; the seismicity increased as the rate of fluid injection increased. The cause is attributed to a significant increase in the pore pressure at the injection depth, which reduced the *effective strength* of the rocks (Brune and Thatcher, 2002).

Geophysicists at the U.S. Geological Survey (Rayleigh and others, 1974) demonstrated the feasibility of earthquake control in an oil well at Rangeley Colorado soon after. Variations in seismicity were produced by controlled variations in the fluid pressure *in a seismically active zone*. Precise earthquake locations revealed that the earthquakes clustered about a fault trending through a zone of high pore pressure produced by secondary recovery operations. Laboratory measurements of the frictional properties of the reservoir rocks and an in situ stress measurement made near the earthquake zone were used to predict the fluid pressure required to trigger earthquakes on pre-existing fractures. Fluid pressure was controlled by alternately injecting and recovering water from wells that penetrated the seismic zone. Fluid pressure was monitored in observation wells, and a computer model of the reservoir was used to infer the fluid pressure distributions in the vicinity of the injection wells. The results of this experiment confirm the predicted effect of fluid pressure on earthquake activity and indicate that earthquakes can be controlled wherever we can control the fluid pressure in a fault zone (the critical pore fluid pressure was 1.1×10^4 pascals in this case).

The U.S. Bureau of Reclamation's Paradox Valley Unit (PVU) extracts aquifer brine from nine shallow wells along the Dolores River, Paradox Valley, in southwestern Colorado and, after treating, high pressure injects the brine 4.3–4.8 km below the surface. PVU injects at rates between 800 and 1300 L/min. Since 1991, PVU has emplaced over 4 x 106 m^3 of fluid and induced more than 4000 surface-recorded seismic events. The events are recorded on the local 15-station Paradox Valley Seismic Network. The induced seismicity at Paradox separates into two distinct source zones: a principle zone (>95% of the events) asymmetrically surrounding the injection well to a maximum radial distance of 3 km, and a secondary, ellipsoidal zone, 2.5 km long and centered 8 km northwest of the injection well. The expansion of these zones has stabilized since mid-1999, about three years after the onset of continuous injection. Within the principal zone, hypocenters align in distinct linear patterns, showing at-depth stratigraphy and the local Wray Mesa fracture and fault system.

The primary faults of the Wray Mesa system are aseismic, striking subparallel to the inferred maximum principal stress direction, with one or more faults, probably, acting as fluid conduits to the secondary seismic zone. Individual seismic events in both zones do not discernibly correlate with short-term injection parameters; however, a 0.5 km^2 region immediately northwest of the injection well responds to long-term, large-scale changes in injection rate and the surpassing of a threshold injection pressure. Focal mechanisms of the induced events are consistent with simple double-couple, strike-slip moments and sub-horizontal extension to the northeast. In addition, the fault planes are consistent with principal stress directions determined from borehole breakouts. More than 99.9% of the PVU seismicity is below human detection (M 2.5). However, approximately 15 events have been felt locally, with the largest being a magnitude M 4.3. Because of the M 4.3 and two earlier-felt M 3.5 events and injection economics, PVU changed injection strategies three times since 1996. These changes reduced seismicity from 1100 events/year to as low as 60 events/year

A 60 day long-term fluid injection experiment was performed at the 9.1 km deep Kontinentale Tiefbohrung (KTB), borehole in Germany. About 4000 tons of water were injected into the well head to induce seismicity near the open-hole section at 9 km depth. Due to several leaks in the borehole casing, seismicity occurred at distinct depth levels between 3 km and 9 km depth. Two events occurred at 10 km and 15 km depth. The combination of a temporary, 40-element, 3-component surface network of seismometers and a 3-component downhole sonde at 3.8 km depth in the nearby pilot hole enabled absolute hypocenter locations using a velocity model that was calibrated using several downhole shots at depths of 5.4 km and 8.5 km. Out of a total of 2799 induced events, hypocenter locations were obtained for 237 events having good signal to noise ratio (SNR) at surface stations. The spatio-temporal distribution of hypocenters at each depth level exhibits complex structures extending several hundred meters from the injection points with strong spatial and temporal clustering. Regions which were seismically active at a certain time often show reduced or no activity at later times indicating local shear stress relaxation.

The limitation of hypocentral depths to 9.1 km for events near the borehole suggests changes of rheological properties of the upper crust and thus supports a transition from the regime of brittle failure to ductile deformation at this depth. Large fluid level changes observed in the nearby pilot hole demonstrate that fluid flow occurs over distances >1.5 km and that major flow zones are not mapped by the induced seismicity. This might also explain the occurrence of isolated events at greater distances and depths. Brittle failure at depths exceeding 10 km indicates the existence of critically stressed fractures even at temperature greater than 300°C.

These examples of fluid injection causing earthquakes are not similar to the Chowilla situation. In all cases I have mentioned, injection has been into relatively hard rock at depths of at least 3 km.

Earthquakes Worldwide

In interplate environments, it is common belief that large or damaging earthquakes tend to occur on developed or active fault systems. In other words, large earthquakes rarely occur where no fault exists, and the small ones that do occur do not last long enough to release substantial energy. Also, it is presumed that it is difficult to create a large, new fault, because there is usually a pre-existing fault that will slip first. For example, all significant historical activity above magnitude 5.0 that has been observed in California has occurred on pre-existing faults (bulletins of the Seismographic Stations, University of California).

The size of the fault (in addition to the forces available) and the strength of the rock determine how large an event may potentially be. It has been shown that in almost all cases, large earthquakes (magnitude 6 and above) start at depths of at least 5 to 10 km (Brune and Thatcher, 2002). It is presumed that only at depth can sufficient energy be stored to provide an adequate amount of force to move the large volumes of rock required to create a large earthquake.

Earthquakes in Australia

The Australian continent is entirely within the Australian Tectonic Plate, earthquakes in Australia are intraplate. There are no major through-going active faults like the San Andreas fault in California, the Alpine Fault in New Zealand or the Philippine Fault in the Philippines. However if one could image the crust in sufficient detail, we would find fractures, joints and faults anywhere.

The level of seismicity within intraplate Australia is at least an order of magnitude lower than that in countries straddling a plate margin and most earthquakes do not seem to occur on mapped faults here, even in areas with dense deployments of seismographs (Love, Cummins and Balfour, 2006). The 1986 Marryat Creek earthquake did seem to rupture a pre-existing fault but the location uncertainties of South Australia's other large earthquakes in 1897, 1902 and 1954 are too large to definitely associate them with known mapped faults. The largest fault in Australia, WA's Darling Fault, seems to be inactive even though large earthquakes like the 1968 Meckering earthquake occurred nearby on no pre-existing fault.

That said, the seismicity in Australia is not distributed evenly throughout Australia. Some areas are known to have higher hazard than others. This is reflected in earthquake hazard maps of Australia such as that published by GSHAP for the International Decade for Natural Disaster Reduction in the 1990s. This map reflects the hazard map in the current Australian Loading Code AS1170.4-1993.

Earthquakes in South Australia

Earthquakes have been observed and monitored ever since Adelaide was first settled by Europeans in 1836.

The first seismograph was installed at the Adelaide Astronomical Observatory in 1909, an insensitive Milne recorder of gain 6. No records from this era have survived. A more sensitive Milne-Shaw seismograph was installed in 1924 and operated until around 1954. Some records of this period remain though the station was mainly useful for detecting major earthquakes at large distance. In 1958 Dr David Sutton of the University of Adelaide installed a 3-component short period station in Adelaide to monitor local and regional earthquakes. By 1964 a 3-station network was used for locating earthquakes in the state, and the number of stations grew to 12 by 1978. Following the death of David Sutton the network was maintained but not expanded by the University. Operations were moved to Flinders University in 1985. In 1986 operations were again moved to the Department of Mines and Energy. Further expansion began in 1988 building up to the present 22 stations. The Department of Mines and Energy became part of Primary Industries and Resources South Australia in 1998. The nearest seismograph to the Chowilla site is that at Stevens Creek near Broken Hill NSW. The site is operated by Geoscience Australia.

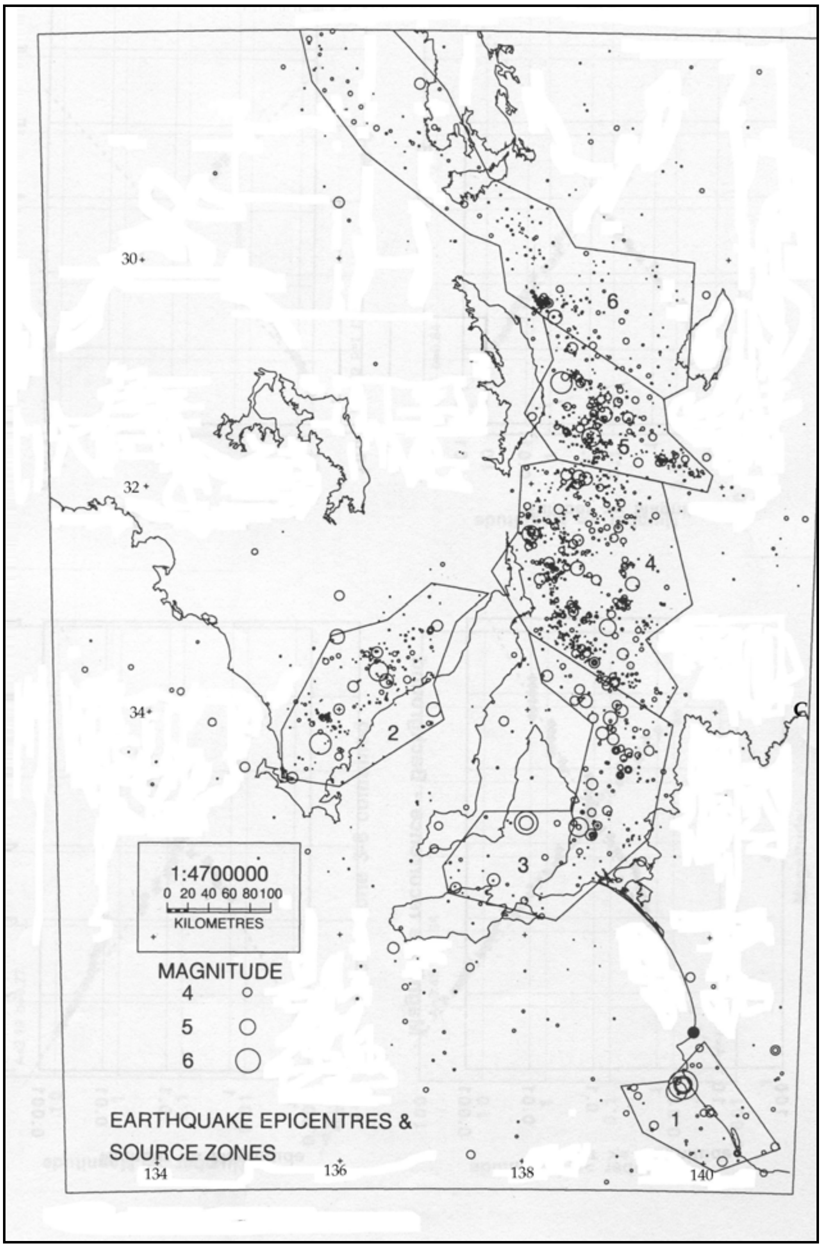


Figure 1 Earthquake epicentres and source zones of South Australia. The Chowilla site near the Murray R and state border is marked 'C' (from Love, 1996).

The largest known earthquakes in South Australia

1897 - Approximate magnitude ML6.5. Largest known earthquake near Kingston and Beachport, about 250 km south of Adelaide. Severe damage and liquefaction in the epicentral area. Minor damage in Adelaide, Intensity III-IV at Chowilla.

1902 - Approximate magnitude ML6.0. Location uncertain but probably in the sea about 50 to 100km west of Adelaide. Caused minor damage in Adelaide and two deaths there from shock, Intensity III–IV at Chowilla.

1954 – Magnitude about 5.5. Adelaide damaged with intensities MM 5 to 6 in the central city area and a small area of MM 8 in the outer southern suburbs. This earthquake caused about $100M damage, the worst damage in an Australian city until the 1989 Newcastle earthquake. Intensity III-IV at Chowilla

1986 - Magnitude Ms 5.8 in the far north of the state caused a surface rupture more than 13km long. Maximum displacement was about 0.6m vertical and 0.8m horizontal. No damage was done. Not felt at Chowilla.

1997 - Magnitude ML5.1, the earthquake occurred about 130km north of Adelaide. Damage was minor. Intensity III-IV at Chowilla.

Focal mechanisms and principal stress directions. Very few focal mechanisms have been calculated for South Australian earthquakes and most of them are only poorly constrained. The author (McCue, 1975) obtained mechanisms of three small earthquakes in the Flinders Ranges, two thrusts, one strike-slip, which indicated a NE to SW principal stress direction. In recent times composite mechanisms have been calculated for one swarm and one aftershock sequence. Love and others (2006) selected 95 earthquakes and averaged the computed causative principal stress directions and their strike and dip:

Table 1 Implied stress directions in the Flinders Ranges, South Australia

Stress axis	strike	plunge
σ_1	101	18
σ_2	344	55
σ_3	vertical	

This would imply that the Flinders Ranges at least were under ESE to WNW compression resulting in thrust faulting. However the mechanism for the magnitude 4 Hawker earthquake of 22 November 2003 reported by Cummins and others (2004) is that of a normal fault with σ_3 near horizontal and oriented NE to SW. Obviously the tectonics of this region are not simple, the stress directions not uniform throughout, but neither are they consistent between observers. The focal depth range is significant for the injection project, most of the earthquakes rupturing deeper in the crust than the proposed depth of injection.

Detection capability. Earthquake monitoring in South Australia is done by PIRSA (previously MESA and Flinders and Adelaide Universities). Since about 1977 the detection capability of the network has not varied significantly. Between 170 and 330 events per year are located in the state. The epicentres are computed using a simple one layer model. As the average spacing of stations is about 100 km, focal depths would not be expected to be highly accurate, however various tests have suggested that they are better than expected.

In regions where dense networks of stations are deployed the focal depths are better constrained and in the Flinders Ranges region they ranged from near surface to 24 km in the middle crust (Love and others, 2006), only 20% of them in the top 5 km.

Earthquake hazard in the vicinity of Chowilla, SA

Only three natural earthquakes have been recorded within 100 km of the site at Chowilla (see Table 2 from the Geoscience Australia earthquake database). The strongest shaking at Chowilla was rated MM III-IV which is well below the damage threshold, not felt by all residents. On the basis of the location and frequency of earthquakes of different magnitudes in South Australia several studies have been made of the earthquake hazard in the state. One of the first was done by the author in 1975 which became part of the hazard map in the first Australian Earthquake code (AS2121 – 1979). In this the Chowilla site is in zone zero due to the lack of recorded seismicity. Love and colleagues have done a number of studies of earthquake hazard in South Australia (Greenhalgh and McDougall, 1990; Love, 1996) which have been incorporated into the latest draft earthquake Loading Code.

There were several intermediate hazard analyses including that for AS1170.4 – 1993) in which the zone zero classification was removed. The hazard in the vicinity of Chowilla is rated as between 0.04 and 0.05 (acceleration coefficient with a 10% probability of exceedence in 50 years) compared with Adelaide about 0.1. Earthquake risk in the Chowilla area is contributed by infrequent large distant earthquakes to the west in the lower Flinders Ranges (Figure 2 from Love, 1996).

Table 2 Earthquakes located near Chowilla SA (magnitude on ML scale).

DATE	TIME UTC	LAT	LON	Depth km	ML	Dist km	COMMENTS
19780728	090826.3	-33.44	139.78	2	2.0	118	50 km N Morgan
19781210	193640.1	-33.58	140.07	27	1.1	88	50 km NNE Morgan
19791023	163314.7	-34.31	140.31	17	2.3	60	W Barmera
19871104	233741.0	-34.67	139.79	4	1.3	122	50 km NE Murray Bridge
19910205	233547.9	-33.09	140.29	15	1.8	116	100 km NNE Morgan
19921108	154547.9	-34.73	140.14	14	2.0	104	Mercunda SA
19991231	084838.5	-33.18	139.90	0	3.0	128	Near Peterborough SA
20001023	213852.1	-34.55	141.78	5	3.6	103	Near Mildura Vic. Felt in Merrinee
20020613	065846.2	-33.65	139.97	3	2.3	92	Near Burra SA

In almost all cases, large earthquakes (magnitude 6 and above) start at depths of at least 5 to 10 km (Brune and Thatcher, 2002) because it is only at depth that sufficient energy can be stored to move the large volumes of rock required to create a large earthquake.

The question is whether the hazard rating at Chowilla might increase as a result of fluid injection? Whether earthquakes large enough to cause damage may occur?

Discussion

There is no certainty in this field. An earthquake could occur anywhere in Australia at any time as far as we know. There is no location in Australia that could be considered to have zero earthquake hazard. Some areas of Australia obviously experience more earthquakes than others, areas in SA such as the Southeast, Eyre Peninsula and Flinders Ranges are obviously more seismically active than the Riverland.

What we do know is that no earthquake larger than about magnitude 2 has occurred near Chowilla since the mid 1970s and none larger than magnitude 3.5 since about 1900. The lack of data and lack of knowledge of what causes earthquakes in intraplate regions makes it impossible to do a more reliable formal risk analysis at this site than has already been done.

We know that the risk factors for induced seismicity are low in the proposed pumping operation, the reservoir depth is relatively shallow, the host rock is a permeable sand and it is unlikely that fluid would penetrate sufficiently deep (5 or 6 km) within the basement to generate a damaging earthquake. Therefore the earthquake hazard rating should not change. To the authors knowledge no damaging earthquakes have ever been triggered by fluid injection under these conditions (indeed under any conditions; Majer et al., 2005; Baria et al., 2006).

The precautionary principle would dictate that a small network of about 6 seismographs should be operated around the site (at least two in 100m deep boreholes and all of them sampled at 1000 s/s) for the first few years of pumping (preferably installed as soon as possible to establish a baseline) to monitor the near-site seismicity.

An operational plan should be developed so that pumping can be quickly stopped in the event of an earthquake above some threshold (say magnitude 2) within a few km of the injection site. That would require that an earthquake detection and alert system would need to be established with 24 hour accessibility.

It is recommended that the site seismograph network be closely linked to the current state network with rapid data exchange between the groups.

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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

~	approximately equal to
δD	hydrogen isotope composition
$\delta^{18}O$	oxygen isotope composition
^{14}C	carbon-14 isotope (percent modern carbon)
CFC	chlorofluorocarbon (parts per trillion volume)
EC	electrical conductivity (µS/cm)
pH	acidity
ppm	parts per million
ppb	parts per billion
TDS	total dissolved solids (mg/L)

GLOSSARY

AGD — Attorney Generals Department.

AHD — Australian Height Datum.

Anabranch — A branch of a river that leaves the main channel.

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 and the water is held at greater than atmospheric pressure. Water in a penetrating well will rise above the surface of the aquifer.

ASR — Aquifer, storage and recovery. The process of recharging water into an aquifer for the purpose of storage and subsequent withdrawal.

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 resource 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.

Artesian — Under pressure such that when wells penetrate the aquifer water will rise to the ground surface without the need for pumping.

AWQC — Australian Water Quality Centre.

Basin — The area drained by a major river and its tributaries.

bgl — Below ground level.

bgs — Below ground surface.

Biological diversity (biodiversity) — The variety of life forms: the different life forms including plants, animals and micro-organisms, the genes they contain and the *ecosystems (see below)* they form. It is usually considered at three levels — genetic diversity, species diversity and ecosystem diversity.

CSIRO — Commonwealth Scientific and Industrial Research Organisation.

DEH — Department for Environment and Heritage (Government of South Australia).

DEM — Digital Elevation Model.

DWLBC — Department of Water, Land and Biodiversity Conservation (Government of South Australia).

EC — Electrical conductivity**.** 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C. Commonly used to indicate the salinity of water.

Floodplain — Of a watercourse means: (a) the floodplain (if any) of the watercourse identified in a catchment water management plan or a local water management plan; adopted under Part 7 of the *Water Resources Act 1997*; or (b) where paragraph (a) does not apply — the floodplain (if any) of the watercourse identified in a development plan under the *Development Act 1993*, or (c) where neither paragraph (a) nor paragraph (b) applies — the land adjoining the watercourse that is periodically subject to flooding from the watercourse.

FRP — Fibreglass reinforced plastic.

Geological features — Include geological monuments, landscape amenity and the substrate of land systems and ecosystems.

GL — Gigalitre. One thousand million litres (1 000 000 000).

Groundwater — *See underground water.*

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes, and the properties of aquifers. *(See hydrology.)*

Hydrology — The study of the characteristics, occurrence, movement and utilisation of water on and below the Earth's surface and within its atmosphere. *(See hydrogeology.)*

ICP-ES — Inductively Coupled Plasma Emission Spectrometry.

Infrastructure — Artificial lakes; dams or reservoirs; embankments, walls, channels or other works; buildings or structures; or pipes, machinery or other equipment.

ID — Internal diameter

Land — Whether under water or not, and includes an interest in land and any building or structure fixed to the land.

MDBC — Murray–Darling Basin Commission.

ML — Megalitre. One million litres (1 000 000).

MGL — Murray Group Limestone.

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

MS — Monomon Sands.

Natural recharge — The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc.).

NHT — Natural Heritage Trust.

Natural resources — Soil; water resources; geological features and landscapes; native vegetation, native animals and other native organisms; ecosystems.

Permeability — A measure of the ease with which water flows through an aquifer or aquitard. The unit is m^2/d.

PIRSA — Primary Industries and Resources South Australia (Government of South Australia).

Potentiometric head — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer; the unit is metres (m).

PSD — Particle size distribution.

RG — Renmark Group Aquifer.

SWL — Standing water level.

Surface water — (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir.

TSS — Total suspended solids.

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

VSS — Volatile suspended solids.

Water body — Includes watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers.

Well — (a) an opening in the ground excavated for the purpose of obtaining access to underground water; (b) an opening in the ground excavated for some other purpose but that gives access to underground water; (c) a natural opening in the ground that gives access to underground water.

Wetlands — Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic to intermittent inundation, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tides does not exceed six metres.

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