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# Aquifer Storage and Recovery of Stormwater Andrews Farm, South Australia: Compilation of Data from the 1993-98 Trial

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## **Abstract**

This report presents the data set from a study on aquifer storage and recovery (ASR) that has involved the Department of Water, Land and Biodiversity Conservation, CSIRO Land and Water, the Centre for Groundwater Studies, the Australian Water Quality Centre and the Hickinbotham Group. The study was carried out from April 1993 to July 1998 at the Andrews Farm site in Adelaide, South Australia. It is the most detailed investigation in Australia on the impact of ASR with passively treated stormwater on groundwater quality.

The data cover the following areas:

- (1) mineralogical and physico-chemical characteristics of the aquifer targeted for ASR,
- (2) periods, rates and volumes of injection, redevelopment and recovery
- (3) piezometric heads during periods of injection and final recovery
- (4) physical, chemical and microbiological analyses of the quality of the injectant and groundwater at three observation wells and the ASR well during recovery
- (5) water quality changes during well redevelopment

No interpretation of these data is provided here, but a list of publications arising from the trial is provided, where analysis of these data can be found.

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## 1. INTRODUCTION

In the five-year period from April 1993 to July 1998, a trial was conducted at Andrews Farm in South Australia to evaluate the technical, environmental and economic sustainability of injecting winter stormwater flows into a brackish limestone aquifer, for the purpose of providing irrigation supplies during the summer months. Such methods of artificial recharge, where water is injected and recovered from the same well, has become known as aquifer storage and recovery (ASR).

This study represents the most detailed investigation in Australia on the impact of ASR with passively treated stormwater on groundwater quality. It was also an integral part of a broader project aimed at developing national water quality guidelines for the injection of stormwaters and reclaimed waters into aquifers for non-potable reuse (Dillon and Pavelic, 1996). As such, the site has been the focus for parallel studies on adsorption of organic and inorganic contaminants, and the survival of pathogenic microorganisms in groundwater.

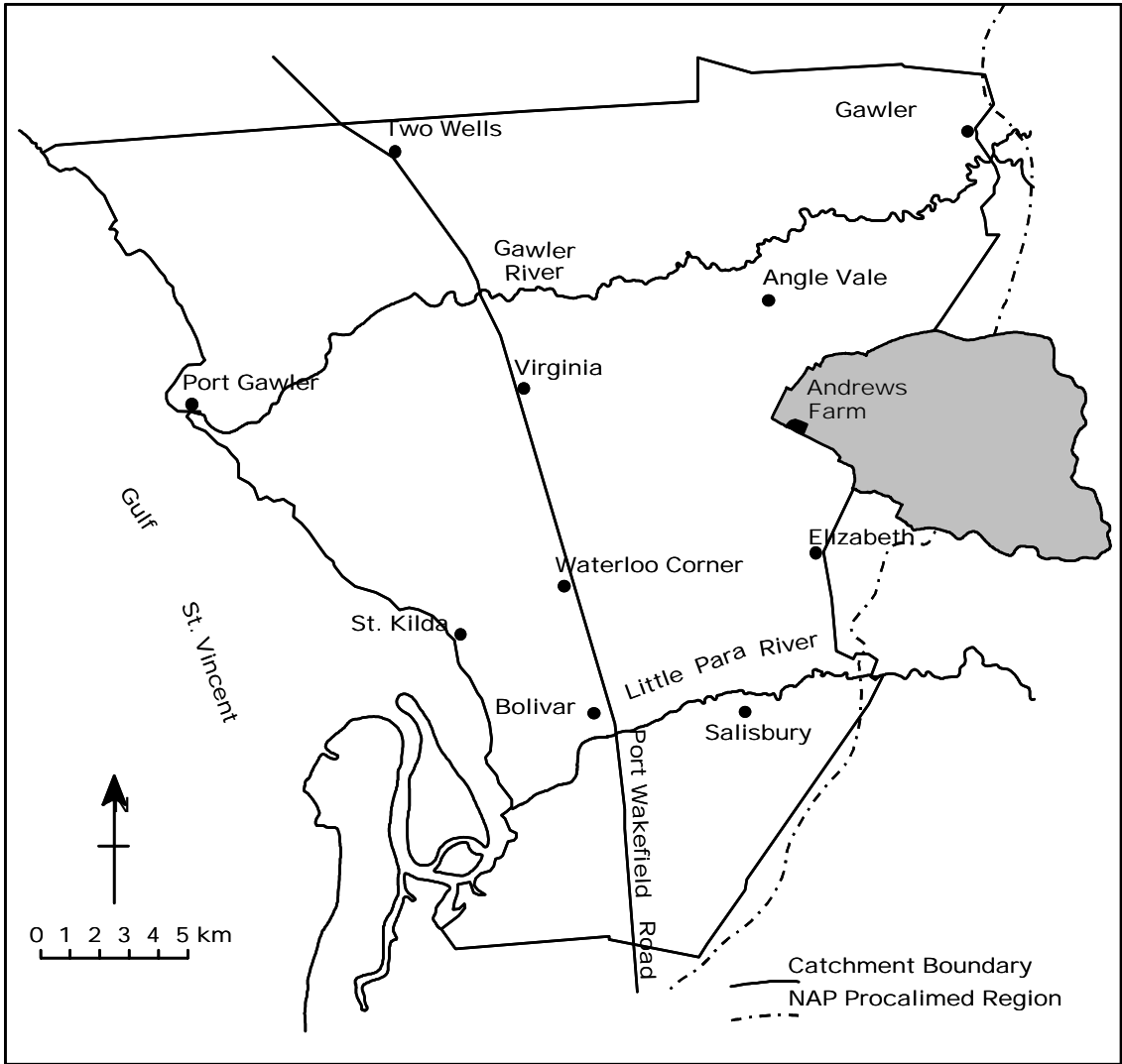
ASR was allowed to proceed at the Andrews Farm site primarily because of the brackish ambient groundwater had no significant beneficial use. An experimental licence was granted by the then SA Department of Environment, Heritage and Aboriginal Affairs, DEHAA (now Department Water, Land and Biodiversity Conservation) subject to the condition that: (i) the injectant meets the criteria for non-potable reuse, as defined by National Water Quality Management Strategy (1992) guidelines for irrigation water, or (ii) if any parameter were to exceed the level set in the irrigation guidelines, that this be no greater than that of the ambient groundwater at the site. Under the conditions of the licence, and in keeping with the principles of the 1996 guidelines, the data should be published to provide a benchmark for future studies and guidelines. This is a comprehensive final report of the data, and extends from a progress report to the SA Department of Environment and Natural Resources produced in July 1995 (Dillon, *et al.*, 1995).

All publications associated with this study are documented at section 7. The complete digital data set is available on the attached CD-ROM in Excel format.

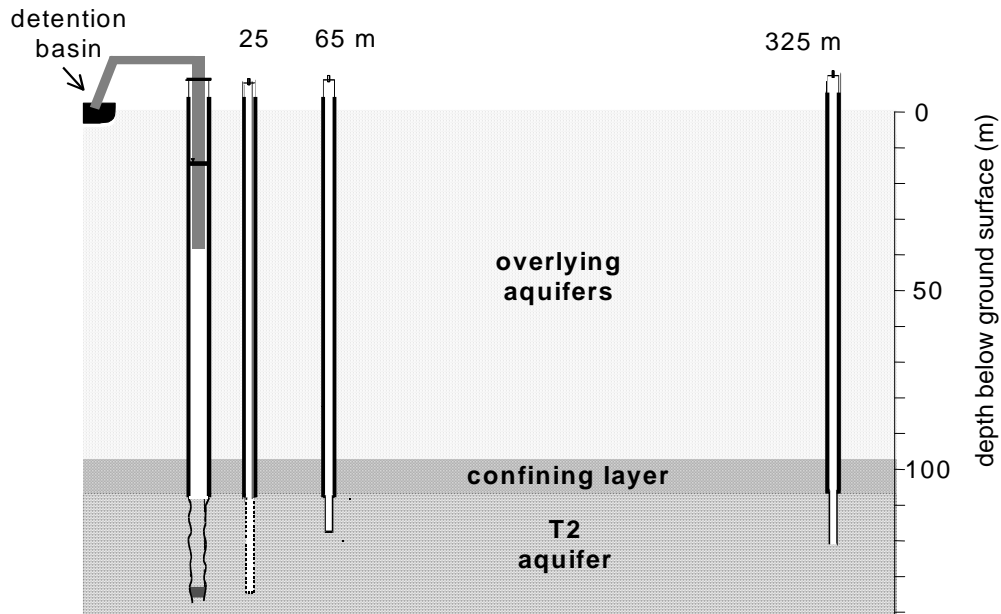
## 2. SITE DESCRIPTION

The Andrews Farm experimental site is situated in the northern metropolitan area of Adelaide, and within the Northern Adelaide Plains, NAP (Figure 2.1).

The aquifer targeted for ASR is a confined Tertiary carbonaceous sand, known locally as the "T2" aquifer, intersected at a depth of 105 metres below ground surface and typically characterised by variably cemented sandy limestone (Gerges *et al.*, 1995). The uppermost 19 metres of the aquifer was targeted for injection, and this interval was completed as 'open hole'. Three observation wells were drilled at distances of 25, 65 and 325 meters down-gradient of the injection well to examine changes in water quality and piezometric head (Figure 2.2). These wells are steel cased, the 25 m well has an open interval comparable to the ASR while the 65 and 325 m wells have open intervals in the upper 13 to 15 metres of the aquifer.

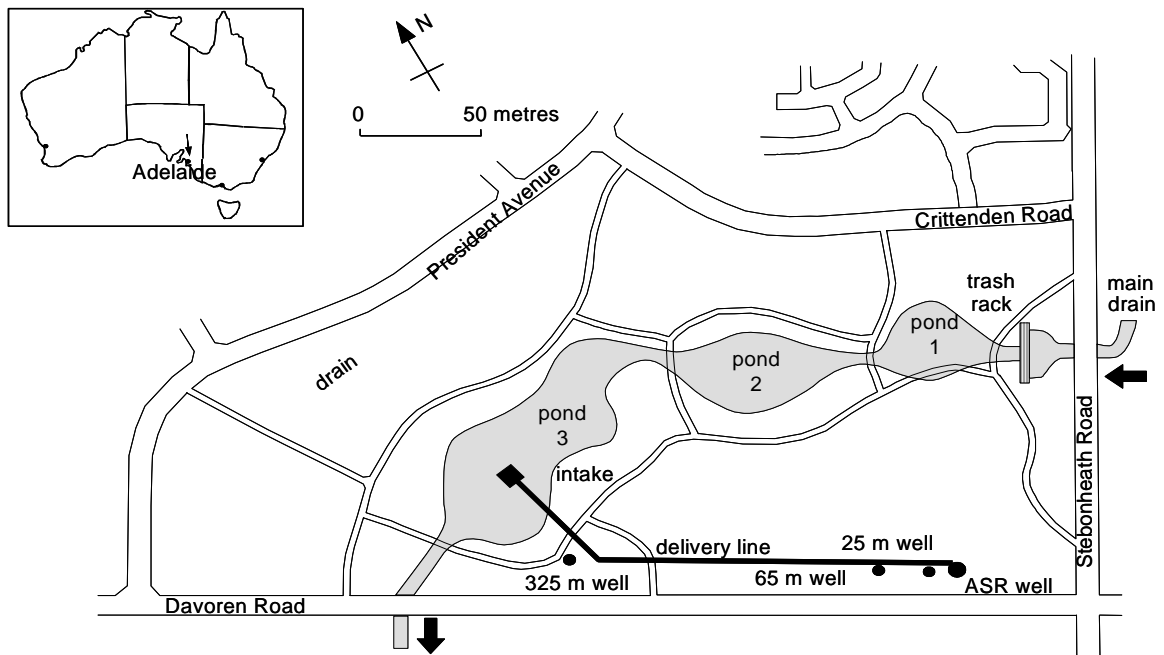


**Figure 2.1.** Northern Adelaide Plains showing the Andrews Farm site



**Figure 2.2.** Schematic vertical section of the Andrews Farm site showing ASR and observation wells

Ephemeral stormwater runoff is stored in a wetland/detention basin system before being pumped under pressure from a floating intake attached to a pontoon in the downstream basin, overland to the ASR well via a stainless steel filter (100  $\mu\text{m}$ ). Figure 2.3 shows the layout for the Andrews Farm study site.



**Figure 2.3.** Andrews Farm experimental ASR site location and layout

### 3. EXPERIMENTAL PROGRAM

Four injection seasons took place from 1993 to 1996. Injection was intermittent and occurred during the winter to spring period once sufficient rainfall had filled the detention basin, and prospects for follow-up rainfall appeared good. The first season commenced with a mains then a stormwater injection, with the second, third and fourth injection seasons being stormwater only. In each season the average rates of injection varied between 10 and 20 Ls<sup>-1</sup>. Volumes of stormwater recharged roughly doubled in each successive season due to a combination of improved operational experience and higher rainfall. By March 1997 a net total of 248 ML of water had been added to the storage, with minimal recovery up to this point, apart from a few small redevelopment events to maintain the viability of the well. A small recovery phase (5 ML) occurred in the summer months of 1993/94.

Redevelopment of the ASR well was carried out by airlift using a compressor pump whenever rates of recharge declined to levels that the site operators (DWR), considered to be inadequate or when piezometric heads approached being artesian. In July 1997 a major recovery phase commenced with a total of 151 ML water being pumped out by July 1998. The sequence of events and the volumes of water injected/recovered are outlined in Table 3.1. Figure 3.1 shows the total cumulative volume in storage (ie. injection - redevelopment + recovery) for the duration of the experiment.

Sampling of the injectant (mains or stormwater) was carried out during each of the injection events in 1993 to 1996 downstream of the filter.

Groundwater samples were collected from the observation wells on the same day as the injectant was sampled. When there was no injection groundwater samples were collected at regular intervals from all four wells (including the ASR well). Prior to sampling, each well was purged using a submersible pump by evacuating at least three casing volumes of groundwater and ensuring the electrical conductivity, pH and temperature readings had stabilised. To minimise the chance of cross-contamination between wells, the pump, delivery lines, taps and fittings were all rinsed with hypochlorite solution. All sample containers were prepared according to the sample laboratory guidelines, and were rinsed three times with sample prior to filling (except containers with acid). Samples were then stored in accordance with standard sampling guidelines, for example: storage on ice during transport, refrigeration prior to analysis (if required), filtration for soluble metals. Figure 3.2 shows each of the sampling events for the injectant, recovered waters and each of the wells.

Field measurements of electrical conductivity, pH, temperature and dissolved oxygen were made at each of the wells prior to sampling using a TPS field analyser. Piezometric heads were logged using pressure transducers installed in each of the wells.

Groundwater and injectant were analysed for a detailed suite of general inorganics, nutrients, heavy metals, oxygen demand, physical, microbiological and isotopic parameters. Samples for organics, enteric viruses/protozoa and isotopes were collected on a less regular basis. Throughout the study there was periodic reevaluation of each of the analytical parameters, which resulted in some adding and subtracting of analytes. Table 3.2. lists the suite of analytes monitored throughout the study. An inventory of the analytical approach, detection limits, references and laboratories for each of the analytes are included in Table 3.3. The majority of analyses were performed at the Australian Centre for Water Quality (AWQC).

Prior to the beginning of the experiment in 1993, water levels in the downstream detention basin were monitored by the Department of Water, Land and Biodiversity Conservation. The earliest of these data have been collated and analysed by Santich (1996) and have not been included in this report.

**Table 3.1.** Summary of injection and recovery events during the course of the study 1993 to 1998

Event	Volume <sup>1</sup> (ML)	Average Flow Rate (L s <sup>-1</sup> )	Period
Injection (mains water)	6.5	15.5	11-16 August 1993
Injection	19	14.2-20	4 events between 29 October and 30 November 1993
Recovery	- 5.4	13	3 December 1993 - 22 February 1994 <sup>2</sup>
Injection	32.7	10-19.5	4 events between 6 July and 17 August 1994 <sup>3</sup>
Redevelopment	- 0.6	13	14-15 September 1994 <sup>2</sup>
Injection	64.9	16.2-19.2	1 July - 16 August 1995
Redevelopment	-0.2	13	7 August 1995
Redevelopment	-2.3	13	21 - 25 June 1996 <sup>2</sup>
Injection	132.8	18.3-15.3	2 events between 26 June and 11 October 1996
Redevelopment	-0.3	13	6 August 1996
Recovery <sup>4</sup>	- 22.9	9.1	30 July - 26 September 1997 <sup>2</sup>
Recovery <sup>4</sup>	-127.8	10.3	3 March - 24 July 1998

<sup>1</sup> Positive number indicates injection, negative indicates recovery

<sup>2</sup> discontinuous recovery, and only over daylight hours

<sup>3</sup> step injection <sup>4</sup> Details of recovery in 1997-1998 are given in Table 4.3.8 (pg19).

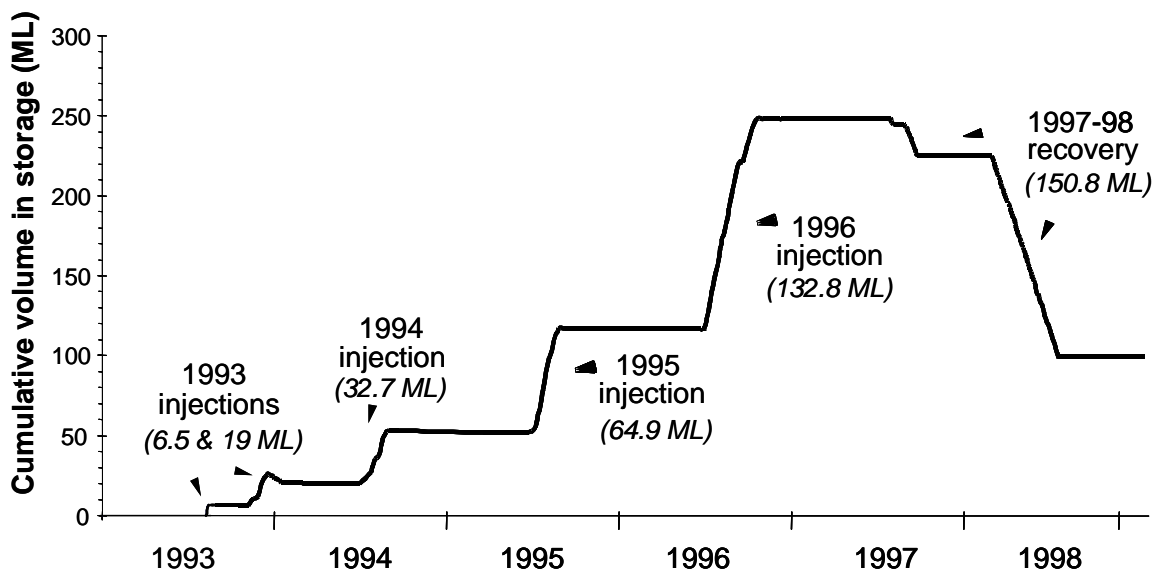
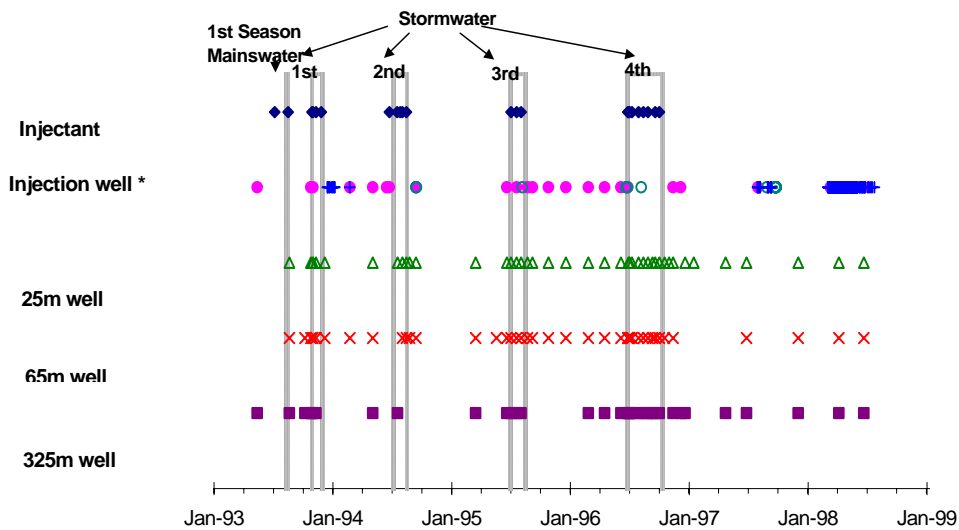


Figure 3.1. Water Balance - Andrews Farm



\* Including abstraction tests (+) & redevelopments (o)

Figure 3.2. Sampling events for duration of study

**Table 3.2.** Total suite of analytes measured in the injectant and groundwater

Class	Parameter
Field	electrical conductivity, pH, temperature, dissolved oxygen, redox potential
General inorganic	Alkalinity <sup>1</sup> , calcium, magnesium, sodium, potassium, bicarbonate, sulphate, chloride, fluoride, silica <sup>2</sup> , total dissolved solids
Nutrient	ammonia, nitrate, total Kjeldahl nitrogen, phosphate
Heavy metal <sup>3</sup>	arsenic, boron, cadmium <sup>4</sup> , chromium <sup>4</sup> , copper, iron, lead, manganese, nickel <sup>5</sup> , zinc
Gross organic and oxygen demand	total organic carbon, dissolved organic carbon, BOD <sup>6</sup> , COD <sup>6</sup>
Volatile hydrocarbons <sup>7</sup>	benzene, toluene, m- and p-xylene, o-xylene, ethyl benzene, 1,3,5-trimethyl benzene, trichloroethylene (TCE), tetrachloroethylene, 1,1-dichloroethane, 1,2-dichloroethane, chloroform, carbon tetrachloride
Polyaromatic hydrocarbons <sup>7</sup>	naphthalene, 1-methyl naphthalene, 2-methyl naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthrene, pyrene, benzo (a) anthracene, chrysene, benzo (b) fluoranthene, benzo (k) fluoranthene, benzo (a) pyrene, dibenzo (a,h) anthracene, benzo (g,h,i) perylene, indeno (1,2,3 -cd) pyrene
Phenols <sup>8</sup>	total halogenated, pentachlorophenol, trichlorophenol, tetrachlorophenol
Polychlorinated biphenyls <sup>9&amp;4</sup>	1016, 1221, 1232, 1242, 1248, 1254, 1260
Insecticides	Aldrin <sup>10</sup> , dieldrin <sup>10</sup> , endosulfan <sup>10</sup> , endosulfan sulphate <sup>10</sup> , heptochlor <sup>10</sup> , heptochlor epoxide <sup>10</sup> , lindane <sup>10</sup>
Herbicides	Atrazine, chlorthal-dimethyl, simazine, trifluralin <sup>10</sup> , azinphos-methyl <sup>10</sup> , diazinon, fenitrothion <sup>10</sup> , hexazinon <sup>10</sup> , malathion <sup>10</sup> , parathion <sup>10</sup> , parathion-methyl <sup>10</sup> , prometryne <sup>10</sup>
Physical	turbidity, suspended solids, particle size, hardness <sup>6</sup> , volatile solids <sup>6</sup>
Microbiological	heterotrophic colony counts (@ 20°C/72hr & 35°C/24hr <sup>11</sup> ), faecal coliforms, total coliforms, faecal streptococci <sup>6</sup> , enterococcus <sup>6</sup> , heterotrophic iron prec. bacteria <sup>8</sup> , enteric viruses <sup>8</sup> , total algae <sup>5</sup> , chlorophyll <sup>5</sup> , enteric protozoa <sup>4</sup>
Isotopes	δDeuterium, Oxygen-18 <sup>4</sup> , δS-34 <sup>12</sup> , δC-13 & C-14 <sup>12</sup>

<sup>1</sup>start 1996    <sup>2</sup>start 1995    <sup>3</sup>including soluble forms to end 1995    <sup>4</sup>cease 1996

<sup>5</sup>only one sample    <sup>6</sup>1994 only    <sup>7</sup>1994 to 1995    <sup>8</sup>start 1994

<sup>9</sup>nomenclature used to identify type of PCB (details available in Nicolson, 1984; p159-160)

<sup>10</sup>1997 and 1998    <sup>11</sup>ceased after 1994,    <sup>12</sup>1995 to 1996

**Table 3.3.** Methods of chemical analysis on waters

Analysis type	Pretreatment	Analytical method	Instrument	Detection limit (mg/L)	Lab.	Ref.
<b>Sodium/Calcium/ Magnesium/ Potassium/ Boron</b>	0.45µm filtered, 1% HNO <sub>3</sub>	emission spectrometry	spectro fitted with polychromator	1 ,0.1 ,0.1, 0.1, 0.005	AWQC	1
<b>Alkalinity/Bicarbonate/ Carbonate</b>		potentiometric titration to end-point pH		1	AWQC	1
<b>Chloride</b>		automated colorimetric	SKALAR segmented flow analyser	1	AWQC	1
<b>Fluoride</b>		automated specific ion electrode	ORION specific ion electrode	0.1	AWQC	1
<b>Silica</b>	sample filtered through 0.45 um membrane.	automated colorimetric	SKALAR segmented flow auto analyser	1 mg/L	AWQC	1
<b>Chromium/Copper/Iron Manganese/ Nickel/Zinc</b>	acid digestion, 1% HNO <sub>3</sub> final strength	emission spectrometry	spectro fitted with polychromator	0.005	AWQC	1
<b>Arsenic</b>		AAS/Continuous hydride generation	VARIAN SpectrAA-20 Plus	0.001	AWQC	1
<b>Lead/Cadmium</b>		electrothermal AAS	VARIAN SpectrAA-40	0.001, 0.0002	AWQC	1
<b>Ammonia</b>			SKALAR segmented flow analyser	0.005	AWQC	1 & IH
<b>Nitrate+Nitrite</b>		automated colorimetric cadmium reduction method	SKALAR segmented flow analyser	0.01	AWQC	1
<b>Total Kjeldahl Nitrogen</b>		Kjeldahl digestion followed by automated colorimetric method	SKALAR segmented flow analyser	0.05	AWQC	1
<b>Filterable reactive Phosphorus</b>		automated ascorbic acid reduction method, colorimetric	SKALAR segmented flow analyser	0.005	AWQC	1

<b>Total Phosphorus</b>		H <sub>2</sub> SO <sub>4</sub> /K <sub>2</sub> SO <sub>4</sub> /HgO digestion followed by automated ascorbic acid reduction	SKALAR segmented flow analyser	0.005	AWQC	1
<b>TOC/DOC</b>	none / 0.45 um membrane	uv/persulfate oxidation followed by reduction of CO <sub>2</sub> to CH <sub>4</sub> and detection by FID	SKALAR-SK12 organic carbon analyser	0.2	AWQC	1
<b>BOD</b>		5-day test		1	AWQC	1
<b>COD</b>		open reflux followed by titration		5	AWQC	1
<b>Volatile hydrocarbons, PAH's: naphthalene / 1-methyl naphthalene / 2-methyl naphthalene</b>		microextraction	gas chromatography	0.005	LWP	2
<b>Other PAH's</b>	USEPA SW846, Method 8310 (HPLC) and 8270 (GCMS)				MGT	
<b>PCB's</b>	USEPA SW846, Method 8080				MGT	
<b>Phenols</b>		solid phase extraction	gas chromatography using VARIAN 3500		AWQC	IH
<b>Organochlorine pesticide scan</b>		solvent microextraction	gas chromatography using VARIAN 3500	0.00001-0.0001	AWQC	IH
<b>Organophosphate herbicide scan</b>		solid phase extraction	gas chromatography using VARIAN 3400CX	0.00002-0.0001	AWQC	IH
<b>Suspended solids</b>		oven drying at 103-105°C		1	AWQC	1
<b>Turbidity</b>		nephelometric method	VARIAN UV-Visible spectrophotometer	0.1 NTU	AWQC	1
<b>Total Dissolved Solids</b>		TDS calculated from the electrical conductivity.	conductivity measured using conductivity meter and cell.	1mg/L TDS	AWQC	IH

<b>Hardness</b>	sample filtered through 0.45 um membrane and acidified (1mL/100mL nitric).	determination of magnesium and calcium by Inductively Coupled Plasma followed by a calculation for hardness.		1 mg/L	AWQC	IH
<b>Volatile Suspended Solids</b>		aliquot of sample filtered through a GFC filter paper, dried at 105 deg C and weighed. Filter then ignited at 550 deg C. The difference in weights is the VSS		1 mg/L	AWQC	IH
<b>Particle size distribution</b>	calgon added followed by ultrasonic bath	laser diffraction	MALVERN MASTERSIZE	0.1 µm	LWP	IH
<b>Faecal Coliforms/ Total Coliforms/ Faecal Streptococci</b>		membrane filtration method then colony count			AWQC	IH
<b>Heterotrophic Colony Count</b>		pour plate method then colony count			AWQC	IH
<b>Total Algae</b>	sample with air gap.	microscopic examination		1 per mL	AWQC	IH
<b>Chlorophyll</b>	sample should be a 1.25 L plastic iced and stored in the dark.	ethanol extraction followed by spectrophotometric analysis at 456 Nm		0.1 mg/L	AWQC	IH
<b>Entrococcus Species</b>	sample taken in a sterilised bottle and iced, to be analysed within 12 hours .	membrane filtration		0 colonies per 100 mL (depending on sample turbidity and sample dilution)	AWQC	IH
<b>Enteric Species- E. Coli</b>	sample taken in a sterilised bottle and iced, to be analysed within 12 hours.	colilert (most probable number technique)		0 colonies per 100 mL	AWQC	IH
<b>Enteric Species-Giardia and Cryptosporidium</b>	10L required per sample with a 10L control (per batch of similar samples), stored at room temperature.	calcium carbonate flocculation, concentration then microscopic examination of stain.		1 in 10L	AWQC	IH

<b>Echo-/ Enteroviruses</b>	<b>Polio-</b>	ultrafiltration of 10L sample to 1-2mL, decontaminate with chloroform, then 3 passages through 2 cell lines	identified by lytic cytopathic effect in cell culture				10 <sup>-2</sup> TCID <sub>50</sub> /L	USA	IH
<sup>18</sup> O		distillation if EC>3000 uS/cm for samples high in Ca/Mg add NaF	equilibrate with CO <sub>2</sub> and measure <sup>16</sup> O/ <sup>18</sup> O by mass spectrometry	dual inlet mass spectrometer			0.15 per mill (‰) (natural abundance) 0.4 per mil (enriched)	LWA	IH
δD		as for <sup>18</sup> O	oxidise with H <sub>2</sub> O in Uranium, measure <sup>2</sup> H gas by mass spectrometry	dual inlet mass spectrometer			1 per mill (‰) (natural abundance) 3 per mill (enriched)	LWA	IH
δ <sup>34</sup> S		filtered, acidified, boiled then precipitated using BaSO <sub>4</sub> then ppt. washed and dried	BaSO <sub>4</sub> ground with CuO & quartz and heated in a vacuum line to produce SO <sub>2</sub> - heated to 600oC to suppress O <sub>2</sub> & eliminate SO <sub>3</sub> - purified using vacuum line techniques then <sup>34</sup> S/ <sup>32</sup> S ratio determined using mass spectrometry	FISIONS VG Optima mass spectrometer			Ratio <sup>34</sup> S/ <sup>32</sup> S (‰)	UA	IH
<sup>14</sup> C		precipitated using BaCl <sub>2</sub> , NaOH and magnafloc to BaCO <sub>3</sub>	evolve CO <sub>2</sub> gas from ppt. Using HCl & purify using vacuum line techniques <sup>3</sup> by bubbling through a Carbosorb:Permafluor solution.	LKB Quantalus liquid scintillation counter			% modern carbon (pmc)	LWA	IH
δ <sup>13</sup> C		precipitated using sat.SrCl/NH <sub>4</sub> OH solution then washed and dried	<sup>13</sup> C/ <sup>12</sup> C ratio determined using mass spectrometry	VG 602D mass spectrometer			Ratio <sup>13</sup> C/ <sup>12</sup> C (‰)	LWA	IH

<sup>1</sup>American *et. al.*, (1992) <sup>2</sup>Patterson *et al.*, (1993) , Leaney *et.al.*, (1994)

AWQC = Australian Water Quality Centre, LWA = CSIRO Land and Water - Adelaide, LWP = CSIRO Land and Water - Perth

USA = University of South Australia, MGT= MGT Environmental Consulting, Melbourne, IH = in house, UA = University of Adelaide

## 4. RESULTS

The tables and figures in this section (excluding Tables 4.3.2 and 4.3.8) are presented in sequence as Appendix I at the end of this report.

### 4.1. Characterisation of the aquifer and injectant sediments

Core material was collected during drilling of the 25 m observation well (Unit #28493). In Table 4.1.1 the mineralogy determined for the core samples taken at twelve different depths and injectant (collected before and during the 2<sup>nd</sup> injection season) are presented. Table 4.1.2. shows the mineralogy results using X-ray fluorescence on core sub-samples from 113-114m, 125-126m and 126-127m depths.

Particle size distributions were determined for the aquifer samples and are presented in Table 4.1.3. Figures 4.1(a) - (l) plot the cumulative and frequency percentages for each of the samples.

### 4.2. Monitoring of the injectant and groundwater during 1993 to 1996 injections

The data have been divided into the following groups:

#### (a) Piezometric heads

During each of the injection seasons, piezometric heads were logged for each of the 4 wells. Piezometric levels have been presented as the difference in standing water level from the start of the injection season. These are tabulated and plotted against time for each season in Tables 4.2.1 - 4.2.5 and Figures 4.2.1 - 4.2.5.

#### (b) Particle size distributions

Samples of injectant were collected during the 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> injection seasons. In August 1995 replicate samples from groundwaters recovered by pumping the ASR, 25 m and 65 m wells were collected to verify the analytical technique. Tables 4.2.6(a) - (b) and 4.2.7 and Figures to 4.2.6(a) - (f) and 4.2.7(a) - (f), present the cumulative and frequency percentages of the samples.

#### (c) General inorganic and nutrients

Tables 4.2.8(a) - (e) include all field measurements as well as inorganic and nutrient data. Figures 4.2.8(a) - (u) plot each of the parameters over time for the injectant as well as the groundwater samples from the observation wells. The analytes remained relatively constant for both injectant and groundwaters throughout the study, with silica and alkalinity being added to the suite after 1994. Hardness was only measured in 1994, fluoride was not analysed in 1996 and analysis of soluble phosphorus ceased after 1995.

#### (d) Heavy metals

Tables 4.2.9(a) - (e) include all the results of heavy metal analyses carried out on the injectant and groundwaters. Total and soluble heavy metals were analysed until the end of 1994. Following the re-evaluation of the analytes in 1994, analysis for soluble metals was reduced to arsenic and lead only, and from 1996 onwards they were measured on

only 2 further occasions in 1996. From the beginning of 1996, analysis for total cadmium and chromium also ceased. Total nickel was only analysed once at the beginning of the study. Figures 4.2.9(a) - (i) show the time series data for total metals.

#### (e) Organics

In 1993 a limited suite of analytes were measured including total and dissolved organic carbon, total insecticides and herbicides and atrazine. From 1994, phenols, PCB's, polyaromatic hydrocarbons and volatile hydrocarbons were added to the analytes, BOD and COD were analysed on occasions in 1994 only. In 1995 simazine was added to the suite of analytes. Analysis of polyaromatic and volatile hydrocarbons ceased at the end of 1995. During the post-injection phase in 1997/98 an extended suite of insecticides and herbicides were monitored. Sampling for organics were carried out less frequently than for inorganic, nutrients and heavy metals. Tables 4.2.10(a)-(e) and 4.2.11 - 4.2.13. include all the results of analyses on the injectant and groundwaters. Total and dissolved organic carbon have been plotted against time in Figures 4.2.10(a) and (b).

#### (f) Suspended solids, microbiota and isotopes

Samples were initially collected for determination of suspended solids, heterotrophic colony counts (@ 20°C and 35°C), total and faecal coliforms and stable isotopes of water. In 1994, following re-evaluation of the analytes, heterotrophic iron bacterial counts were included, as well as a single analysis/sampling for volatile solids, total algae and chlorophyll and enteric viruses in the injectant and groundwater from the injection well in June 1994. Sampling for turbidity, enteric protozoa, cryptosporidium, giardia and enteric viruses began in 1995 on the injectant only, except for a one off analysis for cryptosporidium and giardia on the groundwater recovered from the injection well in July 1997. Stable isotope analysis ceased after February 1996.  $\delta^{34}\text{S}$ ,  $\delta^{13}\text{C}$  and  $^{14}\text{C}$  isotopes analyses were undertaken on samples collected during 1995-96. Tables 4.2.14(a) - (f) include all the results of analyses carried out on the injectant and groundwaters. Time series plots of turbidity, suspended solids, colony count (20°C) and total and faecal coliforms are presented using logarithmic scale, Figures 4.2.11(a) - (e). Time series isotope data ( $\delta\text{D}$ ,  $\text{O}^{18}$  and  $\delta^{34}\text{S}$ ) are presented in Figures 4.2.11(f) - (h).

### 4.3. ASR well - redevelopment and recovery

#### (a) Step-test 1993

In April 1993, prior to the main monitoring phase of the study a step-test was carried out by the Department of Water, Land and Biodiversity Conservation, and the drawdowns at the ASR and 25 m wells monitored, refer to figure 4.3.1. Flow rates for each of the four steps were 5.15, 13, 17.6 and 23 L/s. Further details on this test and well production tests are given by Gerges et.al, (1995).

#### (b) Initial recovery - 1993/94

In the summer of 1993/94 following the 1<sup>st</sup> injection season of mains and stormwater in 1993, there was a recovery of 5.4 ML of water from the ASR well to refill the detention basins. Pumping from the ASR well was by airlift at an average flow rate of 13 Ls<sup>-1</sup> and only occurred during daylight hours. Changes in electrical conductivity (EC) and temperature were monitored during the recovery and the resulting data in Table 4.3.1 were plotted as a function of the cumulative recovered volume in Figures 4.3.2(a) & (b).

(c) Redevelopments during 1994 to 1996 injection events

Monitoring of redevelopment events commenced in 1994. Although a number of redevelopments occurred in 1993, samples were not collected for monitoring purposes.

From 1994 onwards a number of redevelopments took place to maintain the viability of the ASR well. The volumes extracted are summarised in Table 3.1 (page 9). Table 4.3.2 summarises the samples collected and analyses made during these redevelopments.

**Table 4.3.2.** Summary of redevelopment events - September 1994 to August 1996

Date	Reason	# samples	Parameters
14-15 September 1994	post-injection airlift to unclog ASR well	8	EC (field & lab), pH (field), TDS, turbidity, TSS, VSS, coliforms, het.Fe bacteria & PSA <sup>1</sup>
7 August 1995	airlift during 3 <sup>rd</sup> injection season to prevent ASR head levels rising above well head	15	EC (lab), TDS, turbidity, TSS, VSS & PSA <sup>2</sup>
21-25 June 1996	airlift in preparation for 4 <sup>th</sup> injection season	7 (day 1), 2 (day 5)	TSS, VSS, Cl, total Coliforms & PSA <sup>3</sup>
6 August 1996	airlift during 4 <sup>th</sup> injection season as per 7/8/95	8	TSS, VS, Cl, total Fe & PSA

<sup>1</sup> Particle size analysis @ 11 & 352 mins only, <sup>2</sup> @ 10, 12, 60 & 270 mins, <sup>3</sup> day 1 samples only

Table 4.3.3 lists the data recorded during all redevelopments of the ASR well during the years 1994 - 1996. Water quality variations during the four airlifts are plotted in Figures 4.3.3 - 4.3.6. The cumulative and frequency percentages for particle size distribution (PSD) in each of the samples are presented in Tables 4.3.4 - 4.3.7 and Figures 4.3.7 - 4.3.10 respectively.

(d) Final recovery - July 1997 to July 1998

There was no injection season in the years 1997 - 1998. The final recovery of the ASR well began on 30 July 1997. This involved a discontinuous pumping of groundwater from the ASR well between July and September 1997, including 2 airlift/redevelopment events in August and September 1997, finishing with a continuous 'pump-out' between March and July 1998. Volumes pumped and average flow rates are presented in Table 3.1 (page 9). Table 4.3.8 (page 19) summarises the sampling program during the final recovery period from July 1997 to July 1998.

**Table 4.3.8.** Summary of data collected for final recovery 1997 to 1998

Date of Event	# samples	Parameters
<b>Start pumping</b>		
30 July 1997 (day 1) 31 July 1997 (day 2)	9/day 1/day	TDS, turbidity, TSS, Cl, total Fe, major ions <sup>1</sup> , microbiology <sup>2</sup> , TOC <sup>3</sup> , nutrients <sup>3</sup> , other heavy metals <sup>3&amp;4</sup> and PSA
2, 6 and 7 August 1997	1/day	EC and TDS only
<b>Pump stopped (due to clogging with sand)</b>		
Start 1 <sup>st</sup> airlift 28 August 1997	9	EC, TDS, turbidity, TSS, Cl, total Fe, microbiology <sup>5</sup> , TOC and PSA
Continued pumping with periodic sampling 30 August to 11 September 1997	8	TSS and Cl only
<b>Pump stopped again (due to clogging with sand)</b>		
Start 2 <sup>nd</sup> airlift 22 September 1997	7	TDS <sup>6</sup> , turbidity, TSS, Cl, Psuedomonas and PSA <sup>7</sup>
Continued pumping 23 to 26 September 1997	6	EC, TDS and Cl
<b>Pump Stop</b>		
<b>Pump Re-start 3 March 1998</b>		
3 March to 3 June 1998	~ 1/day	EC, TDS, TSS <sup>8</sup> , Cl and major ions <sup>9&amp;10</sup>
4 June to 26 June 1998	~ 5/week	As above <sup>11</sup>
27 June to 24 July 1998	~ 1/week	As above
<b>END RECOVERY</b>		

<sup>1</sup> Ca, Mg, Na, K, HCO<sub>3</sub>, SO<sub>4</sub>, F, <sup>2</sup> includes colony counts, total coliforms, faecal coliforms, heterotrophic iron bacteria, Pseudomonas species + 2 samples for protozoa and gardia @ 30 & 1485 mins, <sup>3</sup> 31.07.01 only, <sup>4</sup> As(inorg), B, Cu, Pb, Mn & Zn, <sup>5</sup> Total Coliforms, Het.Fe.Bacteria, Ps.spp, <sup>6</sup> 120min sample only <sup>7</sup> @ 3, 30 & 120 mins, <sup>8</sup> no TSS 29.05.98 to 3.06.98, <sup>9</sup> no F until 11.03.98, <sup>10</sup> daily sampling for major ions ceased on 29.03.98, except for one sample on 6.04.98, <sup>11</sup> no TSS till 22.06.98 & only 2 major ion samples

Table 4.3.9(a) - (d) lists all the data available for the period between 30 July and 26 September 1997 during the final recovery cycle. The start of recovery and two airlifts are presented in Figures 4.3.11 - 4.3.13. The particle size distribution data is presented in Tables 4.3.10 - 4.3.12 and Figures 4.3.14 - 4.3.16.

During the recovery phase between March and July 1998, piezometric heads were monitored. The changes in heads calculated from the standing water levels measured on the 10 March 1998 are presented in Table 4.3.13 and the respective drawdown in Figure 4.3.17.

Tables 4.3.14 and 4.3.15 present the remaining data available for this stage of the final recovery. Figures 4.3.18 - 4.3.20 present the changes in electrical conductivity, total suspended solids and chloride of the recovered water as a function of cumulative volume during the final recovery, July 1997 to July 1998.

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