Managed Aquifer Recharge and Urban Stormwater Use Options: Public Health and Environmental Risk Assessment Final Report

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Contents

List of Figures

List of Tables

Acknowledgments

This is a Report of the Managed Aquifer Recharge and Stormwater Use Options (MARSUO) research project which is supported under the Raising National Water Standards Program through the National Water Commission, and by the Goyder Institute for Water Research, CSIRO Water for a Healthy Country Flagship Research Program, City of Salisbury, Adelaide and Mount Lofty Ranges Natural Resources Management Board and the former United Water International. Data were provided by South Australian Water Corporation, City of Salisbury, CSIRO and University of South Australia.

Foreword

This report documents the assessment of maximal and residual risk to public health and the environment of twelve different options for harvesting stormwater in the Parafield and neighbouring catchments of Salisbury, South Australia. It focuses on three distinct uses: open space irrigation, residential supply to third pipe systems and drinking water. Of these uses, stormwater supplied to open space irrigation and third pipe systems which blend the harvested stormwater with reclaimed water have already been in operation successfully for a number of years.

The Water Safety Expert Panel was formed to guide the work of the Managed Aquifer Recharge and Stormwater Use Options research project in producing authoritative risk assessment and risk management procedures for human health and environment protection and to produce reliable results of risk assessment for the harvesting, aquifer recharge, storage, supply and use of harvested stormwater in Salisbury, South Australia.

This risk assessment is published with the consent of the Water Safety Expert Panel as an example of best current practice for risk assessment in stormwater harvesting and use. Although the risk assessment is specific to a stormwater harvesting and managed aquifer recharge system in Salisbury, the methodology is broadly applicable in Australia and elsewhere.

The project used historical data and additional data acquisition on water quality to provide a reliable basis for risk assessment that is in accordance with the Australian Guidelines for Water Recycling of the National Water Quality Management Strategy. The assessment is applied from catchment to tap.

The log reduction required for pathogens in stormwater for potable use were determined and until further data are available should not be construed as representing requirements in other catchments.

Water Safety Expert Panel:

David Cunliffe, SA Department of Health and Ageing

Don Bursill, SA Chief Scientist

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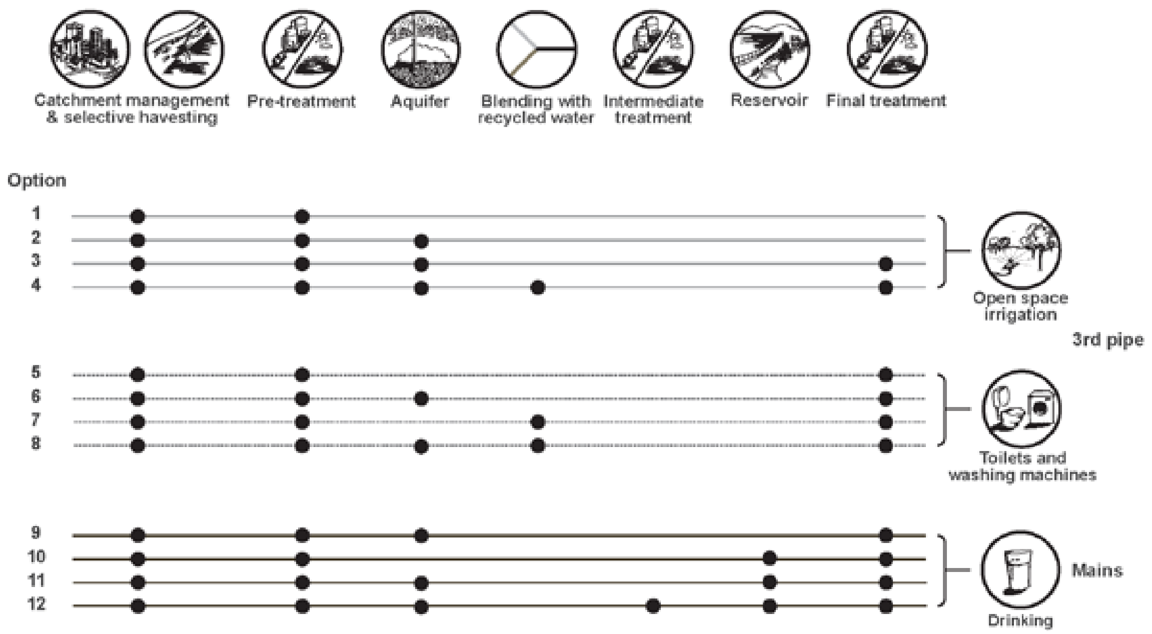
Executive Summary

This public health risk assessment report contributes to the Managed Aquifer Recharge and Stormwater Use Options (MARSUO) project, supported by the National Water Commission, Goyder Water Research Institute and partners to assess safety, public acceptance, economics and environmental impacts of alternative options for stormwater use in Australia.

This report presents qualitative and quantitative water quality risk assessments performed based on the combined Salisbury ring main and associated stormwater harvesting systems with a detailed focus on the Parafield stormwater harvesting system. The Parafield system uses aquifer storage and recovery (ASR) where injection and recovery occurs through a single well, and aquifer storage, transport and recovery (ASTR) where separate wells are used for injection and recovery. ASTR typically involves longer aquifer storage times and a lateral aquifer transport component. This report extends previous risk assessments that have been undertaken for individual components of the system, to include:

- the ASR system as well as the ASTR system for managed aquifer recharge;
- all the stormwater catchments contributing to the Salisbury ring main in addition to the Parafield catchment;
- considering twelve potential stormwater reuse options notably in three categories; restricted open space irrigation, residential and non potable supplies and unrestricted irriagtion; and potable supplies
- all water quality hazards as previously addressed;
- additional targeted pathogen (virus, protozoa, bacteria) monitoring of stormwater to enable a Quantitative Microbial Risk Assessment (QMRA) for each of the options; and
- makes use of all data available by end December 2012.



The twelve options evaluated for stormwater use; options 1-8 include non-potable use with and without managed aquifer recharge and blending with reclaimed wastewater; and options 9-12 include indirect potable reuse with and without managed aquifer recharge, intermediate treatment and reservoir storage before the final treatment plant for drinking water mains supply.

The risk assessment utilised catchment land use and water quality data to evaluate the risks to human health and the environment for targeted end uses and gives example treatment processes required in order to meet those uses according to the most relevant Australian National Water Quality Management Strategy guidelines.

The development of risk assessments that have been undertaken for the Parafield site and extended within the MARSUO project are illustrated in the table below.

A detailed geographical information system based stormwater catchment land use analysis method was developed to assess stormwater quality risks. Catchment land use risk assessment methods used were consistent with those described for drinking water catchments in the Australian Drinking Water Guidelines and Australian Guidelines for Water Recycling and the results refined through a series of project stakeholder workshops comprised of representatives from the MARSUO technical committee, the South Australian Water Corporation, South Australian Department for Environment, Water and Natural Resources, the City of Salisbury, the University of South Australia and representatives from MARSUO project satellite sites in Singapore, Melbourne, Geelong, Orange and Brisbane. For open space irrigation unacceptable maximal risks were associated with pathogens, for third pipe nonpotable use additional unacceptable risks were associated with aesthetic quality (colour) and salinity and for drinking water use further unacceptable maximal risks were associated with inorganic chemicals.

The results indicated a degree of uniformity in the stormwater catchments connected to managed aquifer recharge sites which fed into the ring main system for supply of harvested stormwater by the City of Salisbury. All stormwater catchments were dominated by residential and commercial land uses which contrasted with the Little Para Reservoir catchment which had a higher degree of rural-residential land uses, horticulture and livestock grazing activities. Sewer overflows were also mapped in the urban catchments which represented the highest risks for pathogens. Pathogen risks in rural catchments were driven by the high likelihood of runoff contamination through septic system failures and livestock operations and so are not necessarily of lower risk than urban areas.

Stormwater, wetland-treated and aquifer recovered and reservoir water quality was monitored for each of the twelve options considered in this report. Water quality from nearly a decade of monitoring was assessed and it was found that untreated stormwater quality had unacceptable risks associated with pathogens, inorganic chemicals, organic chemicals, nutrients, turbidity and salinity depending upon the end use.

Table 1 Risk assessment development for the Parafield site and MARSUO project.

Date of report		**Swierc *et al*. 2005**	**Page *et al*. 2008**	**Page *et al*. 2009**	**Barry 2010**	**MARSUO Milestone Report 4b**	**MARSUO Milestone Report 5b (Mar 2012)**	**MARSUO Milestone Report 7a (Jun 2013)**
Site	Parafield ASTR	ü	ü	ü	ü	ü	ü	ü
	Parafield ASR					ü	ü	ü
	Ring main catchments						ü	ü
	Satellite sites							ü
Risk assessment	Pathogen QMRA			ü		ü	ü	ü
	Other water quality hazards		ü	ü			ü	ü
Data		Sep 2005	Sep 2008	Apr 2009	Dec 2009	Nov 2011	Mar 2012	Dec 2013
Use	Open space irrigation						ü	ü
	Residential non-potable						ü	ü
	Residential potable supplies	ü	ü	ü			ü	ü
End-point	Human health			ü			ü	ü
	Environment			ü				ü

Targeted event-based monitoring of adenovirus, *Cryptosporidium* and *Campylobacter,* representing viruses, protozoa and bacteria in stormwater from the Parafield drain gauging station was undertaken to allow for a human health risk assessment of stormwater for drinking and other uses (Australian Drinking Water Guidelines). This allowed the determination of a 95th percentile of pathogen numbers in stormwater (2 n/L for adenoviruses, 1.4 n/L for *Cryptosporidium* and 11 n/L for *Campylobacter*) for use in a risk assessment. A tolerable risk of 10^{-6} DALYs per person per year was then used to determine the exposure reduction or water treatment requirements that, if met, will ensure that human health is protected. The treatments suggested below for each of these options are examples only and different combinations could potentially be used as long as the required health-based targets are met. Treatments and control measures to manage these risks for the different end uses included:

- Open space irrigation requires 1.6 $\log_{10}$ reduction for viruses, 0.6 $\log_{10}$ for protozoa and 1.2 $\log_{10}$ for bacteria and can potentially be managed using exposure controls. This option has already been implemented for a number of years and the risk assessment verified that the health based targets are being met.
- Third pipe systems which include potential exposure through toilet flushing and washing machine use requires 2.7 $\log_{10}$ reduction for viruses, 1.8 $\log_{10}$ for protozoa and 2.3 $\log_{10}$ for bacteria. Aquifer treatment could potentially deliver this treatment if it were validated otherwise UV disinfection would be required in addition to chlorination for protection of the distribution system. Although viruses usually require the higher health-based target different treatments vary in efficacy. For example, to meet the same health-based target for protozoa 1.8 $\log_{10}$ are required but as chlorination is ineffective for protozoa, enhanced cross connection controls, aquifer treatment or UV light disinfection was suggested. For UV light disinfection, aesthetic quality especially colour from high iron concentrations and salinity that can affect disinfection efficacy would also need to be managed using iron removal and blending with mains water. Blending with highly treated recycled effluent may also occur.
- Drinking water required 5.8 $\log_{10}$ for viruses, 4.8 $\log_{10}$ for protozoa and 5.3 $\log_{10}$ for bacteria as a health based target and would involve appropriate treatment depending on the specific option considered. For example, this could be achieved using ultrafiltration membranes and disinfection with UV followed by chlorination.

Aquifer treatment was also considered in addition to the more common engineered treatments. Pathogen attenuation and attachment were assessed and a 4.0 $\log_{10}$ inactivation credit could potentially be assigned to the ASTR system but suitable validation scheme would need to be developed. In addition, the detention time in the aquifer needs to be quantified historically and a commitment to the management of detention times need to be clearly set. The ASR system as currently operated did not guarantee a suitably long residence time in the subsurface. This highlights the potential advantages of longer detention and aquifer travel times in the ASTR system for water treatment if pathogen attachment and inactivation is considered.

Other water quality parameters were assessed, including inorganic chemicals, organic chemicals, nutrients, turbidity, salinity and radionuclides. It was found that in the majority of cases, the aquifer recovered water quality met most Australian Drinking Water Guideline health criteria. Aesthetic targets were occasionally exceeded e.g. high colour limits exceeded due to high iron concentrations, occasional turbidity and high salinity caused by excessive entrainment of brackish groundwater in recovered water.

Residual risks to human health were assessed for each of the twelve use options. Risks were found to be acceptable and met health based and aesthetic water quality targets with appropriate treatment and controls for each of the end uses of recovered water. Treatment for pathogens, turbidity and colour particularly were required prior to third pipe and drinking water use. System specific options such as mixing in the distribution or reservoir systems, customer satisfaction and economic considerations were not assessed as part of this report.

Environmental risks were also assessed using the same seven water quality groups and in addition five environmental categories (injection pressure, aquifer dissolution, contaminant migration, groundwater dependant ecosystems and green house gas emissions). The ASR, and ASTR systems have been operating for a number of years and recycled stormwater has been similarly used for open space irrigation and blending with treated wastewater in third pipe systems. The risk assessment verified that risks to the environment were well managed. Monitoring results also indicated that there would be minimal risks to the environment for the drinking water options.

However in addition to meeting these water quality requirements for human health and the environment, a water safety plan would need to be fully implemented and accepted by stakeholders, regulators and the community to ensure the risks can be managed on an ongoing and sustainable basis. This is the subject of a separate report for this project for the case of non potable use of water from a third pipe system and for public open space irrigation.

1 Introduction

The scope of the Managed Aquifer Recharge and Stormwater Use Options (MARSUO) project is to develop methods to assess safety, public acceptance, economics and environmental impacts of alternative options for stormwater use in Australia and apply them in a case study. This report focuses on assessing risks to human health and the environment for a number of stormwater use options. This was performed through a case study in Adelaide, South Australia involving stormwater harvesting and managed aquifer recharge (MAR) schemes owned and operated by the City of Salisbury that distribute recycled stormwater via an interconnected trunk main system. The Parafield stormwater harvesting scheme is the focus for some aspects of the report building on previous research on this system. Methods to assess land use risks to the quality of urban stormwater are developed and applied to all catchments connected to the Salisbury stormwater trunk main.

Figure 1 shows potential generic pathways for stormwater harvesting and reuse. The urban stormwater source is shown at the left, storage and treatment options in the centre and potential end uses on the right. This report focuses on one of the key limiting factors in the realisation of these options, which is lack of appropriate data for use in formal risk assessments.

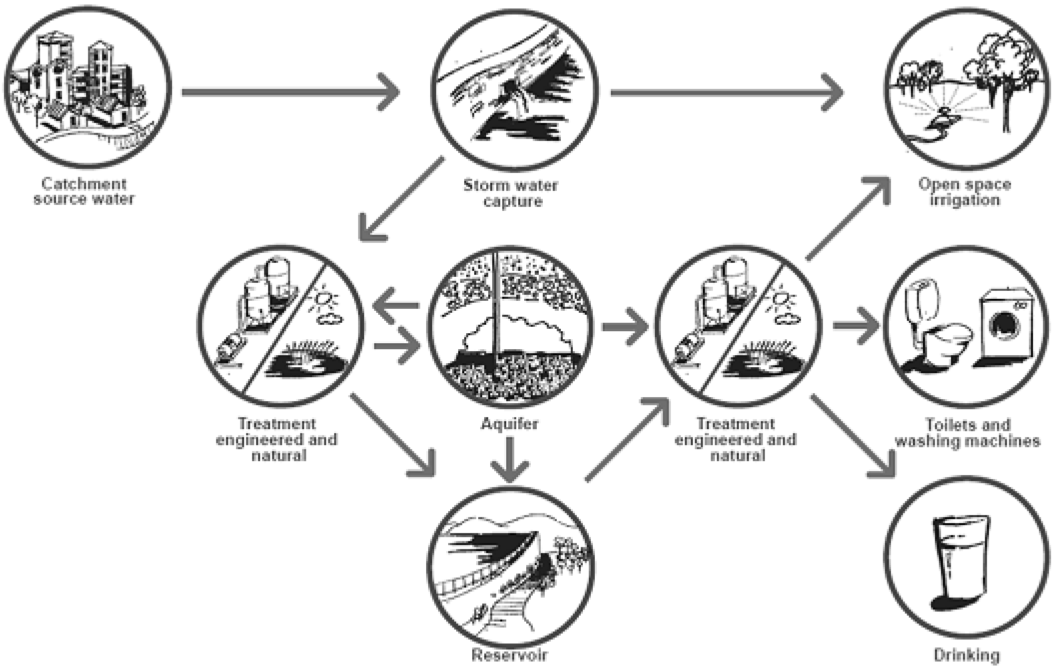


Figure 1 Potential configurations of stormwater use options to be considered within the MAR and Stormwater Use Options Project at the Parafield case study site.

1.1 Objectives of this report

The objectives of this report were to undertake a water quality human health and environmental risk assessment that would allow the performance of the existing Parafield stormwater harvesting system options to be evaluated, to make a preliminary assessment for alternative options and to provide a basis for developing risk management plans.

In developing the risk assessment of urban stormwater, catchment land uses were assessed using a geographical information system (GIS) based approach for all catchments connected to the Salisbury stormwater trunk main and to the local catchment of the Little Para Reservoir. Land uses were ranked according to the likelihood and severity of potential impacts to water quality.

Water quality samples were collected during wet weather events and monitored for physio-chemical and microbial parameters. Samples were collected at points in each system component of the stormwater harvesting system, within the storage zone, and at the point of end-use. In addition, Quantitative Microbial Risk Assessments (QMRA) were undertaken for each end use in order to quantify the human health risks.

An environmental risk assessment was undertaken with respect to groundwater quality protection and protecting environments exposed to recovered water.

Specific objectives of the project reported here are:

- Characterisation of untreated urban stormwater quality;
- Development of a methodology for stormwater catchment land use analysis; and
- Assessment of the risks to human health for the twelve options for stormwater use (outlined in section 2).

1.2 MAR risk assessment framework

The MARSUO project adopted the twelve element framework given in the Australian Guidelines for Water Recycling for assessing systems and managing risks for end use options. Figure 2 is taken from the Guidelines and decribes these elements. Element 2 is the main subject of this report though treatment requirements and control measures covered in Element 3 are also discussed and informs the subsequent elements addressed within the MARSUO risk management plan (Page *et al.,* 2013).

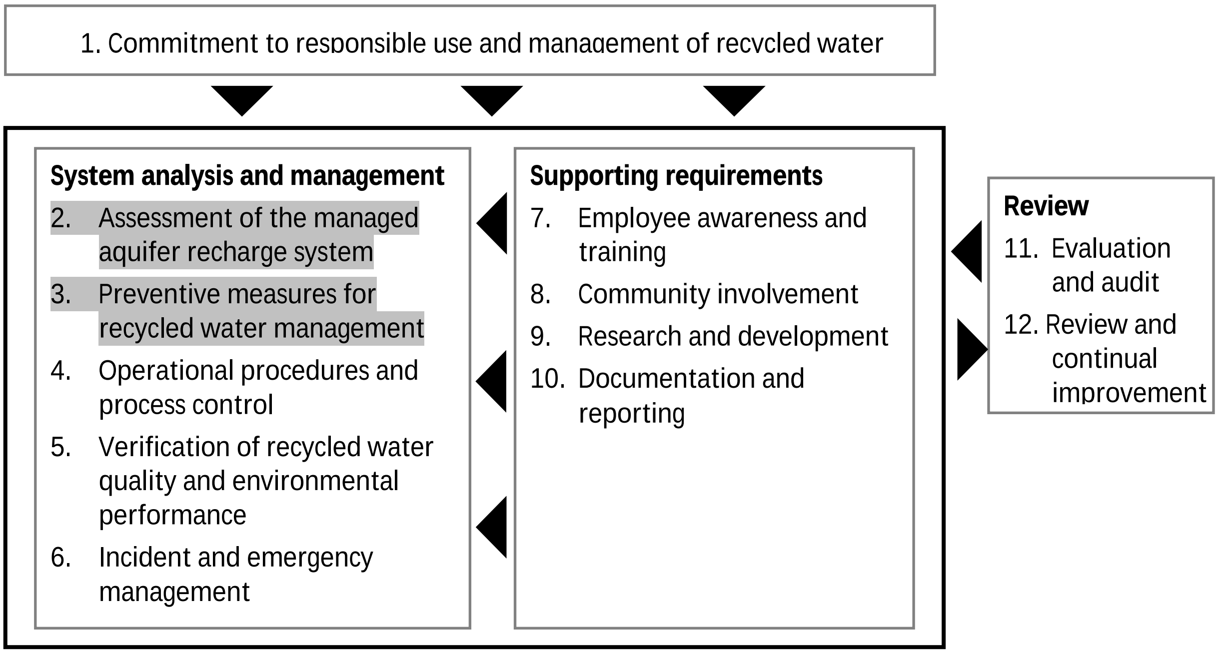


Figure 2 Elements of the framework for management of water quality and use, elements highlighted in grey are addressed in this report (after NRMMC-EPHC-NHMRC 2009b, p. 23).

By addressing the elements of Figure 2, a risk management plan can be developed for each option, spanning elements 1 to 12, that allows for selection of suitable preventative measures, supporting requirements and review procedures so that the risks to human health and the environment are managed.

2 MAR stormwater use options

The main study site, located in the City of Salisbury, has established stormwater catchment and harvesting facilities. These harvesting facilities supply source water for MAR, via Aquifer Storage and Recovery (ASR) and Aquifer Storage Transfer and Recovery (ASTR) systems. The primary focus is on the Parafield stormwater harvesting and MAR scheme and builds on previous research undertaken at this site.

This document refers to four different water types:

1. Recycled stormwater –stormwater that has been harvested and recycled via an aquifer
2. Reclaimed wastewater – treated effluent from the Bolivar Dissolved Air Flotation and Floculation (DAFF) plant
3. Drinking water – potable water for the Adelaide mains distribution system
4. Recycled water – a blend of reclaimed wastewater, recycled stormwater and/or drinking water

The water recovered from MAR currently has a range of non-potable uses including restricted municipal irrigation (limited public access and night irrigation of reserves, ovals and schools) and delivery of water for use in industrial processes (e.g. wool scouring). In addition, water recovered from the Parafield stormwater harvesting MAR scheme is used for blending with reclaimed wastewater for reticulation via a third pipe system to households in the residential suburb of Mawson Lakes. This blended recycled water product can be used for toilet flushing, car washing, filling ornamental pools (with no fish), pet washing, unrestricted garden and municipal irrigation and in evaporative coolers and air conditioners. The Little Para Reservoir and the Little Para Water Treatment Plant supply drinking water via the Adelaide mains distribution system.

The Little Para Reservoir has a small local catchment and was commissioned in 1979 primarily as storage for water pumped from the River Murray. The Parafield ASR and ASTR systems are also integrated into a regional stormwater recycling grid established as part of the *Waterproofing Northern Adelaide* initiative (Water Smart Australia project funded by the Australian Government's Water for the Future Initiative). There is currently no infrastructure connecting the recycling grid to the Little Para Reservoir. However, the volumes of stormwater harvestable in wet years could be of significance in the potential augmentation of the Little Para Reservoir if water quality can be managed effectively and efficiently.

The MARSUO project is evaluating twelve specific options for stormwater use based on historical and current use options in Salisbury and MARSUO project satellite sites, and potential future use options. The final twelve options were finalised by the MARSUO technical committee and Water Safety Expert Panel. These include non-potable existing uses (restricted municipal irrigation, domestic non-potable uses and drinking water use options.

Use of aquifers to improve water quality, to buffer out water quality variations, and to store water is expected to be useful for part of the Adelaide metropolitan area and also parts of other cities. However, suitable aquifers are not available everywhere and the project will address options for stormwater use, with and without aquifer storage.

These twelve options are conceptually illustrated in Figure 3. The options in Figure 3 are listed in three classes of use with increasing human exposure. The lowest exposure and risk are at the top (restricted open space irrigation; options 1-4), followed by domestic non-potable use (toilet flushing and washing machines; options 5-8) and the highest risk, potable use (drinking water supply augmentation; options 9-12) is at the bottom. In each class the requirement of the classes above also need to be met, e.g. drinking water also needs to be suitable for garden irrigation. Within each class are four options listed in order of increasing number of preventative measures or barriers that form part of the multi-barrier approach to management of water quality (illustrated by dots). A dot indicates that a component is present in the system. However each dot representing treatment is a treatment to result in water fit for purpose so dots in any column do not imply that the treatment is the same.

Option 1, irrigation of urban stormwater with no aquifer stormage has previously been implemented in the past but is no longer used and these systems were converted to Option 2 open space irrigation that recycles stormwater via an aquifer. Option 8 is also currently in use where urban stormwater recycled via an aquifer is blended with reclaimed wastewater for third pipe systems.

Each of the twelve options was assessed and the associated risks are discussed separately in this report.

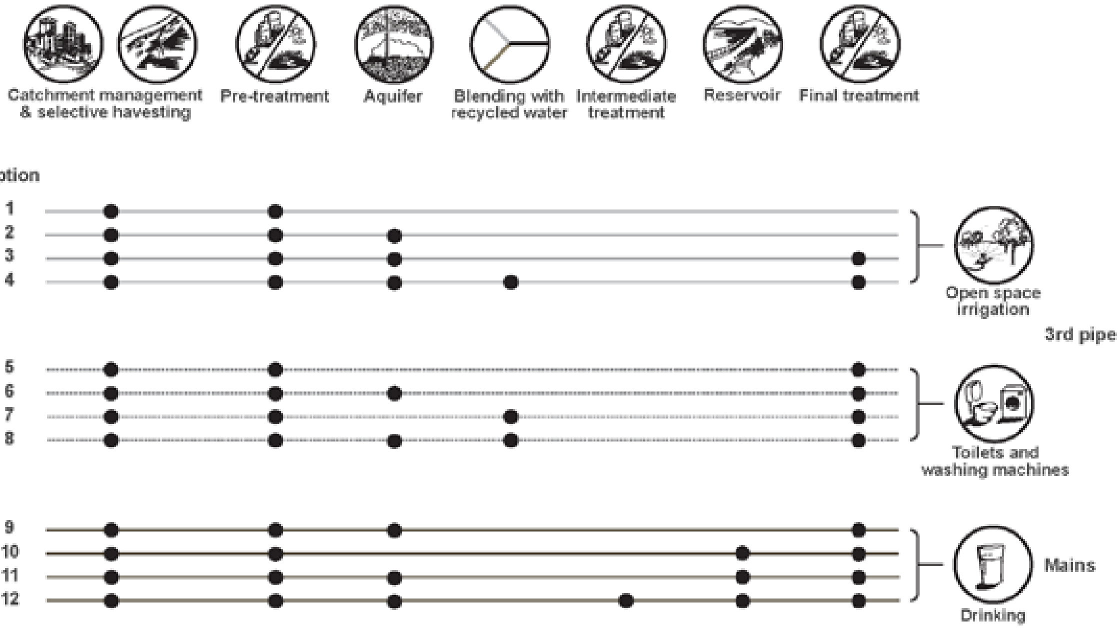


Figure 3 The twelve options evaluated for stormwater use; options 1-8 include non-potable use with and without managed aquifer recharge and blending with reclaimed wastewater; and options 9-12 include indirect potable reuse with and without managed aquifer recharge, intermediate treatment and reservoir storage before the final treatment plant for drinking water mains supply.

3 Salisbury stormwater harvesting system configuration

The locations and configurations of the Salsibury stormwater harvesting systems, comprising wetland systems (for harvesting and pre-treatment) and MAR bores for the schemes supplying the Salisbury ring main stormwater distribution pipeline are shown in Figure 4. The Parafield site harvests primarily from the Parafield stormwater catchment with water from the Cobbler Creek catchment periodically pumped into the drainage system to enhance volumes. Stormwater use options 4, 7 and 8 (Figure 3) also include blending with reclaimed wastewater from the Bolivar Wastewater Treatment Plant (activated sludge/ clarification and stabilisation lagoons) and Recycled Water Treatment Plant (media filtration, chlorination). An important note is that *only stormwater recovered from the Parafield ASR and ASTR schemes is blended with reclaimed wastewater*. A further three hydrological sub-catchments (Little Para Reservoir, Gould Creek and Upper Little Para) are involved if the Little Para Reservoir is considered in options 10-12. Other stormwater harvesting and MAR schemes connected to the Salisbury ring main are also included as the reservoir options may involve transfer via the ring main pipeline and mixing of water from contributing schemes. The distance beween the closest points of the Little Para Reservoir and ring main pipeline is approximately 5.1 km. The elevation difference between these points is around 35m.

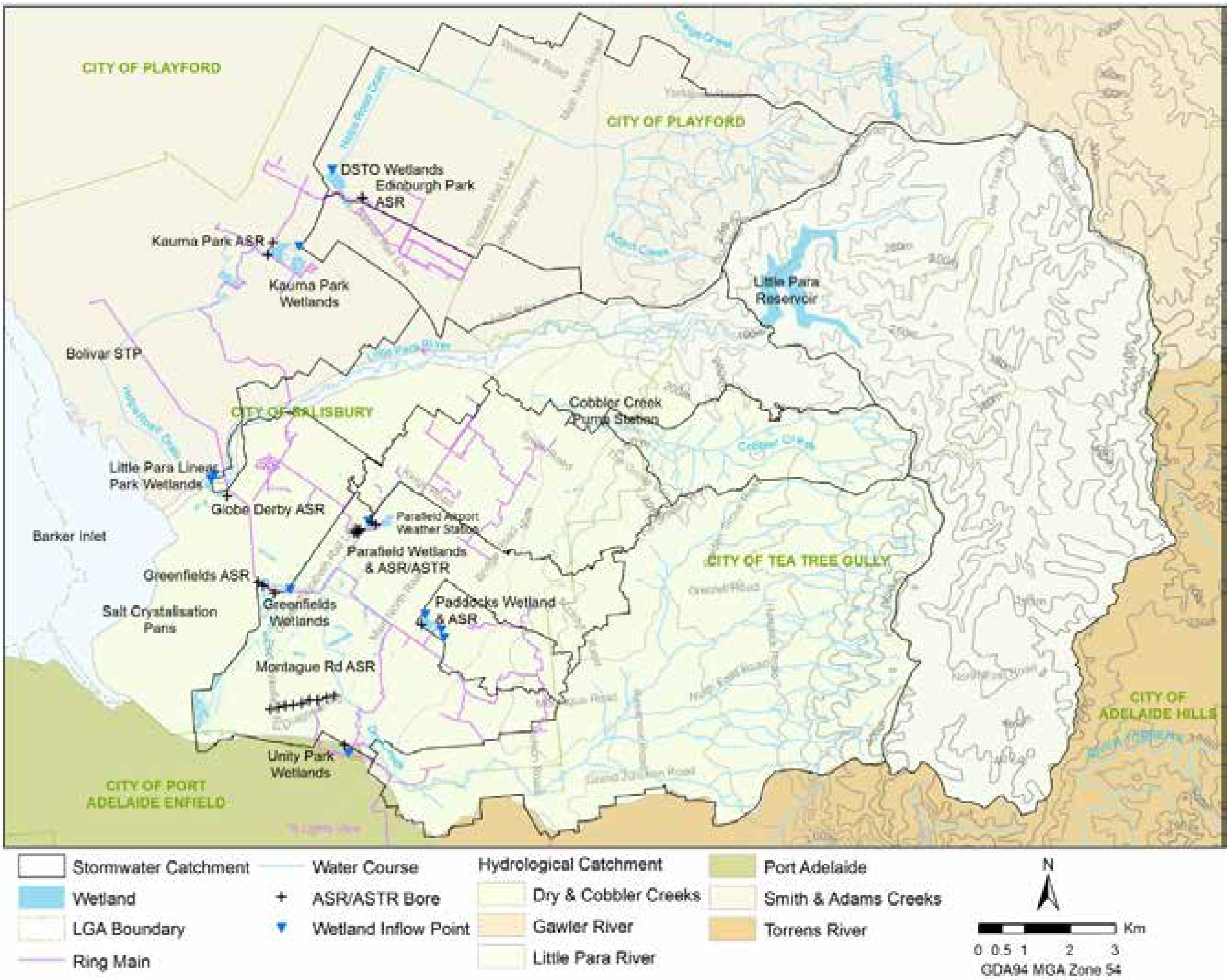


Figure 4 Salisbury stormwater harvesting catchments and MAR schemes shown in relation to Little Para Reservoir and hydrological sub-catchments Dry and Cobbler Creeks, Little Para River, Smith and Adams Creeks (DEWNR, 2012a).

The eight stormwater harvesting sites contributing to the Salisbury ring main pipeline and the Little Para Reservoir are located within three hydrological catchments in two separate basins. The Edinburgh Parks ASR schemes consisting of the Kaurna Park wetlands and ASR site (stage 1) and the Defence, Science and Technology Organisation (DSTO) wetlands and ASR site (stage 2) are in the Smith and Adams Creek catchment, which is part of the Gawler River Basin. The Parafield site (including the ASTR and ASR systems), Paddocks wetlands and ASR site, Unity Park wetlands and ASR site and Greenfields wetlands (stage 1 and 2) and ASR site are located in the Dry and Cobbler Creeks catchment, which is part of the Torrens River Basin. The Little Para Reservoir, Gould Creek and Upper Little Para sub-catchments that drain into the reservoir are located in the Little Para River catchment, which is also part of the Torrens River Basin (DEWNR, 2012a). The Globe Derby Park ASR scheme will harvest water from Little Para River through the Little Para Linear Park wetlands and is also within the Torrens River Basin. This means that the source water for the Globe Derby scheme will be a combination of local runoff from below the Little Para Reservoir dam wall and harvesting of any water released from the Little Para Reservoir. Table 2 compares the stormwater MAR scheme capacities and in relation to the Little Para Reservoir yield and wastewater recycling in South Australia.

Each of the urban stormwater catchment systems are described in detail in Section 5.2. Operation of these systems is described in the following section.

Table 2 Summary of Salisbury stormwater harvesting schemes.

Site name	Year injection commenced	Catchment area (ha)	% Urban area	Estimated annual yield (GL)
Parafield ASR/ASTR	2003	1,590	73	1.1 [a]
Cobbler Creek*	2009	1,017	38	
Unity Park ASR[‡]	2006	5,116	77	0.5 [b]
Paddocks ASR	2000	456	89	0.5 [b]
Greenfields ASR	2008	11,371	71	0.3 [b]
Edinburgh Park ASR	2004	4,417	61	1.2 [a]
Kaurna Park ASR	200	5,512	64	0.3 [b]
Globe Derby Park ASR[†]	n.a.	2,628	61	1.0 [a]
Total		32,107		4.9
Little Para Reservoir		8,185	7	9

Urban proportion of catchments is calculated from summed area of industrial, institutional, recreational, residential and roads/rail land use classes divided by the total catchment area. Land use data were sourced from The South Australian Department of Planning and Local Government as at June 30th 2011 (DPLG, 2011).
*Water sourced from Cobbler Creek augments the Parafield stormwater harvesting scheme; [†]scheme not yet in operation, due for completion in 2013; [‡]Estimated annual yield of 1.5 GL once scheme is full operational.
[a] design capacity; [b] based on Jul 2009-Dec 2011 injection volumes

4 Parafield system operation and monitoring 2003-2012

4.1 Data sources

System operation data for the Parafield stormwater harvesting system and ASR/ASTR operations were supplied from the City of Salisbury 2003-2012 (end Oct). Water quality monitoring data were used from the Parafield stormwater harvesting system 2006-2012. Additional water quality data associated with the other ASR sites that feed into the Salisbury ring main were supplied by the City of Salisbury. Data for the Mawson Lakes reticulation system, the Little Para Reservoir and the Little Para treated water were supplied by SA Water.

4.2 Rainfall and quantities captured by the Parafield stormwater harvesting system 2003-2012

From January 2003 to December 2012 the annual rainfall at the Parafield Airport Bureau of Meteorology weather station (station 23013, latitude 34.80 °S longitude 138.63 °E) varied between 259 mm in 2006 and 483 mm in 2010. Between 2006 and 2008 the mean annual rainfall was 323 mm, 92 mm lower than the 2003-2012 annual average of 414 mm (Table 3).

On average 855 ML/yr was captured by the Parafield stormwater harvesting system between 2003 and 2012, reaching a maximum of 1,187 ML in 2009 with a return to above average rainfall and the addition of harvesting from Cobbler Creek catchment.

Table 3 Annual rainfall and volumes harvested in Parafield catchment from 2003 to 2011.

Year	Rainfall (mm)[3]	Harvested volume Parafield [1] (ML)	Volume lifted from Cobbler Creek (ML)	Harvested volume over catchment (ML)	% rainfall harvested [2]
2003	445	422	0	422	4
2004	440	857	0	857	7
2005	456	1,034	0	1,034	9
2006	259	500	0	500	7
2007	380	749	0	749	8
2008	329	677	0	677	8
2009	475	1,187	275	1,462	12
2010	483	1,097	206	1,303	10
2011	470	856	41	897	7
2012	407	571	77	648	5
Average	**414**	**795**	**174**	**855**	
Total	**4,145**	**7,950**	**598**	**8,548**	

based on: [1] volume recorded in holding storage; [2] combined total catchment area of 2,607 ha for Parafield and Cobbler Creek; [3] based on closest active weather station (23013) to the centroid of catchment, variability of rainfall across the entire catchment is not accounted for.

4.3 ASR/ASTR system quantities injected and extracted 2003-2012

The ASR well field consists of two wells (ASR1 and ASR2) and the ASTR well field consists of four injection wells (IW1-4) surrounding two recovery wells (RW1 and RW2) (Figure 5). The ASR scheme has been operational since 2003 and the ASTR scheme commenced in 2006. From September 2006 to June 2008, the ASTR site operation was dedicated to a flushing period to freshen the storage zone whereby 377 ML injection was undertaken via the recovery wells. Following this, the ASTR operational mode with injection via the injection wells commenced in September 2008.

In the period of 2003 to 2012 (end Oct), 4,241 ML harvested stormwater has been injected into the Tertiary T2 aquifer via the Parafield ASR and ASTR operations. The ASR operation has added 3,172 ML and ASTR have added a further 1,069 ML. A total of 2,854 ML has been recovered in this period, 2,189 ML from ASR and 666 ML from ASTR, leaving a net volume of 1,629 ML within storage in the aquifer (Table 4). Monthly operational data for the Parafield ASR and ASTR operations are in Appendix 1. Aquifer detention times for the ASTR scheme were determined from groundwater modelling by Kremer *et al*. (2008).

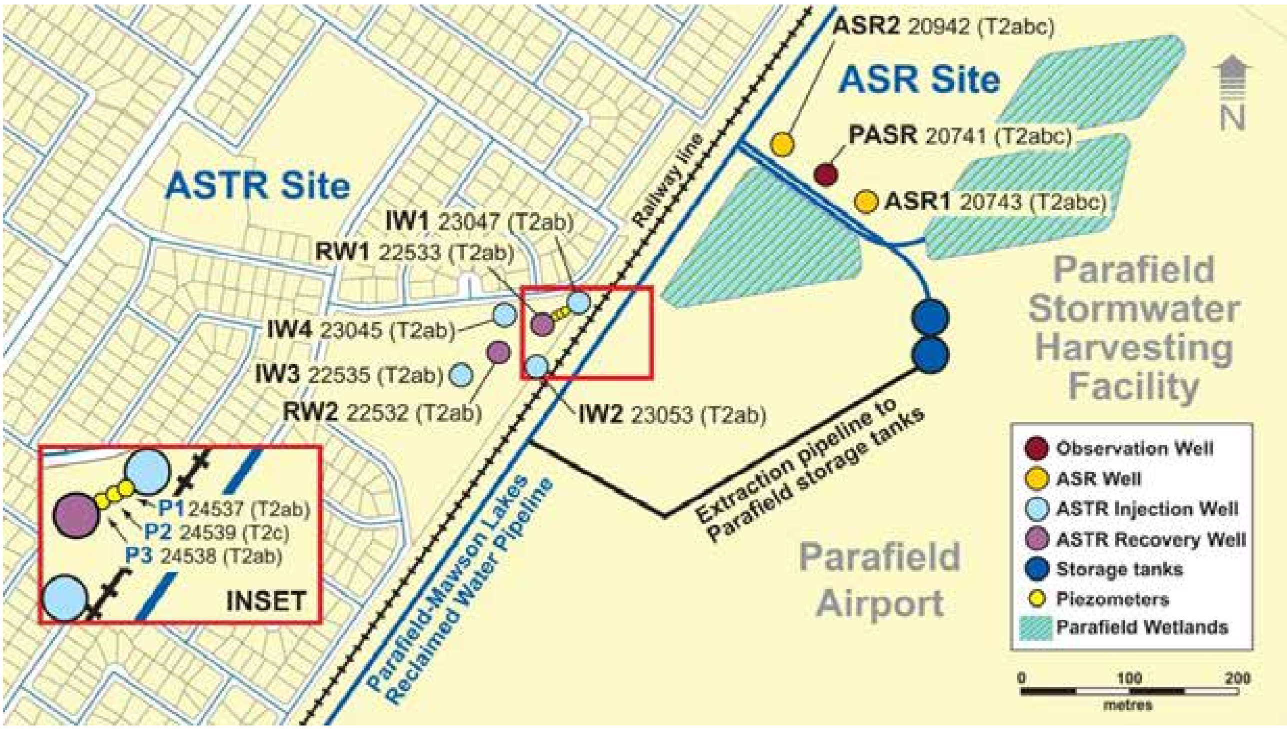


Figure 5 City of Salisbury water harvesting facilities in the Parafield area, identifying the location of wells at the ASTR and ASR sites (after Kremer *et al.,* 2008). Well unit numbers (preceeded with 6628-) and aquifer sections intersecting with well screened sections are annotated.

For comparison, a summary of injection and extraction history for additional ASR operations within the City of Salisbury is presented in Appendix 1. Kaurna Park and Unity Park ASR and Parafield ASR and ASTR schemes target the T2 aquifer while Greenfields and Paddocks ASR target the overlying T1 aquifer, which is also used for irrigation water supply in the area.

Table 4 Quantities of water injected and extracted by ASR and ASTR from 2003 to 2011.

Year	Harvested volume over catchment (ML)	ASR injection volume	ASR recovery volume	ASTR injection volume	ASTR recovery volume	Cumulative volume injected	Cumulative volume extracted	Cumulative net aquifer replenishment
2003	422	256	0			256	0	256
2004	857	520	38			776	38	738
2005	1,034	455	108			1,231	146	1,085
2006	500	2	228	77	0	1,310	374	936
2007	749	195	306	150	0	1,655	680	975
2008	677	203	417	166	1	2,027	1,098	949
2009	1,462	516	219	135	162	2,697	1,479	1,218
2010	1,303	336	275	180	152	3,213	1,906	1,308
2011	897	285	252	194	108	3,692	2,266	1,426
2012	648	404	346	145	242	4,241	2,854	1,387
Mean	**855**	**317**	**219**	**153**	**95**			
Total	**8,548**	**3,172**	**2,189**	**1,069**	**666**			

[1] based on volume recorded in holding storage

5 Characterisation of stormwater catchments

5.1 General overview

The hydrology of the area can generally be described as a westerly draining system with the Mount Lofty Ranges to the east and the Adelaide Plains area upon which the Parafield site, Salisbury ring main and associated stormwater harvesting systems are located. Little Para Reservoir is located approximately 22 km north-east of Adelaide (S 34° 44' 40", E 138° 43' 30") at around 200m in elevation, about 150m above the Adelaide plains. The layout of the ASR and ASTR sites, wetlands and Little Para Reservoir in relation to hydrological basins, catchments and sub-catchments is shown in Figure 4 and discussed in Section 3.

As land use varies considerably between harvesting schemes it is critical to understand the inflow and outflow points and creek diversions in order to define sources and delineate the catchments that harvest stormwater and runoff for land use assessment and risk assessment purposes. Equally, for evaluating risks of use options involving transfer to the Little Para Reservoir (options 10, 11, 12); the catchment feeding Little Para Reservoir was also examined as a comparison to the urban stormwater catchments.

The area that directly contributes water to the Parafield harvesting site is hereafter referred to as the Parafield catchment (1,590 Ha), the area feeding into Cobbler Creek is hereafter referred to as the Cobbler Creek catchment (1,017 Ha) and the catchment flowing into Little Para Reservoir is referred to as Little Para Reservoir catchment (8,185 Ha) (see Figure 4). A number of other ASR schemes exist that harvest and supply recovered water to the Salisbury ring main stormwater distribution system. These sites and their respective catchments are also considered for the land use characterisation and water quality risk assessment and also shown in Figure 4.

The delineation methods used by Swierc *et al*. (2005) to define the Parafield stormwater catchment were not clear and at that stage the Cobbler Creek area was not included. Revised stormwater catchment boundaries (including the Parafield site) were delineated using a combination of digital elevation model (DEM) data, stormwater infrastructure and modelled flow layers, water course lines, aerial imagery, roads and land parcel data in a Geographical Information System (GIS) (ESRI ArcGIS™ Version 10). A detailed description of boundary delineation methods and spatial data sources is given in Appendix 2. The boundaries of the hydrological sub-catchments draining to Little Para Reservoir were sourced from a publicly available spatial database server (DEWNR, 2012a). Three hydrological sub-catchments; Little Para Reservoir, Gould Creek and Upper Little Para, were included.

Catchment characterisation in terms of land use was used to help inform stakeholder workshops on hazard identification and risk assessment and management. A generalised, state-wide land use layer was sourced from the Department of Planning and Local Government (DPLG) from a publicly available online server (DPLG, 2011). These data were re-coded from 18 classes to 12 to simplify assessments e.g. by grouping different residential and vacant land use types (see Appendix 2). These data provided reasonable precision for metropolitan areas but were less useful in more rural areas e.g. Little Para Reservoir sub-catchments.

Coverage of the Little Para Reservoir catchment area (including the upper area of the Globe Derby and Unity Park catchments) by the DPLG layer lacked spatial precision (compared to aerial imagery and land tenure data) and also contained little detail on land use. Publicly available land use data using the Australian Land Use and Management (ALUM) classification system were sourced from the Australian Bureau of Agricultural and Resource Economics and Sciences web server (ABARES, 2012). The ALUM classification system provides a nationally consistent land use data set but is focussed on rural regions at the catchment scale and metropolitan areas are unmapped. These data were also re-coded in line with methods applied to the DPLG sourced layer. Spatial modelling methods and data source are described in detail in Appendix 2. Results of the general land use assessment for the stormwater catchments that feed water into the various harvesting facilities and Little Para Reservoir are given in Table 4 and a map output example for the Parafield ASTR site is given in Figure 6.

5.2 General land use assessment

For catchment management to protect water quality, the importance of "*knowing your catchment*" cannot be over-emphasised. The stormwater catchments were assessed using this same attention to details as it is essential to understand the characteristics of the stormwater system, what hazards may arise, how these hazards create risks (termed hazardous events), and the catchment processes that affect stormwater quality such as residence time and any water sensitive urban design features that may affect water quality. This principle is an essential component of the Australian Guidelines for Water Recycling (Phase 1) (NRMMC–EPHC–AHMC, 2006) framework for managing water quality.

For urban stormwater harvesting systems a diagram showing system components is useful to identify barriers for water quality management, as well as understanding the nature and boundaries of the stormwater catchment system. These graphics are valuable in risk assessment workshops with stakeholders and project partners. The assessment and evaluation of stormwater quality may be facilitated by breaking the source down into sub-catchments and understanding dominant land uses. It is important to understand the linkages between the sub-catchments which can be supported by diagrams. For example, in the current project recognition was given to the location of sampling points in relation to different land uses in sub-catchments to facilitate evaluation of cause and effect relationships on stormwater quality.

The total area and the proportion of the catchment occupied by each general land use class are summarised for each catchment in Table 5 and displayed in Figure 6. Vacant land parcels comprise mainly open grassland and scrub that are generally classified as 'vacant allotment, conservation or recreation'. This general land use assessment provided a critical first step toward identifying the variety of potential hazards and risks in the catchments associated with different land uses. The following sub-sections briefly describe the basic hydrology and land use for each catchment. This is followed by a description of catchment risk assessment based on hazards associated with the identified land uses (section 6).

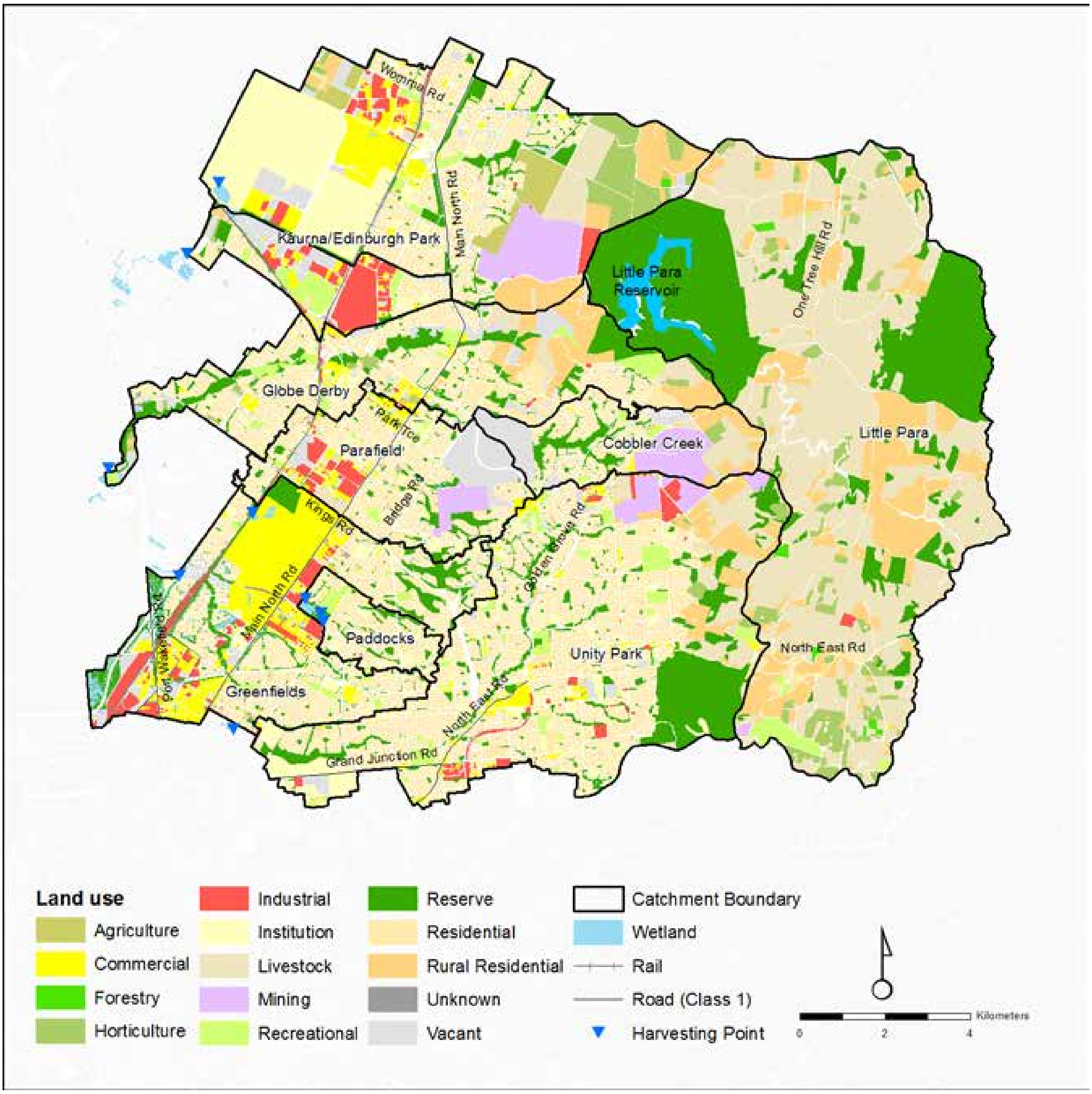


Figure 6 Catchment land uses related to stormwater harvesting and reuse schemes. Land use data sourced from DPLG (2011) and ABARES (2012).

Table 5 General land use types in the stormwater catchments.

	Parafield		Cobbler Creek		Edinburgh Park		*Greenfields		Kaurna Park		Paddocks		*Unity Park		*Little Para		*Globe Derby	
Land Use	Area (ha)	% Catch.	Area (ha)	% Catch.	Area (ha)	% Catch.	Area (ha)	% Catch.	Area (ha)	% Catch.	Area (ha)	% Catch.	Area (ha)	% Catch.	Area (ha)	% Catch.	Area (ha)	% Catch.
Agriculture	0	0	0	0	189	4	0	0	191	4	0	0	42	0.8	0	0	10	0.4
Commercial	72	5	3	0.2	319	7	935	8	365	7	5	1	124	2	2	<0.1	73	3
Forestry	0	0	0	0	4	0.1	0	0	4	0.1	0	0	0	0	29	0.4	0	0
Horticulture	3.4	0.2	15	2	284	6	60	0.5	289	5	0	0	35	1	379	5	39	1
Industrial	125	8	6	1	128	3	428	4	339	6	0	0.1	136	3	9	0.1	18	1
Institution	61	4	17	2	1,016	22	575	5	1,029	19	23	5	347.2	7	1	<0.1	58	2
Livestock	21	1	91	9	172	4	450	4	172	3.2	0	0	171	3	3,943	48	107	4
Mining	82	5	166	16	290	6	388	3	290	5	0	0	136	3	9	0.1	0	0
Recreational	15	1	16	2	62	1	323	2.8	155	3	26	6	163	3	83	1	121	5
Reserve	115	7	97	10	209	5	1,469	13	238	4	69	15	371	7	2,089	26	367	14
Residential	574	36	225	22	793	17	3,860	34	895	17	234	51	1,922	37	62	1	922	35
Rural Residential	0.5	<0.1	107	11	322	7	368	3.2	329	6	0	0	476	9	1,123	14	309	12
Roads/Rail	308	19	121	12	495	11	1,779	16	599	11	95	21	892	17	449	6	402	15
Unknown	0	0	0	0	8	0.2	48	0.4	8.1	0.2	1.2	<0.1	23	0	0	0	5	0.2
Vacant	213	13	153	15	265	6	731	6	416	8	1	0.3	414	7.9	0	0	197	8
Catchment Area (ha)	1,590		1,017		4,556		11,414		5,319		456		5,252		8,178		2,628	
Urban Proportion		73%		38%		62%		69%		64%		84%		68%		7%		61%

Areas are summed for each land use type and '% Catch.' is the proportion of the total catchment area occupied by that land use type. Urban proportion of catchments is calculated from summed area of industrial, institution, recreational, residential and roads/rail land use classes divided by the total catchment area. Land use data sourced from The South Australian Department of Planning and Local Government as at June 30th 2011 (DPLG, 2011).
*Land use also sourced from the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) using Version 6 of the Australian Land Use and Management (ALUM) classification system for South Australia 2007-2008 (ABARES, 2012).

5.2.1 Parafield stormwater catchment

The Parafield site, including the Parafield airport wetlands and ASTR and ASR locations are located in the Dry and Cobbler Creek hydrological catchment, which is part of the Torrens River Basin. The topography of the Parafield stormwater catchment is generally westerly sloping with a shallow gradient. Stormwater collected from the catchment through the weir on the Parafield Drain passes through a series of two 50 ML detention basins and a 2 Ha constructed wetland prior to injection into the Parafield ASR or ASTR schemes into the T2 aquifer. Based on runoff coefficient (impervious area) modelling by Richard Clark & Associates (2001), the total impervious area across the catchment is 40% (pervious area 60%).

The Parafield stormwater catchment has an area of 1,590 Ha and is primarily urban (73%). It is composed of mainly residential (36%) but also has vacant land (13%) and industrial areas (8%). Roads and rail lines account for 19% of the catchment area. The industrial areas include a pharmaceuticals factory, a wool processing plant, a dairy processing facility and a beverage manufacturing factory and a variety of small to medium metal and cement manufacturing industries. A variety of commercial properties (5%) are also found, including a number of automotive service and repair businesses and numerous warehousing facilities. There are also a number of small market garden horticultural properties and one livestock grazing paddock adjacent the harvesting off take point. 'Recreational' land uses include mainly sports fields and 'institution' includes libraries and council buildings. A major rail line runs along the western part of the catchment.

5.2.2 Cobbler Creek stormwater catchment

The Cobbler Creek stormwater catchment has an area of 1,017 Ha and has a greater topographic relief than Parafield also sloping to the west and features a major water course (Cobbler Creek) that the majority runoff from this catchment drains to. Cobbler Creek features a dam constructed just above the CCk1 water quality sampling point that was built for flood mitigation purposes and whose operation is managed by the City of Salisbury. This dam collects water that can be released and pumped into the Parafield catchment if additional yield for the system is required. The pump station is equipped with a Grundfos S1-304AM1 pump that is run at 30 L/s (City of Salisbury pers. comm.).

The Cobbler Creek catchment is predominantly a rural catchment but its urban component is mainly residential properties (22% of the catchment). Only 1.2% of the catchment is zoned as industrial or commercial. Mining (sand and clay quarries) also occupies a large area of the catchment (16%) and vacant land accounts for a further 15%. Roads account for 12% of the catchment area. A number of livestock (mainly sheep) production and horticulture properties exist in the east (11% area). There are also a number of unsewered rural residential properties (11%) with on-site waste water treatment systems (septic tanks). Some of these rural residential zoned properties were observed to have domestic livestock including horses and catteries present.

5.2.3 Greenfields stormwater catchment

The Greenfields wetlands and ASR scheme is located in the southwest of the City of Salisbury adjacent the Salisbury Highway in the suburb of Greenfields. Progress reports from 1994 and 1995 shortly after the construction of the wetlands (stage 2) in 1993, found that the only inflow of significance was through diversion of the Dry Creek Channel into the stage 2 wetlands near McKenzie Circuit, Greenfields (Jenkins, 1996). This point remains the main inflow point for diversions from the Dry Creek Channel to the scheme, which now includes an extension to the stage 1 and 2 wetlands (stage 3). This point is also downstream from the pump station adjacent Royal Avenue that lifts Dry Creek flow into the Unity Park wetlands and downstream of the junction between the Dry Creek Channel and the Parafield Drain and Greenfields Drain. This means that the Greenfields stormwater catchment potentially harvests water from the combined area of Parafield, Cobbler Creek (through pumping at Bridge Road), Paddocks and Unity Park plus an additional local stormwater catchment component. The total area of the catchment is then the largest assessed in this study at 11,379 Ha though according to early progress reports, only a minor proportion (<5%) of the total flow in Dry Creek Channel is diverted and captured in the Greenfields wetlands (Jenkins, 1996). Captured stormwater passes through Stage 2 and then Stage 1 wetlands; Stage 3 provides additional surface storage capacity for Stage 1. It is then injected via either of two ASR bores into the T1 aquifer. Injected water volumes are used for transfer of water credits to allow extraction at other wells under current State regulations. Water is generally not extracted at the Greenfields ASR scheme and does not contribute to the Salisbury ring main. Water injected at Greenfields is used to transfer water allocation credits to allow extraction at other sites e.g. community wells.

Land use for the Greenfields scheme is a combination of classes seen in Parafield, Cobbler Creek, Paddocks and Unity Park with some additional industries and businesses in the local catchment. It is difficult however, to determine what proportion of the catchment area contributes to the water volume and quality at the wetland inlet without hydrographical records at various points across the system. Overall, the catchment area is dominated by urban land uses totalling 69% of the catchment including residential (34%), roads and rail (16%), public institution (5%), industrial (4%) and commercial (4%), see Table 5. Areas of agriculture, horticulture and livestock along with rural residential properties and some mining (sand and clay quarries) are distributed in the eastern part of the catchment towards the hills. Industries to note include abattoir/meat processing facilities off Churchill Road North and Newcastle Crescent in the suburb of Dry Creek and a large rail maintenance yard and switching station near Port Wakefield Road in Dry Creek. Other industries include structural metal production, cement, lime and gypsum productionor packaging and plastics manufacturing.

5.2.4 Edinburgh Park (stage 2) stormwater catchment

The Edinburgh ASR scheme is stage two of the Edinburgh Parks stormwater harvesting scheme, stage one is the Kaurna Park wetlands and ASR system to the south (Figure 4). Both stages capture water primarily from the Helps Road Drain which is an extension of Adam Creek and natural tributaries to the east. The catchment for the Edinburgh Park stage two system comprising the DSTO wetlands and ASR bores, is in effect a subset of the Kaurna Park stage one system downstream to the south. Above the inflow point at the DSTO wetlands the catchment area is 4,558 Ha. Captured stormwater is pumped from the DSTO wetlands and injected via nearby ASR wells into the T2 aquifer.

Edinburgh is mainly urban (62%) and Table 5 shows that land use is comprised mainly of public institutions (22% of the catchment area) dominated by the Edinburgh Royal Australian Air Force (RAAF) base (715 Ha), residential areas (17%) and road surface and a major rail line (11%). This catchment also contains a number of commercial properties comprising 7% of the catchment and also has a variety of industrial properties including motor vehicle manufacturing and allied industries, plastics manufacturing facilities, a tannery, printers, various chemical manufacturers, a fertiliser factory and an electricity sub-station together accounting for 3% of the catchment area. Rural residential properties occupy 7% of the total catchment land use. In the southeast of the catchment is a relatively large crushed stone quarry (291 Ha) comprising 6% of the catchment area. The upper eastern part of the catchment is mainly classed as horticulture, livestock and agriculture (6%, 4%, 4% respectively) and a small area of forestry (<1%).

5.2.5 Kaurna Park (Stage 1) stormwater catchment

The Kaurna Park (Burton) wetlands and ASR system is stage one of the Edinburgh Parks stormwater harvesting scheme located in the suburb of Burton (stage two is the DSTO wetlands and Edinburgh ASR system). As in the Edinburgh system, the primary inflow to the extensive Kaurna Park wetlands system of 22 Ha, is from the Helps Road Drain coming in under Diment Road to the north east of the wetlands. Stormwater not captured and stored at the stage two Edinburgh scheme can pass through Helps Road Drain to the Kaurna Park wetlands. Water moves through a series of winding channels and lagoons south and west of the inflow where the pump station lifts it out prior to injection in one of two ASR bores into the T2 aquifer. There also appears to be a local stormwater catchment component draining urban runoff into the eastern-most lagoons via stormwater pipes and at least one outlet drain. In effect, the total catchment area comprises the extent of the Edinburgh catchment (4,558 Ha) plus the local catchment and area draining into the rest of Helps Road Drain south of the DSTO wetlands (762 Ha), hence the total catchment area is potentially 5,320 Ha.

The additional catchment area included when considering both stage one and two of the Edinburgh Parks harvesting schemes does not change significantly compared to looking at the stage two systems separately.

The largest proportion of land use is public institutions (19%) followed by residential (17%) and roads and rail (11%). The same major features appear including the quarry, vehicle manufacturing facility, RAAF base and rural residential and agricultural properties in the upper catchment. Locally, a number of recreational properties including a large golf course (73 Ha) and a number of sports fields are included. A 9.5 Ha plant nursery is located just south of the wetland along with a number of irrigated horticultural fields and glasshouses.

5.2.6 Paddocks stormwater catchment

The Paddocks wetlands stormwater catchment is positioned in the south eastern part of the City of Salisbury and parts of the western area of the City of Tea Tree Gully in the suburb of Para Hills. The wetlands were constructed primarily for flood mitigation purposes and are similar to wetlands constructed to improve water quality (Tomlinson *et al*., 1993). The wetlands consist of meandering channels and ponds with grass swales and native bushland vegetation (Tomlinson *et al*., 1993). The total catchment area is around 456 ha and has a southeast-northwest elevation gradient sloping toward the northwest with a gradient of about 1:25. Runoff generally flows northwest draining to the Paddocks Wetlands via at least two visible entry points. Drains are also located on the north western side of the wetlands that empty into the system via a creek. Tomlinson *et al*. (1993) focussed on only the first inlet weir and stormwater catchment in Ingle Farm to the south west of the wetland. Other inflow points were established upon site visits and GIS analysis. Captured stormwater is then injected via ASR to the T1 aquifer. Total injected volumes range from around 27 ML to 83 ML per year averaging at about 47 ML from 1997 to 2005 (data from the City of Salisbury). Based on modelling by Richard Clark & Associates (2001) the catchment surface is 45% impervious.

The Paddocks catchment contains a very high proportion of urban surface area (84%). The land use is mainly residential (51% of catchment) and roads 21% with scattered recreational areas (11%), reserves (10%), public institution (5%) and commercial properties (1%). A very small proportion of the catchment (<1%) is industrial and contains no mining, rural residential agriculture or forestry land uses (Table 5).

5.2.7 Unity Park stormwater catchment

The Unity Park wetlands are located near the southern border of the City of Salisbury in the suburb of Pooraka. It differs from the Parafield site in that the Unity Park wetlands are filled only through stream diversions from Dry Creek at a pump station off Royal Avenue. The wetlands consist of a series of 2 detention ponds and a constructed wetland where water is pumped from one to another. The Unity Park stormwater catchment is essentially the Dry Creek catchment area above the pump station on Royal Avenue. This is a large catchment area of 5,252 Ha draining from higher elevation and slope in the west and following the northwest topography. Following capture and pre-treatment in the wetlands and passage through a series of 6 vertical biofilters, the water is injected into the T2 aquifer via a nearby ASR bore. Future expansion of the scheme involves pumping up to the Montague Road extension where it can be injected in any of nine ASR wells into the T2 aquifer. The Unity Park scheme is not yet operating at full capacity but is designed to capture and store up to 1.5 GL per year (Table 2).

Land use in the catchment is mainly urban (68%) consisting primarily of residential (37%) and road surface (17%) area. Rural residential properties located high up in the catchment account for 9% and a further 7% are reserves many of which are along Dry Creek. Public institutions occupy another 7% the largest of which is the Yatala Labour Prison (55 Ha) as well as a number of education facilities (schools and technical colleges). Industrial land uses and mining (sand and clay quarries in the upper part of the catchment) each account for 3% and livestock production (also high in the catchment) occupies 3% (Table 5).

5.2.8 Globe Derby Park stormwater catchment

The Globe Derby Park scheme is the newest stormwater harvesting ASR project in Salisbury and is not yet operational. It is dues for completion in 2013. It is located within the Little Para River hydrological catchment (Figure 4). It is designed to produce 1 GL per year of recycled stormwater (City of Salisbury pers. comm.). The scheme will pump water from the Little Para River following its passage through the Little Para Linear wetlands. Water will then be injected into the T2 aquifer via bores to be located nearby on the reserve on the corner of Whites Road and Ryans Road. The scheme will harvest water released from Little Para Reservoir as well as runoff from the 2,628 Ha local stormwater catchment of Little Para River below the level of the dam wall. For the purposes of this catchment risk assessment, only the local catchment is considered as the Little Para Reservoir catchment is considered separately. In effect the catchments are linked and water quality will be a product of one or both systems.

The urban proportion of land use in the local stormwater catchment is 58%. Land use is mainly residential (35%), road surface accounts for 15% and there are large areas of and reserves located mainly along Little Para River comprising 14% of the catchment area. 12% of the catchment is zoned as rural residential and vacant land occupies 8%. There are relatively small areas of other general land uses except for forestry and a rail line intersects the catchment. Livestock, horticulture and agriculture together occupy just over 5% of the catchment mostly located in the eastern headwaters area where most of the rural residential properties are also found. There is a relatively small area (1%) of industrial land use comprised mainly of small, light industries including metal fabrication, furniture and rubber manufacturing businesses.

5.2.9 Little Para Reservoir catchment

The Little Para Reservoir catchment is primarily a surface water runoff catchment and was commissioned in 1979 by the State government as a drinking water supply catchment. The Little Para Reservoir has a capacity of 20.8 GL and as of 2011-12, holds a 5-year average of 10 to 13 GL. The reservoir functions mainly as a balancing storage for River Murray water pumped via the Mannum-Adelaide pipeline The reservoir is kept below the full supply level so that it can serves a flood mitigation role (SA Water, 2012). Unlike the urban stormwater catchments described above, it does not contain stormwater drains and pipes but consists of a series of open water courses. It comprises of three hydrological sub-catchments (as defined by DEWNR); Little Para Reservoir, Gould Creek and Upper Little Para that together feed into the reservoir which together total 8,178 Ha in area. Annual catchment flow (without reservoir or dams) is estimated at 9 GL (RDAB, 2011).

Land use is rural consisting of mainly livestock (grazing pastures) (48% of the catchment area) but also has a large proportion set aside as reserves (26%) of which a large part surrounds the reservoir itself as a natural buffer to protect water quality. Rural residential properties, many with a combination of livestock and horticultural production, account for 14%, residential a further 62 ha (1%), while horticulture occupies 5% (379 Ha) of the catchment and there is 29 Ha of forestry. Roads only occupy 5% of the catchment area and many are unsealed (Table 5). Recreational land use is dominated by mainly by a large golf course and mining includes one active quarry (9 Ha) in the south west that extracts shale and clay (Figure 6).

6 Water quality risk assessment

The risk assessment methodology is based on the approach outlined in the Australian Guidelines for Water Recycling Phase 1 and Phase 2 documents (NRMMC-EPHC, 2006; NRMMC-EPHC-NHMRC, 2009a). The risks assessment includes the seven water quality hazard groups from the Phase 2 MAR guidelines (NRMMC-EPHC-NHMRC, 2009b): pathogens; inorganic chemicals; nutrients; salinity; organic chemicals; turbidity and radionuclides. It follows the generalised framework of hazard identification and qualitative risk assessment. Water quality risks to public health, operational infrastructure and the environment arising from catchment (source) and ambient groundwater were assessed.

Catchment stormwater quality hazards were identified by a series of stakeholder workshops, the first of which was focussed on hazard identification in March 2011. A total of around 20 stakeholders comprised representatives from the MARSUO technical committee, invited guests from various universities and state and local government. This was followed in May 2011 with a satellite sites hazard identification workshop with 20 representatives from existing project satellite sites in Singapore, Orange, Brisbane amoung others from Melbourne, Geelong and Adelaide. In June 2011, the results of the hazard identification workshops were qualitatively assessed for risk by nine members of the technical committee to form an comprehensive list of stormwater quality risks. Lastly, a risk management workshop was held in November, 2011 with an attendance of 12 members of the technical committee and invited guests from universities and consulting agencies. Hazards originating from ambient groundwater, aquifers and interactions between injected stormwater and ambient groundwater and aquifers were identified through literature reviews and review of groundwater quality data.

6.1 Identification of water quality hazards

Hazards can have three attributes; those that raise human health risks, those that raise risks to infrastructure and operations, and those that raise risks to the environment. Identifying water quality hazards was achieved by:

- Recognising land uses and activities in the stormwater catchments that may constitute specific risks to water quality.
- Characterising the ambient groundwater quality, aquifer mineralogoly and interactions with injected stormwater.
- Conducting workshops with project partners and stakeholders.
- Reviewing stormwater and groundwater quality data and identifiying specific trends or issues.

Furthermore, water quality can also be evaluated in terms of either concentration-based or load-based hazards. Characterisation of load-based hazards is especially important where stormwater discharges to the environment (e.g. stormwater outflows to St Vincent's Gulf) and was a focus of water quality monitoring in 2012 with the installation of the Parafield Data Station, an automated water quality sampling and flow gauging station. When reviewing the water quality data for the stormwater catchments, water quality hazards were identified through:

- Exceeding guideline values (depending upon the three options of stormwater use: open space irrigation, dual pipe systems or drinking water);
- Trends in data over a time series;
- Published literature;
- Workshop outputs;
- Expert opinion; and
- Anecdotal information and observation of ecosystem impacts.

6.2 Risk assessment methods

Various literature sources on risk assessments for water safety and quality describe qualitative methods to determine risks from the *likelihood* of occurrence and *severity* of potential impacts of a *hazard* using a matrix-based category approach (Bartram *et al*., 2009; NHMRC–NRMMC, 2011; NRMMC-EPHC, 2006). The method applied to this risk assessment is based on the system described in the Phase 1 Australian Guidelines for Water Recycling (NRMMC-EPHC, 2006) outlined in Figure 7. This generalised method was selected as it is relevant to Australian systems, accounts for all risk types and importantly, uses a rating system that prioritises rare but severe risks.

Likelihood			Severity		
Level		Example Description	Level		Example Description
1	Rare	May occur only in exceptional circumstances. May occur once in 100 years	1	Insignificant	Insignificant impact or not detectable
2	Unlikely	Could occur within 20 years or in unusual circumstances	2	Minor	Health — Minor impact for small population. Environment — Potentially harmful to local ecosystem with local impacts contained to site
3	Possible	Might occur or should be expected to occur within a 5- to 10-year period	3	Moderate	Health — Minor impact for large population. Environment — Potentially harmful to regional ecosystem with local impacts primarily contained to on-site
4	Likely	Will probably occur within a 1- to 5-year period	4	Major	Health — Major impact for small population. Environment — Potentially lethal to local ecosystem; predominantly local, but potential for off-site impacts
5	Almost certain	Is expected to occur with a probability of multiple occurrences within a year	5	Catastrophic	Health — Major impact for large population. Environment — Potentially lethal to regional ecosystem or threatened species; widespread on-site and off-site impacts

		Consequences				
		1	2	3	4	5
Likelihood	1	Low	Low	Low	High	High
	2	Low	Low	Moderate	High	Extreme
	3	Low	Moderate	High	Extreme	Extreme
	4	Low	Moderate	High	Extreme	Extreme
	5	Low	Moderate	High	Extreme	Extreme

Figure 7 Risk assessment categorisation and ranking method adapted from the Phase 1 Australian Guidelines for Water Recycling (NRMMC-EPHC-AHMC, 2006 p. 39).

A *hazardous event* is an incident that can lead to the presence of a hazard in stormwater. Generally, the hazardous event relates to either a natural event like rainfall causing runoff from grazed paddocks; or a man-made direct-discharge incident like a tanker spill. Specific land uses (e.g. automotive repairs workshops) pose certain water quality hazards. When reviewing land uses within a catchment, it was important to recognise the water quality hazards that existed (e.g. stored volumes of oils and hydrocarbons), and the specific hazardous event conditions (e.g. a container spill) under which the hazard may become a risk to stormwater quality. The generalised land use GIS data from DPLG in this regard were insufficient. More detailed land use layers at a scale that identified individual land holdings was sourced from the City of Salisbury (CoS) and the City of Playford (CoP) and an assessment was conducted in order to derive a list of specific land uses within the stormwater catchments.

The catchment land use risk assessment results were incorporated into a GIS to map the spatial extent of different water quality risks across the stormwater catchments. Detailed land use data sourced from the Salisbury and Playford councils contained codes for different land use types. These codes are analogous to the codes used in the Australian and New Zealand Standard Industrial Classification (ANZSIC) system (ANZSIC, 2006). The risk assessment was performed with a similar level of detail so these land use codes became the relational field for the assessments to be joined to a spatial layer.

Cobbler Creek, Globe Derby, Little Para and Unity Park catchments lie partly or wholly outside of CoS and CoP. Specific land use data were unable to be sourced for these areas from the corresponding councils. Specific land use was re-coded using a combination of generalised land use for metropolitan areas (DPLG, 2011) and Australian Land Use Mapping (ALUM) layers for rural areas (ABARES, 2012). This recoding was assisted through field surveys and online map server interrogation (e.g. Google Maps) and business locality databases (e.g. True Local, Yellow Pages) to identify specific businesses and industries. Appendix 2 describes this methodology in greater detail.

From the extensive list of land uses including specific businesses and industries and types of agriculture a clearer understanding of the discrete potential hazards was achieved. A list of hazards was compiled through a series of collaborative workshops with project partners and stakeholders including representatives from satellite sites of the MARSUO project. This began with presenting land use maps of the delineated stormwater catchments and compiling exhaustive lists of hazards associated with different land use types (e.g. nutrient runoff from agriculture, turbidity from mining) and other features e.g. pesticide runoff from spraying of road verges and railway lines and pathogens from sewer overflows. A number of catastrophic rare events were also listed e.g. major spill events from tankers, industrial waste and service stations. Chemicals used in industrial, commercial, mining and agricultural areas were characterised based on the volume and toxicity of chemicals present and how they are utilized within processes. Chemicals used for normal operating processes are identified as present in stored containers for use, and as part of the waste stream from the facility. The waste may comprise air emissions, solid waste, liquid waste in storage containers, or as part of a water waste discharged to the sewer system (trade waste).

Land use hazards were further characterised using pollutant databases and industry reports and profiles to identify commonly used chemicals. Generalised chemical use information for different industry sectors (e.g. metal fabrication, petrochemical, printing, rubber and plastics) was sourced from The United States Environmental Protection Agency (USEPA) compliance and enforcement website industry profiles. Information on mining activities in the area was sourced from the Primary Industries and Resources of South Australia online information geoserver (SARIG, 2011).The Australian Dairy Manufacturing Industry Sustainability Report (Kershaw and Gaffel, 2008) contained general information on milk processing to characterise a facility in the Parafield stormwater catchment.

The Australian Government Department of Sustainability, Environment, Water, Population and Communities, National Pollutant Inventory (NPI) database (NPI, 2011) was electronically queried for pollutant emissions for businesses in the catchments. Listed businesses in the stormwater catchments included: Michel Pty. Ltd (wool processing), PMP Print Pty. Ltd. (paper printing company), Mayne Pharma International (pharmaceutical manufacturing), National Foods Milk Ltd. (dairy processing) and CSR Building Products Ltd. (brick and paving manufacture). Only substances emitted to the air (air total) were listed in the NPI for these businesses for the latest reporting period (2008-2009). Other emissions can be to water e.g. sewage, and to land e.g. via irrigation.

It is important to recognise limitations in the database of pollution (potential hazard) sources in the stormwater catchment. The collection of chemical-specific data for each industry and property represents an ongoing task, particularly as those industries alter their operations and practices. When site-specific information was not available, the default values were selected that represent a conservative inherent estimate based on the characteristic chemicals used by the particular industry. While this task may incorporate chemicals not used or stored, this conservative approach is used to ensure that all potential chemicals in the catchment are identified, and all hazards and related risks are appropriately evaluated prior to identification of management strategies.

The catchment land use water quality risk assessment considered the quality of untreated stormwater i.e. at the inlet of harvesting structures. The first two barriers shown in Figure 3 (catchment management and stormwater harvesting pre-treatment), are common to all 12 of the proposed stormwater use options. These barriers reduce the severity of many of the water quality risks identified in this section of the report. Risks following barriers for each of the 12 options are addressed in Section 10 of this report and management options are discussed in the Preliminary Risk Management Milestone Report 5c (Page *et al*., 2012).

This risk assessment grouped into the key water quality hazards as defined by the MAR guidelines (NRMMC-EPHC–NHMRC, 2009a):

- pathogens (viruses, protozoa and bacteria)
- inorganic chemicals
- salinity
- nutrients
- organic chemicals,
- turbidity, and
- radionuclides.

Each hazard source contained one or more constituents of the seven groups although no radionuclide hazard sources were identified in any of the catchment land uses and activities.

This assessment considered water quality risks to three separate end-points:

1. *Risks to public health* related to human exposure through either direct or indirect contact in non-drinking uses, and/or ingestion through direct or indirect drinking water use. These risks are related to likelihood of exceeding drinking water guideline values (including aesthetic values) and the severity of consequences in the event of occurrence.
2. *Risks to the environment* i.e. aquifers through injection of stormwater and soils and plants irrigated with recycled stormwater. Risks to ecosystems associated with natural or artificial stormwater drainage systems including detention basins and wetlands or the receiving environment e.g. Gulf St. Vincent, are not considered.
3. *Risks to operational infrastructure* including damage to stormwater harvesting basins and wetlands, pumps, pipes, wellheads and wells and irrigation equipment. These risks generally arise through physical, chemical or biological clogging and corrosion potential.

Water quality data from monitoring activities mainly at the Parafield site, but also incorporating data obtained from the other stormwater harvesting catchments, are presented in later sections and discussed with regard to the catchment land use risk assessment results. Some of these data were used to inform the catchment land use risk assessment where indicator parameters for water quality groups were measured.

6.3 Catchment water quality risks

The results of relating the risk assessment ratings to land use, road/rail, water course and sewerage infrastructure data are shown in the following sections. This assessment was conducted for the eight stormwater catchments relating to the ASTR and ASR schemes contributing to the trunk main stormwater distribution system (Figure 4). Results are presented in the water quality groups given in the MAR guidelines (NRMMC-EPHC–NHMRC, 2009b).

6.3.1 Catchment pathogen risks

6.3.1.1 Public Health

Microbiological risks to human health and the quality of harvested stormwater are driven by pathogen contamination arising from untreated or partially treated sewage or animal faeces entering the stormwater system. This may occur when sewers overflow or fail and breach property boundaries or easements and enter stormwater drains as well as septic tank leaks and overflows. Climate conditions are a key driver as high frequency and magnitude of storms can increase stormwater infiltration. Extended dry weather can also affect infrastructure integrity as well as age, length and condition of pipes, joints and pump stations (NWC, 2008).

An analysis of the temporal distribution of sewer choke events was conducted using sewer choke data (United Water) and rainfall data from the Australian Bureau of Meteorology (BOM). Summed monthly sewer overflows for the 7 year period (2003-2010) across the Adelaide metropolitan area were plotted with summed total monthly rainfall for the same period. These data are approximately linearly correlated (R^2>0.66) and indicate higher numbers of sewer overflows in wetter months (June-August). The trend is similar when overflow data from Salisbury and Tea Tree Gully Council areas were compared with rainfall at the Parafield Airport weather station (Figure 8). These data were approximately linearly correlated with an R^2>0.60. These results are similar to previously reported data on the seasonality of sewer overflows documented in the USA (USEPA, 2005a) and in reports for Australian utilities (NWC, 2008).

Human pathogens generally enter stormwater through sewer overflows and leakages. At the screening level, less than 14 overflows per 100 km per year as an average over the five most recent years can be considered relatively low (NRMMC-EPHC-NHMRC, 2009a; p. 19). The number of sewer overflows per 100 km of sewer main for the Adelaide metropolitan area ranges from 7 to 9.8 from 2003 to 2007 according to the National Water Commission reporting figures (NWC, 2008). Within the Parafield and Cobbler Creek catchments, the five-year average annual (from 2006 to 2010) number of sewer overflows per 100 km of sewer main is 16.5 and 17.5 respectively (calculated using data supplied by United Water, see Appendix 2). There may be additional health risks for stormwater harvesting from these catchments. The recommended standard health risk management approach when overflow rates are moderate to high (i.e. 14.5-50 overflows/100 km sewer main/year) is to allow for another 1-$\log_{10}$ pathogen reduction through treatment or exposure controls (NRMMC-EPHC-NHMRC, 2009a; pp. 95-97).

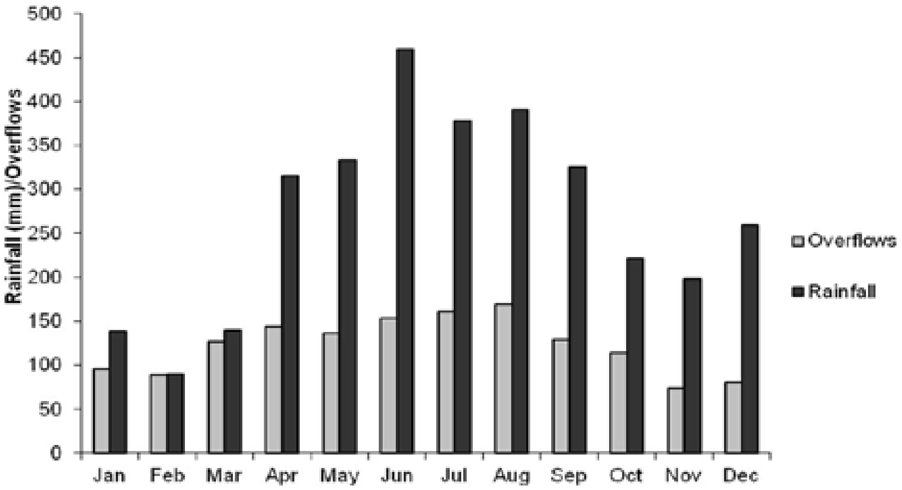


Figure 8 Summed monthly rainfall and summed monthly overflows in Salisbury and Tea Tree Gully Council areas for 7 years from 2003-2010.

Table 6 Sewer overflows proportional to catchment area.

Catchment	Total number of sewer overflows for 2003-2010	Catchment Area (Ha)	Overflows per Ha
Unity Park	733	5261	0.139
Parafield	198	1,590	0.125
Greenfields	1,264	11,381	0.111
Paddocks	48	456	0.105
Cobbler Creek	85	1,017	0.084
Globe Derby	102	2,628	0.039
Edinburgh	97	4,558	0.021
Kaurna	103	5,320	0.019

Sewer overflows that discharge into the environment e.g. road, watercourse, represent the highest risk of pathogen entry into the stormwater system. Sewer overflows to the environment (those which leave dwellings and property boundaries) were assessed as extreme risks to public health particularly considering drinking water augmentation options (9-12). These are symbolised using red points on Figure 9. Sewer overflows appear to occur more frequently in areas where there are significant changes in terrain relief i.e. close to foothills (Figure 9). This is consistent with the hypotheses that the transition from steep to flat terrain is associated with deposition of solids due to lower flow velocities combined with a higher likelihood of pressurisation of sewers at these locations during storm events when stormwater enters sewers high in the sewer catchment. Other factors may also affect sewer overflow frequency e.g. age of pipes, time between maintenance. The number of sewer overflows proportional to catchment areas is given in Table 6. The northern catchments of the Edinburgh Parks system (Kaurna and Edinburgh) despite their size have recorded relatively low numbers of sewer overflows. This could be due to housing density being lower (17% residential, see Table 5). The other catchments all have higher urban residential areas of 33-51% except for Cobbler Creek which has 22%. Cobbler Creek however contains an area of high slope change in the foothills.

Overflow of sewage pump stations, particularly when in close proximity to water courses, within stormwater catchments present risks of contaminating harvested water with pathogens. Three were located within 20 m of water courses and present an extreme risk if they were to break down and overflow into waterways; 1 near Cobbler Creek (Cobbler Creek catchment), 1 near Little Para River (Globe Derby catchment) and another near Dry Creek (Unity Park and Greenfields catchments). Another 4 were within 35 m of a water course; 2 in Cobbler Creek, 1 in Parafield and another in Globe Derby catchment. These were assigned a high risk rating. The remaining 20 sewage pumps stations were further than 35 m from water courses. The potential for overflows from these to enter the stormwater system is reduced so moderate risk ratings were applied.

Pathogens, including faecal indicators in runoff are likely to originate from animals and humans (USEPA, 2005b). The origin of pathogens including protozoa (e.g. *Cryptosporidium*, *Giardia*) in runoff has been attributed to indirect faecal deposition on grazed land (Graczyk *et al*., 2000) or directly in streams or riparian areas (Bryan *et al*., 2009). *Cryptosporidium* is commonly found in surface runoff and is usually associated with farm animals and human sewage (Xiao *et al*., 2000). The persistence of some pathogens, particularly *E. coli* in soils in pasture lands is evidenced to be associated with contamination of drinking water (Jones, 1999). Livestock grazing areas were assessed as a high risk to public health based on a likely occurrence of human infective pathogens.

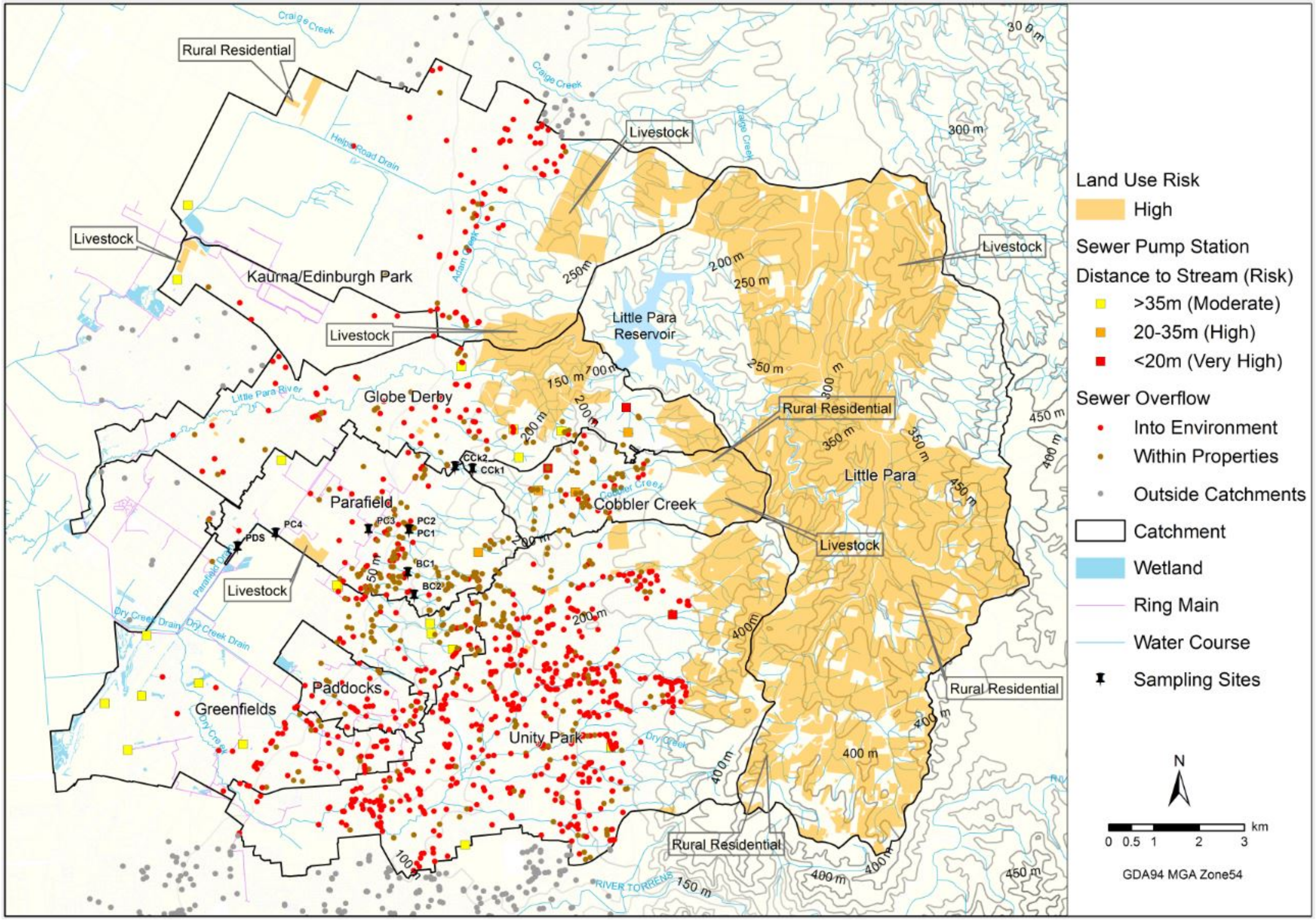


Figure 9 Catchment pathogen risks to public health relevant to augmentation of drinking water options. Sewer overflow data (2003-2010) sourced from United Water.

E. coli as a faecal indicator organism was detected in all catchments/wetland inlets (see Appendix 5) although no data were available for Snake Gully (Little Para Reservoir catchment). *Cryptosporidium* was detected in 64% of samples (n=64) at the Snake Gully sampling location in the Little Para catchment (Appendix 13) and in 56% of samples (n=16) taken at the PDS site in the Parafield catchment.

Livestock grazing pastures are shown around the head waters of Cobbler Creek and Dry Creek (Unity Park catchment), on the northern side of Parafield Drain and large areas of grazing pastures in Little Para and some in Kaurna and Edinburgh Park (Figure 9). Livestock such as cattle carry many potentially infectious human pathogens such as *Cryptosporidium*, *Giardia* and *Campylobacter*. The grazing modified pastures land use class under the ALUM system may include pastures that are under rotation e.g. with cropping (ABARES, 2010). Hence, the areas coded as 'livestock' in Little Para (see Table A.24), may be crops at other times; conversely land use under cropping may also be under pasture at other times (ABARES, 2010). While faecal indicators of pathogens come from a range of sources; some pathogens such as enteric viruses are only present in sewage and septic waste seepage.

Rural residential properties in the Little Para, eastern part of Cobbler Creek and Edinburgh Park and a few also in the Kaurna Park catchments were assessed as a high risk. This was determined mainly on the basis of the potential for septic tanks to leak and/or overflow into drainage paths. In the southern Adelaide metropolitan region up to 57% of septic systems failed and instances of pumping directly to the stormwater system were previously observed (Cugley, 2007). An audit program initiated in 2001 by the Adelaide Hills Council found failure rates were between 41% (in Little Para) to 48% (in Upper Torrens) though >50% were then rectified (Billington and Deere, 2011).

Rural residences are also more likely to contain higher densities of domestic livestock, e.g. chickens, horses, and even catteries, as was observed in the Cobbler Creek catchment area. Historically high septic tank failure rates combined with the increased potential for domestic livestock husbandry supported the assessed high inherent risk for rural residential properties. Table 7 summarises the land use risks for pathogens in each of the catchments.

Table 7 Catchment land use pathogen public health risks.

Land Use Hazard; Event	Risk	Catchment Name	No. Parcels	Area (Ha)	Proportion of Catchment
livestock grazing; faecal deposition and runoff from livestock grazing pastures	High	Little Para	61	3941.2	48.2%
		Cobbler Creek	5	91.2	9.0%
		Edinburgh Park	46	401.2	8.8%
		Kaurna Park	49	409.3	7.7%
		Unity Park	20	338.7	6.4%
		Greenfields	26	450.1	4.0%
		Globe Derby	18	101.9	3.9%
		Parafield	1	20.2	1.3%
rural residential; septic tanks failures, runoff from domestic livestock paddocks e.g. chickens, horses	High	Little Para	131	1,121.9	13.7%
		Cobbler Creek	11	106.9	10.5%
		Unity Park	29	260.9	5.0%
		Globe Derby	28	125.3	4.8%
		Greenfields	41	368.2	3.2%
		Edinburgh Park	11	74.1	1.6%
		Kaurna Park	19	80.3	1.5%

Full descriptions of the hazard identification and risk assessment sorted by the MAR guidelines water quality groups are given in tabulated format in Appendix 14. This includes details of potential contaminants involved, land use hazard and hazardous events that lead to the risks, additional comments and the likelihood, severity and final inherent risk rating.

6.3.1.2 Operational and aesthetic

Pathogen risks by definition can only relate to health risks (human or environment) impacts results from infection. Microbial risks however exist through biological clogging. These can arise through high microbial concentration in source water and growth of extant microbial communities promoted by increased nutrient and iron levels. There are no aesthetic risks for pathogens. Risks for pathogens in MAR are generally driven by human health-based targets.

6.3.1.3 Environment

Currently there is little information on microbial pathogen impacts of MAR on the environment (NRMMC-EPHC-NHMRC, 2009b). The Phase 1 Australian Water Recycling Guidelines do not identify pathogens in the list of key identified MAR environmental risks (NRMMC-EPHC, 2006). Consequently, there were no inherent pathogen risks to the environment identified in this assessment.

6.3.2 Catchment inorganic chemical risks

6.3.2.1 Public Health

The majority of land use risks for inorganic chemicals relate to potential harm to the environment (aquifers and irrigated land). Risks to public health may also exist however Australian drinking water guideline values for health protection and aesthetic values are less stringent by one or more orders of magnitude than the ANZECC freshwater ecosystem trigger value for 95% species protection for most inorganic chemicals.

6.3.2.2 Operational and aesthetic

Aesthetic water quality may be affected by elevated iron and manganese concentrations both of which have more stringent guideline values for aesthetics. Dominant soil types across the catchments (though mapping coverage is limited) feature iron-rich red clays and red loams (Soil and Land Program, 2007) so levels in runoff could be affected through erosion and leaching processes. Due to limited coverage of soils mapping within the catchments, this risk could not be spatially assessed in this study. Land use sources for manganese and iron within the catchment are mainly associated with those that involve disturbance of the soils e.g. quarries, constructions sites and agriculture (Table 8) that may increase erosion and leaching.

Simialrly hydrogen sulphide concentrations in the recovered water can initially cause aesthetic issues due to odour. The odour quickly dissipitates after entry to the mixing tank due to exposure to the atmosphere.

Operational risks are associated with fouling potential of waters that can result in clogging, scaling and corrosion of pumps and irrigation equipment. This is mainly due to pH outside the range of 6 to 9, hardness outside the range of 60-200 mg/L $CaCO_3$ (or as indicated by Langlier or Ryznar indices) and a low chloride to CO_3 ratio (ANZECC-ARMCANZ, 2000). Hardness results mainly from calcium and magnesium ions but others (e.g. manganese, iron, strontium and barium) also factor (NHMRC-NRMMC, 2011). Within the catchments, mineral content and pH of runoff is likely to be affected mainly by soil chemistry however detailed soils information is limited within this area.

6.3.2.3 Environment

Of the inorganic chemicals, metals warrant the most concern as they generally cannot be permanently removed within aquifers. Injecting water with high levels of metals would justify concern. It is advisable to limit inputs, before relying on aquifer treatment as sorption can be reversed (NRMMC-EPHC-NHMRC, 2009b).

A wide variety of metals, metallic compounds and other inorganic chemicals are used and emitted in metal fabrication (USEPA, 1995a). Cement production involves the use of alumina, silica, limestone, clay, lead, zinc and iron oxides (USEPA, 1995c; USEPA, 2006d) and runoff can be contaminated with lead, iron and zinc. There are cement factories and a sand and metal supply yard in the Parafield stormwater catchment that have a constant visible impact on road cleanliness (seen in aerial imagery and from field observations) (Figure 10). These land uses were consequently assessed as extreme risks (Table 8; Appendix 14).

The majority of emissions to air for extractive and masonry production industries are inorganic metallic compounds (NPI, 2011) and quarries are associated with high potential for mobilisation of metallic compounds in runoff (USEPA, 1995b). Quarries were therefore assessed as an extreme risk (Table 8; Appendix 14).

Residential and non-residential land subdivision and development was also considered a risk for similar reasons to quarries but on a lesser scale so was classed as a high risk. Horticulture and forestry production was assessed as high risk due to potential runoff from the application of fertilisers and leaching of metallic compounds (USEPA, 2000a). Chemical manufacturing industries including fertiliser production were also assessed as high risk by the technical committee.

Mains water bursts were identified in stakeholder workshops as being a high risk mainly as a result of repair works. Repair work involves the use of large amounts of chlorine and may also result in turbidity and metal release through excavation of pipes. Data were unavailable to represent this spatially across catchments using similar methods as for sewer choke data in Section 6.3.1.

Figure 10 Road with sand, cement and other debris in the Parafield catchment next to a cement factory.

The dairy processing facilities in Parafield/Greenfields and Kaurna Park catchments were assessed as moderate risk based on widespread use of acid and base cleaning solutions e.g. chlorine dioxide, peroxide and sulphur dioxide (Kershaw and Gaffel, 2008) and the chance of spills to the stormwater system. Similarly, textile industries and print production industries using a variety of inorganic chemicals (USEPA 2006) were assessed as moderate risks. Scrap and waste recycling facilities potentially including hazardous waste are associated with a variety of pollutants including inorganic compounds (particularly metals) (USEPA, 2006a; 2006c) and were assessed as moderate risk (Table 8; Appendix 14).

Roads are identified as risks due to potential contamination of runoff with metals (e.g. zinc, copper and lead) from brake and tyre wear, andother inorganic compounds through vehicle leaks, spills and accidents (Mangani *et al*., 2005; Tonkin Consulting, 2000). Ellis *et al*. (1997) reported that surface water quality impacts were restricted to roads with a mean traffic density >30,000 vehicles per day. High traffic volume roads (>30,000 vehicles per day) within the catchments were assessed as high risk (based on annual average daily traffic volume estimates, DPTI, 2011). These roads totalled 26.5 km, 11.4 km, 6.9 km, 5.5 km 4.3 km and 4.1 km in the Greenfields, Globe Derby, Kaurna Park, Edinburgh Park, Parafield and Unity Park catchments respectively and zero in the Cobbler Creek, Paddocks and Little Para catchments.

Contamination with zinc may also result through runoff contact with zinc plated metal roofing and fencing materials. These are ubiquitous throughout an urban catchment. This diffuse source of pollution was considered a moderate risk but was not included in maps of specific land use risks as it could relate to almost all land use types where there are built structures.

Pharmaceuticals manufacturing potentially involves the use of a variety of metallic compounds (USEPA, 1997b). Mayne Pharma International in the Parafield stormwater catchment manufacture a variety of pharmaceuticals ranging from aspirins, antibiotics, morphine compounds, magnesium sulphate pastes and chloride based medicines. Mayne Pharma International is an accredited manufacturing facility as certified by chief regulatory authorities and is licensed to handle controlled drug substances and use chlorinated solvents and alcohols in the manufacturing process (Mayne Pharma, 2011). It is strictly regulated to comply with environmental protection regulations and has visibly high security. Mismanaged leaks and spills are highly unlikely and any impacts are likely to be minor at most and consequently this land use was assessed as a low risk.

Full descriptions of the hazard identification and risk assessment sorted by the MAR guidelines water quality groups are given in tabulated format in Appendix 14. These include details of potential contaminants involved, land use hazard and hazardous events that lead to the risks, additional comments and the likelihood, severity and final inherent risk rating.

Table 8 Catchment land use inorganic chemical risks to the environment.

Land Use Hazard; Event	Risk*	Catchment Name	No.	Area (Ha)	Proportion of Catchment
building supplies (sand, metal); contaminated runoff	Extreme	Parafield	1	1	0.1%
		Greenfields	1	1	0.01%
cement production; contaminated runoff	Extreme	Greenfields	4	24	0.2%
		Parafield	2	0.5	0.03%
		Kaurna Park	2	1	0.03%
metal/machinery/transport/other manufacturing; contaminated runoff/leaks/spills	Extreme	Kaurna Park	47	187	4%
		Greenfields	94	129	1%
		Parafield	17	15	1%
		Unity Park	11	46	1%
		Edinburgh Park	23	28	1%
		Globe Derby	4	2	0.1%
		Little Para	1	9	0.1%
quarry (sand, clay, shale, crushed stone); contaminated runoff	Extreme	Cobbler Creek	2	167	16%
		Edinburgh Park	1	291	6%
		Kaurna Park	1	291	5%
		Parafield	4	86	5%
		Greenfields	11	388	3%
		Unity Park	5	136	3%
		Little Para	1	9	0.1%
chemical manufacturing incl. fertiliser, petroleum, plastic, rubber, paints; contaminated runoff/leaks/spills	High	Kaurna Park	17	33	1%
		Edinburgh Park	12	20	0.4%
		Greenfields	9	7	0.1%
		Unity Park	2	1	0.01%
horticulture (crops/fields/market gardens); contaminated runoff	High	Edinburgh Park	20	461	10%
		Kaurna Park	23	472	9%
		Little Para	57	341	4%
		Globe Derby	25	40	2%
		Cobbler Creek	1	15	2%
		Greenfields	27	58	1%
		Parafield	18	8	0.5%
forestry; contaminated runoff	High	Little Para	5	29	0.4%
		Kaurna Park	1	4	0.1%
construction/land development; contaminated runoff	High	Cobbler Creek	1	9	1%
		Globe Derby	1	15	1%
		Unity Park	2	12	0.2%
		Greenfields	1	9	0.1%

Land Use Hazard; Event	Risk*	Catchment Name	No.	Area (Ha)	Proportion of Catchment
dairy processing; contaminated runoff, leaks/spills	Moderate	Parafield	1	7	0.4%
		Greenfields	2	7	0.1%
		Kaurna Park	1	0.5	0.01%
horticultural supplies/stores; leaks/spills	Moderate	Greenfields	5	4	0.04%
		Unity Park	1	0.1	0.002%
scrap metal and waste recycling; leaks/spills, contaminated runoff	Moderate	Parafield	1	1	0.04%
		Greenfields	5	2	0.02%
		Unity Park	2	1	0.01%
print production; leaks/spills	Moderate	Parafield	1	3	0.2%
		Greenfields	8	5	0.04%
		Unity Park	7	2	0.03%
		Kaurna Park	3	2	0.03%
		Edinburgh Park	1	1	0.03%
wool, textiles, leather processing; leaks/spills	Moderate	Parafield	3	15	1%
		Greenfields	5	20	0.2%
		Kaurna Park	2	6	0.1%
		Unity Park	1	5	0.1%
		Edinburgh Park	1	4	0.1%

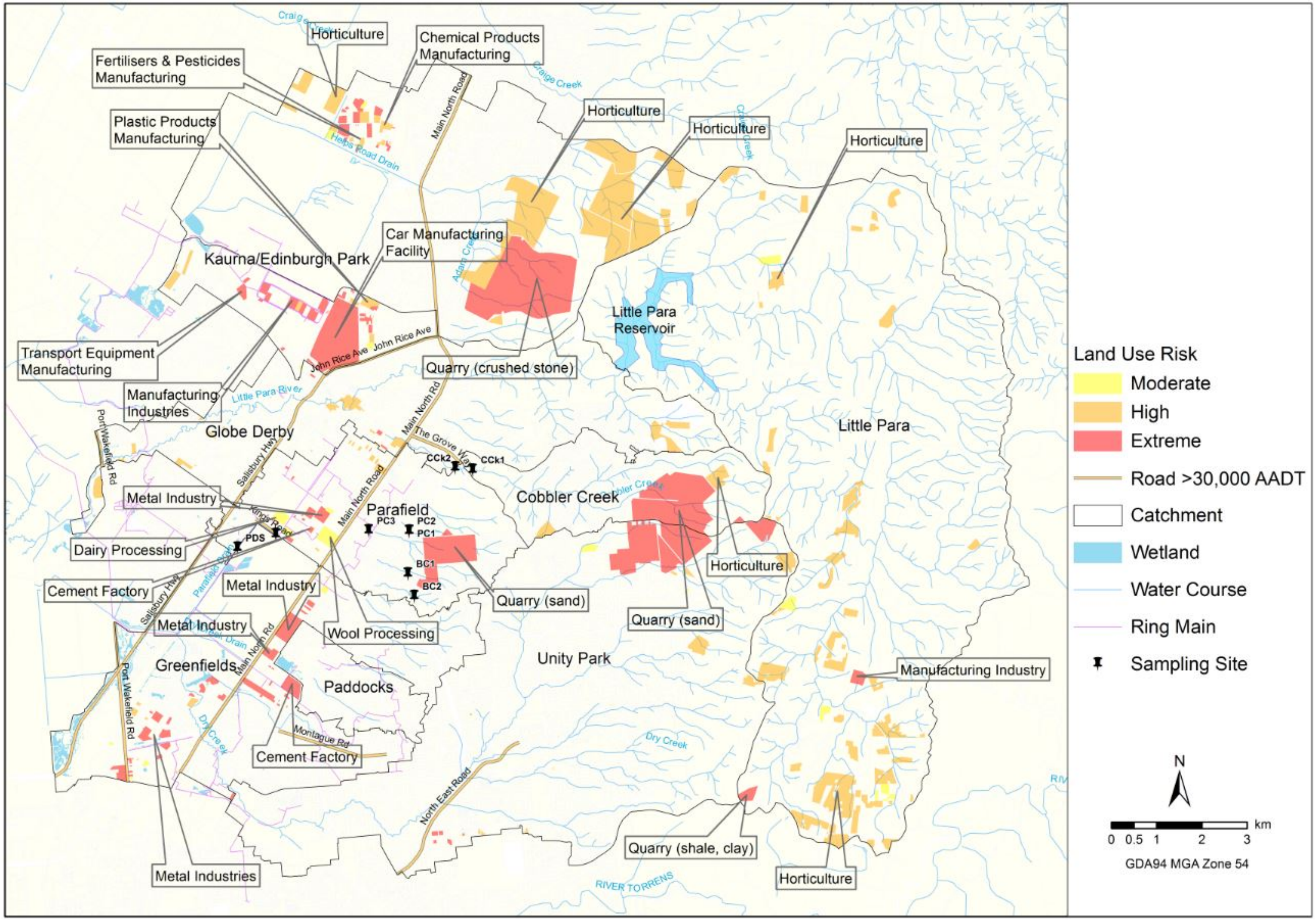


Figure 11 Catchment inorganic chemical risks to the environment.

6.3.3 Catchment salinity and sodicity risks

6.3.3.1 Public Health

There were no direct risks to public health associated with salinity and sodicity.

6.3.3.2 Operational and aesthetic

Australian drinking water guidelines provide an aesthetic value of 600 mg/L TDS based on taste (NHRMC-NRMMC, 2011) and may raise risk for Option 9 (direct potable). Salinity presents an operational risk through damage to infrastructure by scaling and corrosion (NHMRC–NRMMC, 2011). Salt plains (or low lying saline lands) were the main land use hazard source identified and these were only located in the Greenfields catchment. The Greenfields ASR wells are used for injection only and 'water credits' are transferred allowing extraction at other wells under the current regulatory structure. Operational risks are consequently restricted to transfer and injection pumps and well heads for the Greenfields scheme. This risk is accepted by the scheme operator (City of Salisbury).

6.3.3.3 Environmental

The Greenfields wetlands are located adjacent to salt crystallisation plains. Wetland samples confirm consistently high salinity (inlet median and 95th percentile values of 940 mg/L and 3,700 mg/L respectively (see Appendix 5). The wetlands themselves were constructed between 1990 (stage 1) and 1995 (stage 3) on low lying saline land (CoS, 2011) so the salinity is likely to be due to antecedent conditions of the soils and hydrological interaction with the adjacent salt plains. Low lying saline land was assessed as an extreme risk for salinity.

The current EPA license (EPA Lic. No. 2252) for the Greenfields ASR system states that the salinity of the water discharged to the aquifer must not exceed either ANZECC irrigation guideline values or is no worse than the unpolluted ambient groundwater where the ambient groundwater quality does not meet the ANZECC guidelines. The most conservative salinity irrigation trigger value is 950 µS/cm (≈600 mg/L TDS) for sensitive crops (ANZECC-ARMCANZ, 2000) and the average ambient salinity of the T1 aquifer is around 1,000 mg/L TDS (ANRA, 2012). Based on median and 95th percentile concentrations for the Greenfields wetland outlet of 1,000 and 2,655 mg/L TDS respectively (Appendix 6), salinity presents an extreme environmental risk (to the aquifer).

Quarries were identified as potential salinity and sodicity risks where saline groundwater is exposed in cuttings and released to the stormwater system (DECC, 2008). Water quality data collected 800 m downstream from where a stream intersects a quartzite quarry in the Parafield catchment (sampling point PC1, Figure 12) had a salinity consistently below 400 mg/L TDS, well below the drinking water aesthetic value. Quarries were subsequently assessed as a low risk for salinity.

Other non-land use related salinity hazards were identified. The occurrence of high salinity pulses at the start or end of flow events was identified as well as relationships of salinity to antecedent conditions, flow rate and flow volume. These are explored in Section 10.2.3. Potential ingress of saline groundwater to the harvesting system from the shallow saline aquifer beneath and adjacent to the in-stream basin at the Parafield site was also identified. This does not constitute part of the stormwater surface catchment, however and is addressed in the following sections on wetland water quality. There are also likely to be salinity hazards related to soil types in the catchments and stream beds that are not covered in this assessment. Mapping of soils and runoff salinisation indicators e.g. exchangeable sodium percentage (ESP) is deficient within the metropolitan study area. The Australian Soil Resource Information System (ASRIS) indicates that ESP in the first soil horizons is likely to be higher nearer the coast (ASRIS, 2012), however coverage is insufficient to quantitatively compare catchment soil salinity properties.

Full descriptions of the hazard identification and risk assessment sorted by the MAR guidelines water quality groups are given in tabulated format in Appendix 14. This includes details of land use hazards and hazardous events that lead to the risks, additional comments and the likelihood, severity and final inherent risk rating.

Table 9 Catchment land use salinity and sodicity risks to the environment.

Land Use Hazard; Event	Risk	Catchment Name	No.	Area (Ha)	Proportion of Catchment
low lying saline land; runoff/infiltration	Extreme	Greenfields	17	125	1%

6.3.4 Catchment nutrient risks

6.3.4.1 Public Health

There were no direct risks to human health from nutrients identified in the assessment. The only considerable health risk from nutrient enrichment is through the promotion of algal blooms and production of algal toxins in a reservoir. This only applies to indirect potable uses (Options 10, 11 and 12). Ammonia (NH_3) may indicate sewage contamination and/or microbial activity in a system. Nitrate is only a health risk at levels over 50 mg/L (NHRMC-NRMMC, 2011).

6.3.4.2 Operational and aesthetic

Risks for operational infrastructure exist through increased potential for copper pipe corrosion due to high levels of ammonia. The Australian drinking water aesthetic guideline value is given as 0.5 mg/L for NH_3 (NHRMC-NRMMC, 2011). Promotion of microbial growth through elevated nutrient levels may also lead to bioclogging. Risks presented in Table 10 and Figure 13 apply to environmental risks but may also be relevant to operational risks mainly where ammonia is concerned. There were no aesthetic risks for nutrients identified in this assessment.

6.3.4.3 Environmental

Nutrients are group of constituents that are identified as posing key environmental hazards in recycled water (NRMMC-EPHC, 2006). Risks of eutrophication of soils, toxic effects on plants, nutrient imbalances, and pests and disease in plants are associated with irrigation with recycled water as well as contamination of groundwaters (NRMMC-EPHC, 2006). Nutrients can originate from a number of sources and land uses within the catchment (Figure 12). The horticulture industry commonly involves the widespread use of fertilisers including nitrogen and phosphorus based compounds and manure (USEPA, 2000a). Transport of nutrient in runoff from fields is enhanced through erosion particularly during tilling (USEPA 2000a). Nutrient enrichment of runoff from livestock grazing paddocks is related to growth and application of animal feed and deposition of manure (USEPA, 2000b). Horticulture and livestock production were assessed as extreme risks for nutrients. Livestock grazing pastures occupy almost half of the Little Para catchment area and are also prominent in the headwaters of the Kaurna, Edinburgh, Cobbler Creek and Unity Park catchments (Table 10; Figure 12). The Kaurna Park and Edinburgh Park catchments feature large proportions of cropping, irrigated agriculture and market gardens.

High risks were identified for rural residential properties arising from manure (field observations of horse husbandry), and the high potential for septic tank failures (up to 50% in the area; Cugley, 2007) leading to nutrient enrichment of runoff and stream water. Five plantation forestry areas totalling 29 ha in the Little Para catchment and one 4 ha property in Kaurna Park were assessed as a high risk following literature reviews revealing that fertiliser use is common particularly in the establishment of many plantation species (May *et al.*, 2008; Sonogan, 2008). One land-based aquaculture operation exists in the Little Para catchment and was identified as a high risk for nutrients due to the potential for wastewater discharge containing nutrients from uneaten feed, faeces, and in the case of bivalve production, spat settlement plates (Ingerson *et al.*, 2007). The specific nature of the aquaculture activity could not be ascertained.

Stakeholder workshops also identified sewer overflows as a high risk for nutrients (as well as pathogens – 6.3.1), the distribution of these would mirror that of the patterns discussed in Section 6.3.1. Sewage pump station overflows were identified for similar reasons. Large storm events, stormwater gross pollutant trap blockage and overflow and deciduous drops were also assessed by the stakeholder panel as moderate risks for nutrients.

Other moderate risks included recreational grounds (e.g. from fertilisers applied to sports fields, golf courses etc.) and agricultural supply stores and plant nurseries. An equestrian centre in the Globe Derby Park catchment was coded as a recreational facility and is a potential source for high levels of nutrients from animal faeces. Nitrogen and phosphorus compounds are among the most commonly emitted and transferred substances in the food manufacturing industries including dairy, poultry, meat and beverage production (NPI, 2011). Several food manufacturing facilities are located within the Edinburgh Park, Kaurna Park, Parafield and Greenfields catchments (Table 10; Figure 12). Other potential industrial sources included surface treatment processes in metal fabrication (USEPA, 2006e) and compounds agricultural chemical manufacturing (USEPA, 2000c). Risks of spills and leaks into the stormwater system from industrial premises were assessed as moderate (Appendix 14).

Nutrient releases through earth moving in quarries and land development were identified as a potential risk in stakeholder workshops but literature reviews showed nutrient enrichment through cutting and exposure of soils has not factored significantly in industry pollutant emissions data or regulations (USEPA, 1995b; NPI, 2011) or impact studies of quarry runoff (Mayes *et al*., 2005; Pena Gonzalez *et al*., 2006). The US EPA recommends ammonium waste from blasting activity be minimised by proper maintenance of storage containers (USEPA, 1995b). This indicates a possible risk though environmental contamination through storage leaks rather than from the blasting process itself but this risk was assessed to be low.

Full descriptions of the hazard identification and risk assessment sorted by the MAR guidelines water quality groups are given in tabulated format in Appendix 14. This includes details of potential contaminants involved, land use hazard and hazardous events that lead to the risks, additional comments and the likelihood, severity and final inherent risk rating.

Table 10 Catchment land use nutrient risks to the environment.

Land Use Hazard; Event	Risk	Catchment Name	No.	Area (Ha)	Proportion of Catchment
crops/fields/market gardens; contaminated runoff	Extreme	Edinburgh Park	20	461	10%
		Kaurna Park	23	472	9%
		Little Para	57	341	4%
		Globe Derby	25	40	2%
		Cobbler Creek	1	15	2%
		Unity Park	7	35	1%
		Greenfields	27	58	1%
		Parafield	18	8	0.5%
livestock grazing (e.g. sheep); contaminated runoff	Extreme	Little Para	55	3,941	48%
		Cobbler Creek	5	91	9%
		Edinburgh Park	46	401	9%
		Kaurna Park	49	409	8%
		Unity Park	20	339	6%
		Greenfields	26	450	4%
		Globe Derby	18	102	4%
		Parafield	1	20	1%
aquaculture; contaminated runoff/leaks/spills	High	Little Para	1	2	0.02%
forestry; contaminated runoff	High	Little Para	5	29	0.4%
		Kaurna Park	1	4	0.1%
rural residential; septic tank failures, runoff from domestic livestock paddocks/enclosures	High	Little Para	123	1,122	14%
		Cobbler Creek	11	107	11%
		Unity Park	29	261	5%
		Globe Derby	28	125	5%
		Greenfields	41	368	3%
		Edinburgh Park	11	74	2%
		Kaurna Park	19	80	2%
agricultural chemical manuf. (fertilisers, pesticides); leaks/spills	Moderate	Kaurna Park	17	33	1%
		Edinburgh Park	12	20	0.4%
horticultural supplies/stores; leaks/spills	Moderate	Greenfields	5	4	0.04%
		Unity Park	1	0.1	0.002%

Land Use Hazard; Event	Risk	Catchment Name	No.	Area (Ha)	Proportion of Catchment
sports fields (ovals, golf courses); contaminated runoff	Moderate	Paddocks	6	26	6%
		Unity Park	26	138	3%
		Edinburgh Park	14	113	2%
		Kaurna Park	16	133	2%
		Greenfields	65	255	2%
		Globe Derby	26	58	2%
		Parafield	18	31	2%
		Cobbler Creek	4	18	2%
		Little Para	13	83	1%
food manufacturing (dairy, meat, beverage); spills/leaks	Moderate	Parafield	8	26	1.7%
		Kaurna Park	7	19	0.4%
		Greenfields	30	31	0.3%
		Edinburgh Park	3	15	0.3%
plant nursery; contaminated runoff/leaks/spills	Moderate	Unity Park	4	8	0.2%
		Edinburgh Park	1	4	0.1%
		Greenfields	5	9	0.1%
		Kaurna Park	2	5	0.1%

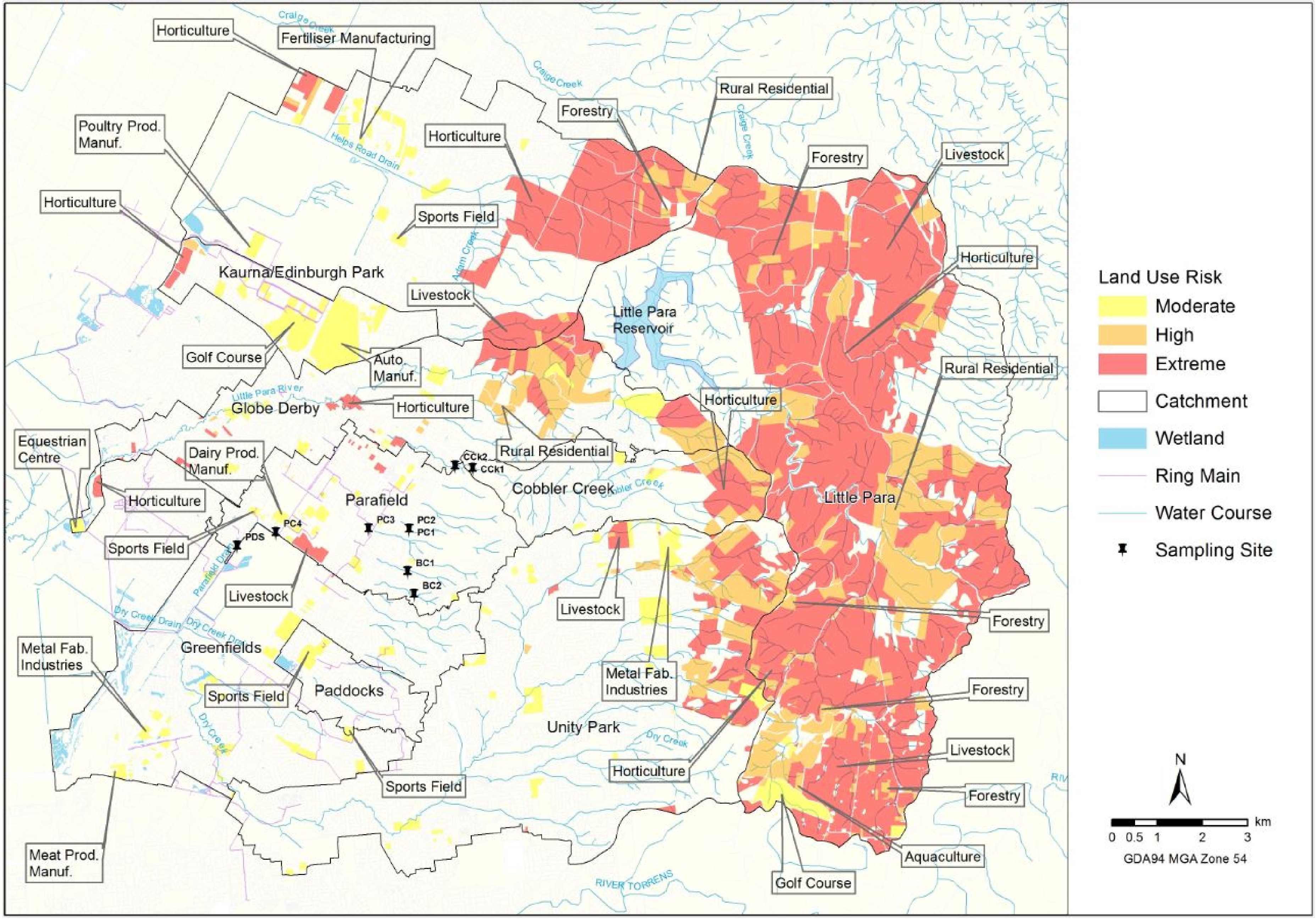


Figure 12 Catchment land use nutrient risks to the environment.

6.3.5 Catchment organic chemical risks

6.3.5.1 Public Health

Based on catchment and wetland inlet data, the concentration of organic chemicals in stormwater runoff were too low to be a realistic risk to public health (see Appendix 5). All pesticides measured from 2006-2010 were below ADWG health values in sampling programs for the ASTR project in Parafield (Page *et al*., 2010). Simazine and atrazine have been detected in catchment/wetland inlet samples for all catchments. The 95th percentile concentrations were below ADWG health values with the exception of Greenfields where the value for simazine was more than twice the ADWG health guideline value of 20 µg/L. The source of simazine in this area is unknown. Previous investigations on the use of herbicides by the City of Salisbury and its contractors to manage roadside verges did not indicate simazine was used. Similarly, although Greenfields has a large railway line running through the catchment, simazine is not used on the railway lines. The Greenfields wetland water is not extracted for use so does not contribute to the quality of the Salisbury recycled stormwater ring main. Risks for organic chemicals are dominated by risks to the environment. Benzene is a risk at concentrations >1 µL in water when ingested and is a known human carcinogen (NHMRC-NRMMC, 2011). Benzene was never detected in catchment or wetland samples at any site.

6.3.5.2 Operational and aesthetic

There were no risks to operational infrastructure from organic chemicals identified in the assessment. Herbicide concentrations were too low to impact on wetland vegetation and treatment performance. Ethylbenzene and toluene (from petroleum products), and xylene (a widely used solvent) pose aesthetic risks in relatively low concentrations. These chemicals were never detected in catchment or wetland samples at any site.

6.3.5.3 Environmental

A wide range of organic chemicals potentially found in recycled water are listed in the Australian Water Recycling Guidelines as posing risks to the environment. These include surfactants, various volatile and non-volatile organic compounds, pesticides and metabolites, disinfection by-products and pharmaceuticals (NRMMC-EPHC, 2006). End-points for environmental exposure include the aquifer (for options including a MAR component) and any land irrigated with recycled stormwater. Risks to ecosystems within stormwater harvesting basins and wetlands are inherently accepted.

Major risks were identified for land uses that commonly apply pesticides. Horticultural practices potentially involve the widespread use of various compounds including organophosphates, carbamates, organochlorides, pyrethroids, chloropenoxy and mecoprop (Reigart and Roberts, 1999). Contamination risks are greatest when recently applied and/or during high rainfall intensity when runoff is also highest (USEPA, 2000a). Catchments containing horticultural areas were conservatively assessed as an extreme risk for organic chemicals. Edinburgh Park, Kaurna Park and Little Para contain the highest proportion of horticultural properties by area and so were considered the highest risk at least in regard to herbicides and pesticides (Table 11; Figure 13). The Edinburgh Park, Kaurna Park, Greenfields and Unity Park catchments also contain chemical manufacturing facilities including fertiliser and pesticide production in Edinburgh Park that were assessed as high risk land uses. Similarly, sports fields e.g. football ovals, cricket grounds, golf courses, were identified as a high risk because pesticide use is likely to be less intensive than in horticulture; a number of these areas are distributed across all catchments (Table 11; Figure 13). A small number of plant nurseries and horticultural supply stores are found in some catchments and a moderate risk of leaks and spills of pesticides and some contamination of runoff was identified (Table 11).

Simazine and atrazine have been detected in catchment/wetland inlet samples for all catchments. The 95th percentile concentrations were an order of magnitude lower than trigger values for freshwater ecosystems with the exception of Greenfields. The 95th percentile value for Greenfields wetland inlet for simazine was 43 µg/L which is more than 13 times the ANZECC 95% freshwater ecosystem species protection trigger level of 3.2 µg/L. Simazine and atrazine are the two most widely used herbicides after glyphosate in Australia with about 3000 tonnes used annually (DSEWPC, 2006). The environmental risk from simazine at Greenfields would be limited to the aquifer as injected water is not extracted. A study undertaken by

Shareef *et al*. (in press) has shown that under anoxic conditions in T2 aquifer material simazine has a half life of 26-32 days and would therefore be reduced to acceptable concentrations for even sensitive environmental ecosystems.

Major passenger and freight rail lines intersect some the stormwater catchments. Literature reviews identified rail lines as potential major sources of organic chemicals; mainly grease and oils from leaking engines and carriages (Ellis *et al*., 1997; USEPA, 1997c). Spraying of pre-emergent herbicides to control weeds along rail lines and street verges was also identified through stakeholder workshops. The western part of the Greenfields catchment is highlighted as a high risk area due to the large rail yard and switching station, together with the line, occupying 93 Ha. The rail line in the Parafield catchment crosses immediately adjacent the Parafield Drain and harvesting point (Figure 13). Median strips and road verges were assessed as high risk (Table 11).

High volumes of road traffic are associated with pollution of organic compounds (mainly oils and grease) from roads and highways (Boxall and Maltby, 1995; Legret and Pagotto, 1999; Mangani *et al*., 2005; Perdikaki and Mason, 1999). Ellis *et al*. (1997) reported that surface water quality impacts were restricted to roads with a mean traffic density >30,000 vehicles per day. High traffic volume roads (>30,000 vehicles per day) within the catchments were assessed as high risk (based on annual average daily traffic volume estimates, DPTI, 2011). These roads totalled 26.5 km, 11.4 km, 6.9 km, 5.5 km 4.3 km and 4.1 km in the Greenfields, Globe Derby, Kaurna Park, Edinburgh Park, Parafield and Unity Park catchments respectively and zero in the Cobbler Creek, Paddocks and Little Para catchments.

Fuel service stations were assessed as high risk due to the potential for diffuse fuel contamination, minor fuel handling leaks and spills and risk of a major spill (Li and McAteer, 2000; Wixtrom and Brown, 1992). Similarly, the risk of spills and leaks from automotive repair workshops and metal manufacturing industries that use a wide range of organic chemicals (USEPA, 1995a) were given a high risk rating.

A range of manufacturing and automotive service industries involve the use of various organic chemical compounds that could potentially enter the stormwater system through undetected leaks and spills (Table 11). Such events were expected to occur within a 1-5 year period and impacts likely to be relatively minor and restricted to local environments. These land uses were therefore assessed as moderate risk.

It is also widely known that pharmaceuticals can enter water supplies from sewage and septic sources following excretion from the human body (NHMRC–NRMMC, 2011). Sewer overflows and septic tank failures were previously considered as potential risks for pharmaceuticals in the ASTR project. There were no pharmaceuticals detected above a drinking water guideline value. Current evidence does not support a general requirement for additional or specialised drinking water treatment to reduce concentrations of pharmaceuticals (NHMRC–NRMMC, 2011). Stakeholder workshops also identified sewer overflows as a high risk for organic chemicals (as well as pathogens), the spatial distribution of these would mirror that of the patterns discussed in Section 6.3.1. Sewage pump station overflows were identified for similar reasons.

Full descriptions of the hazard identification and risk assessment sorted by the MAR guidelines water quality groups are given in tabulated format in Appendix 14. This includes details of potential contaminants involved, land use hazard and hazardous events that lead to the risks, additional comments and the likelihood, severity and final inherent risk rating.

Table 11 Catchment organic chemical environmental risks.

Land Use Hazard; Event	Risk	Catchment Name	No.	Area (Ha)	Proportion of Catchment
horticulture (crops/fields/market gardens); contaminated runoff	Extreme	Edinburgh Park	20	461	10%
		Kaurna Park	23	472	9%
		Little Para	57	341	4%
		Cobbler Creek	1	15	2%
		Globe Derby	25	40	2%
		Unity Park	7	35	0.7%
		Greenfields	27	58	0.5%
		Parafield	18	8	0.5%
rail infrastructure (lines, stations, yards); spills/leaks, herbicide spraying, contaminated runoff	Extreme	Greenfields	40	93	0.8%
		Kaurna Park	24	31	0.6%
		Edinburgh Park	13	17	0.4%
		Globe Derby	14	7	0.3%
		Parafield	8	4	0.3%
fuel service stations; contaminated runoff, leaks/spills	High	Unity Park	13	8	0.2%
		Greenfields	39	14	0.1%
		Globe Derby	12	2	0.1%
		Kaurna Park	8	3	0.1%
		Paddocks	3	0.2	0.05%
		Edinburgh Park	6	2	0.04%
		Parafield	2	1	0.04%
sports fields; pesticide spraying, contaminated runoff	High	Paddocks	6	26	6%
		Unity Park	26	138	3%
		Kaurna Park	16	133	2%
		Greenfields	65	255	2%
		Globe Derby	26	58	2%
		Parafield	18	31	2%
		Cobbler Creek	4	18	2%
		Edinburgh Park	12	56	1%
		Little Para	13	83	1%
median strips, road reserves; herbicide spraying, contaminated runoff	High	Kaurna Park	138	95	2%
		Edinburgh Park	120	72	2%
		Globe Derby*	54	38	1%
		Greenfields*	119	34	0.3%
		Parafield	32	3	0.2%
		Paddocks	4	0.5	0.1%
		Cobbler Creek*	0	0.0	0.0%
		Unity Park*	0	0.0	0.0%
forestry; contaminated runoff	High	Little Para	5	29	0.4%
		Kaurna Park	1	4	0.1%
beverage production; leaks/spills	Moderate	Parafield	3	6	0.4%
		Greenfields	3	6	0.1%

Land Use Hazard; Event	Risk	Catchment Name	No.	Area (Ha)	Proportion of Catchment
dairy processing; leaks/spills	Moderate	Parafield	1	4	0.3%
		Greenfields	2	7	0.1%
		Kaurna Park	1	0.5	0.01%
electrical substations (incl. booster stations); leaks/spills	Moderate	Edinburgh Park	2	33	1%
		Kaurna Park	4	34	1%
		Unity Park	2	4	0.1%
		Paddocks	1	0.3	0.1%
		Greenfields	4	5	0.05%
		Globe Derby	1	0.3	0.01%
		Little Para	1	0.1	0.00%
horticultural supplies/stores; leaks/spills	Moderate	Greenfields	5	4	0.04%
		Unity Park	1	0	0.00%
wood, timber, cork, furniture manufacturing; leaks/spills	Moderate	Parafield	7	2	0.1%
		Greenfields	26	7	0.1%
		Kaurna Park	9	3	0.1%
		Edinburgh Park	5	2	0.05%
		Globe Derby	3	1	0.03%
		Unity Park	4	1	0.02%
wool, textiles, leather processing; leaks/spills	Moderate	Parafield	3	15	1%
		Greenfields	4	20	0.2%
		Kaurna Park	2	6	0.1%
		Unity Park	1	5	0.1%
		Edinburgh Park	1	4	0.1%
plant nursery; contaminated runoff, leaks/spills	Moderate	Greenfields	5	58	1%
		Unity Park	4	8	0.2%
		Kaurna Park	2	5	0.1%
		Edinburgh Park	1	4	0.1%
chemical manufacturing (incl. fertiliser, petroleum, plastic, rubber, paints); leaks/spills	Moderate	Kaurna Park	17	33	1%
		Edinburgh Park	12	20	0.4%
		Greenfields	9	7	0.1%
		Unity Park	2	2	0.03%
metal/machinery/transport/other manufacturing; leaks/spills	Moderate	Kaurna Park	47	187	4%
		Greenfields	94	129	1%
		Parafield	17	15	1%
		Unity Park	11	46	1%
		Edinburgh Park	23	28	1%
		Little Para	1	9	0.1%
		Globe Derby	4	2	0.1%
motor vehicle repairs; leaks/spills	Moderate	Cobbler Creek	1	5	0.5%
		Globe Derby	30	9	0.4%
		Kaurna Park	35	17	0.3%
		Edinburgh Park	18	13	0.3%
		Greenfields	96	32	0.3%
		Parafield	23	4	0.3%
		Unity Park	18	5	0.1%

Land Use Hazard; Event	Risk	Catchment Name	No.	Area (Ha)	Proportion of Catchment
print production; leaks/spills	Moderate	Parafield	1	3	0.2%
		Greenfields	8	5	0.04%
		Edinburgh Park	1	1	0.03%
		Kaurna Park	3	2	0.03%

* Median strips and road reserve geo-data were deficient where reliant on generalised or ALUM land use data in Globe Derby, Greenfields, Cobbler Creek and Unity Park. Figures are likely to be under-representative for these catchments.

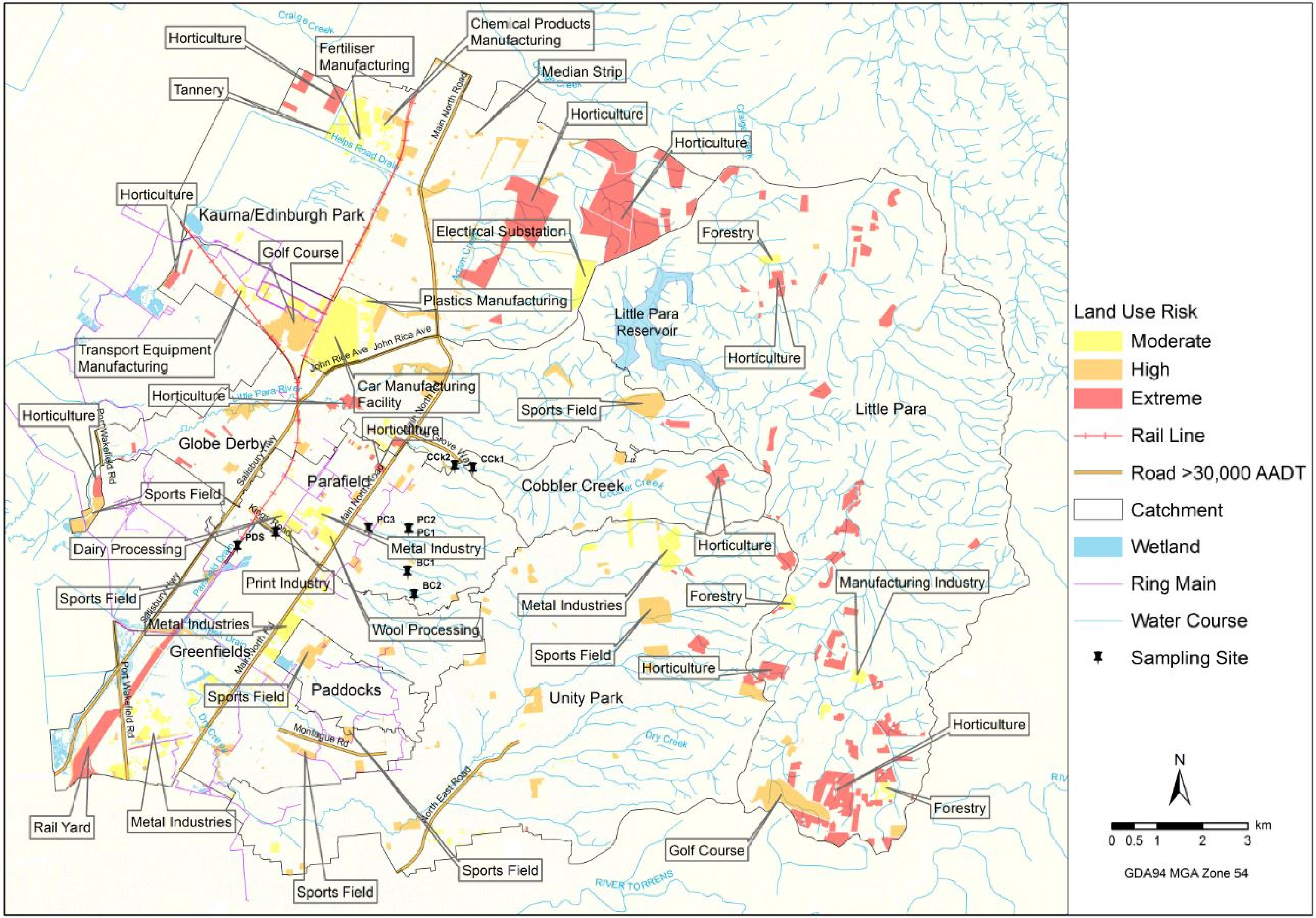


Figure 13 Catchment land use organic chemical environmental risks.

6.3.6 Catchment turbidity risks

6.3.6.1 Public Health

Turbidity is not a direct risk to human health, though high turbidity may interfere with the efficacy of chlorine and ultra violet light disinfection (NHMRC–NRMMC, 2011). Turbidity is mainly related to operational risks in this system. The DHA approval conditions for recycled stormwater supply to the Mawson Lakes Recycled Water Scheme include a turbidity limit of 100 NTU before water can be transferred from the in-stream basin to the holding basin at the Parafield wetlands. Managing turbidity to protect operations (mainly well clogging through injecting turbid water) will manage any risks to health as related to supply to the Mawson Lakes Recycled Water Scheme. This risk assessment found no direct risks to human health as a result of turbidity.

6.3.6.2 Operational and Aesthetic

Turbidity risks mainly relate to potential damage to stormwater harvesting infrastructure and issues with the aesthetic quality of recycled stormwater. Chronic problems with high turbidity in stormwater harvesting wetlands and ASR wells may affect their performance. Regular cleaning may be required if wetlands accumulate high amounts of sediment. The greatest operational turbidity risk is the potential for injection well clogging. Catchments with a higher inherent land use risk of turbidity may require longer wetland residence time (to allow settling) before injection and more frequent cleaning than other catchments with lower risks. Turbidity may also contribute to clogging of irrigation systems (Page *et al*., 2009).

Extractive industries are identified among the land uses with an extreme inherent risk for turbidity. High turbidity in runoff and discharge water from quarries is a common problem (Mountjoy *et al*., 2005; Pena Gonzalez *et al*., 2006). An example of the physical impact on the landscape is shown in aerial imagery of quarries in the Cobbler Creek catchment (Figure 14). Large quarries are located in all catchments with the exception of Paddocks (Figure 15). These quarries extract a range of sand, quartzite, clay, shale and crushed stone through open workings.

Cement kiln dust is identified as the highest waste product associated with cement manufacture (USEPA, 1995c). High amounts of sediment was consistently observed covering road surfaces near the cement factories in the Parafield, Kaurna Park and Greenfields catchments (see Figure 10 in Section 6.3.2) as a result of material handling and transit. Cement factories were consequently assessed as an extreme risk for turbidity.

Similarly, sediment deposition (visible from aerial imagery and field observations) on roads adjacent sand and metal supply yards, scap metal recycling yards and construction sites in Parafield, Cobbler Creek, Greenfields, Globe Derby Park and Unity Park led to assessment of these land uses as extreme risks for turbidity (Figure 15). While relative catchment areas of these land uses are small their potential impacts may be high. Construction sites are also more temporary impacts compared to quarries for example that may have a 20+ year lease for operations. Industry adherence to the EPA code of conduct for the building and construction industry (EPA, 1999) becomes critical for catchment management.

The primary pollution from preparing soils for planting is erosion (USEPA, 2000a). Conventional tillage methods also increase risk of erosion (USEPA, 2000a). This would also be greater on higher slope terrain though for the purposes of this land use risk assessment, slope was not considered. Terrain contours across the catchments are shown in Figure 4. Catchment management activities could be prioritised to focus on the higher slope areas of Cobbler Creek, Unity Park and Little Para Reservoir catchments. Horticulture was assessed as a high risk as occurrence was expected to be at least once a year (particularly following tillage) with moderate impact.

Sediment was considered the top pollutant from agricultural livestock production in the US EPA's 1996 Water Quality Report (as cited in USEPA, 2000b). Turbidity in runoff could occur through erosion due to over-grazing and trampling by animals but also through tillage if pastures are rotated for animal feed production. Occurrence was expected to be multiple times a year (more frequent than horticulture) but with a minor impact mainly to local systems. Impact compared to horticulture was expected to be less than tillage of soils hence livestock grazing was assessed as a moderate risk.

High traffic volume roads are associated with wash off of oil contaminated sediments (Ellis *et al.,* 1997) and suspended solids generally (Mangani *et al*., 2005). Ellis *et al*. (1997) reported that surface water quality impacts were restricted to roads with a mean traffic density >30,000 vehicles per day. High traffic volume roads (>30,000 vehicles per day) within the catchments were assessed as high risk (based on annual average daily traffic volume estimates, DPTI, 2011). These roads totalled 26.5 km, 11.4 km, 6.9 km, 5.5 km 4.3 km and 4.1 km in the Greenfields, Globe Derby, Kaurna Park, Edinburgh Park, Parafield and Unity Park catchments respectively and zero in the Cobbler Creek, Paddocks and Little Para catchments.

Rail upgrade work occurring close to wetland inflow points for the Parafield and Greenfields systems represented a type of construction site and could be considered a risk for turbidity. Risks were offset by the substantial on-site sediment control methods observed on sites. These included maintenance of vegetated buffers, silt fencing and dust suppression activities (sprinklers, water trucks). These sites were consequently assessed as low risk.

Figure 14 Sand and clay quarries in Cobbler Creek catchment area. Aerial imagery sourced from BingMaps™ under license through ESRI ArcGIS 10.

Stakeholder workshops also identified mains water bursts as a high turbidity risk through excavation of pipes during repairs particularly if this coincided with rain events. Bush fires, especially in upper parts of catchments were assessed as a high risk as were the presence of European Carp, through their feeding behaviour, a risk in wetlands themselves (though this is not a catchment risk). Large storm events, stormwater gross pollutant trap blockage and overflow and deciduous leaf drops were identified by the stakeholder panel as moderate risks for turbidity.

Full descriptions of the hazard identification and risk assessment sorted by the MAR guidelines water quality groups are given in tabulated format in Appendix 14. This includes details of potential contaminants involved, land use hazard and hazardous events that lead to the risks, additional comments and the likelihood, severity and final inherent risk rating.

Table 12 Catchment land use turbidity operational risks.

Land Use Hazard; Event	Risk	Catchment Name	No.	Area (Ha)	Proportion of Catchment
building supplies (sand, metal); sediment in runoff	Extreme	Parafield	1	1	0.1%
		Greenfields	1	1	0.01%
scrap metal recycling; sediment in runoff	Extreme	Parafield	1	1	0.04%
		Greenfields	5	2	0.02%
		Unity Park	2	1	0.01%
cement factory; sediment in runoff	Extreme	Greenfields	4	24	0.2%
		Parafield	2	0.5	0.03%
		Kaurna Park	2	1	0.0%
construction/land development; sediment in runoff	Extreme	Cobbler Creek	1	9	1%
		Globe Derby	1	15	1%
		Unity Park	2	12	0.2%
		Greenfields	1	9	0.1%
quarry (sand, clay, shale, crushed stone); sediment in runoff	Extreme	Cobbler Creek	2	167	16%
		Edinburgh Park	1	291	6%
		Kaurna Park	1	291	5%
		Parafield	4	86	5%
		Greenfields	11	388	3%
		Unity Park	5	136	3%
		Little Para	1	9	0%
horticulture (cropping land); tillage, sediment in runoff	High	Edinburgh Park	20	461	10%
		Kaurna Park	23	472	9%
		Little Para	57	341	4%
		Globe Derby	25	40	2%
		Cobbler Creek	1	15	2%
		Unity Park	7	35	1%
		Greenfields	27	58	1%
		Parafield	18	8	0.5%
livestock grazing; overgrazing, trampling, tillage; sediment in runoff	Moderate	Little Para	55	3941	48%
		Cobbler Creek	5	91	9%
		Edinburgh Park	22	401	9%
		Kaurna Park	62	409	8%
		Unity Park	20	339	6%
		Greenfields	26	450	4%
		Globe Derby	18	102	4%
		Parafield	1	20	1%

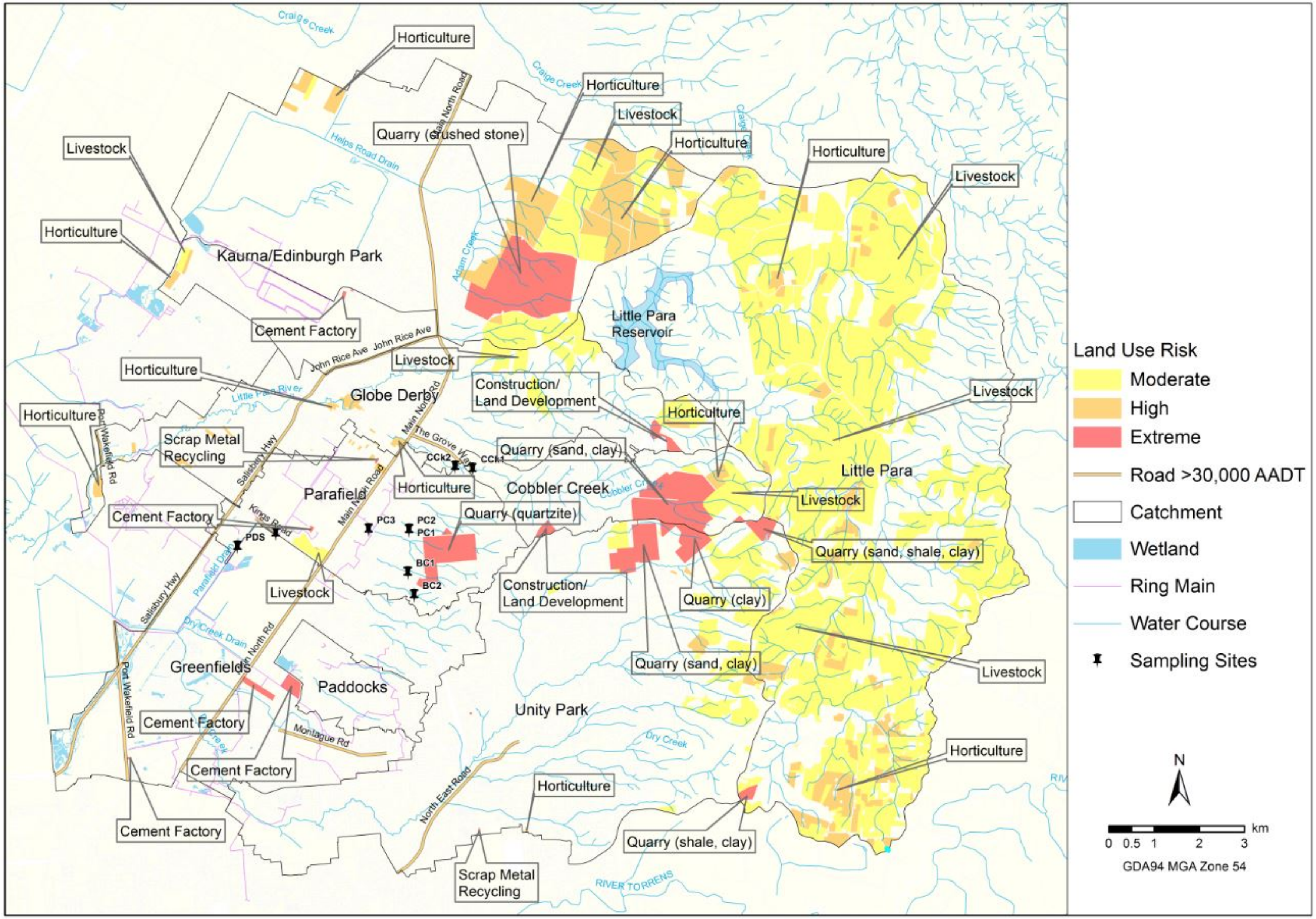


Figure 15 Catchment land use turbidity operational risks.

6.3.6.3 Environmental

As discussed in Section 6.3.6.1 turbidity is mainly related to operational risks in the stormwater harvesting and MAR context. Managing turbidity to protect operational risks of well clogging and wetland performance will manage risks to the environment, in this case the aquifer. This risk assessment found no direct risks to the environment as a result of turbidity.

6.3.7 Catchment radionuclide risks

Radionuclides in stormwater may be present as a result of some medical and industrial land uses. Groundwater may also contain natural background levels of radioactivity particularly in granitic fractured rock aquifers and near coal deposits (NRMMC-EPHC-NHMRC, 2009b). There were no identified land uses within the stormwater catchment that posed an inherent radionuclide risk to the quality of untreated stormwater for public health, operational, aesthetic or environmental end-points. Water quality monitoring at the Parafield wetland outlet site demonstrated that all samples were below the Australian Drinking Water Guideline level of 0.5 Bq/L for radiological quality (see Appendix 5). Following recovery at the Parafield ASTR site, 95th percentile gross alpha and beta activities were an order of magnitude lower than activities at the wetland outlet (Appendix 8) indicating mixing with the groundwater was not introducing further risks.

6.4 Water quality risks related to ambient groundwater, aquifers and MAR processes

A general risk assessment of hazards arising from the aquifers, ambient groundwater and interactions between injected stormwater, ambient groundwater and aquifers through the MAR processes are described according to the seven key water quality hazards for MAR operations (NRMMC-EPHC-NHMRC, 2009b) in the following sections. A more detailed assessment based on the recovered water quality data is presented subsequently in Chapter 7.

6.4.1 Aquifer and groundwater pathogen risks

6.4.1.1 Public Health

A large proportion of human disease outbreaks are related to unconfined groundwater drinking sources mainly resulting from contamination of groundwater with human or animal faecal matter (Macler and Merkle, 2000). Pathogen detections are generally indicative of recent recharge by faecal-contaminated water. In some cases opportunistic indigenous microorganisms may also be present. Opportunistic pathogens include bacteria such as *Aeromonas hydrophila*, *Pseudomonas* species such as *Pseudomonas aeruginosa* and *Pseudomonas stutzeri*, and various *Flavobacterium* species and former *Flavobacterium* species (Toze 1998). These bacterial strains have been implicated in a range of diseases and infections, particularly in the very young and old, the ill, and the immune compromised. Many opportunistic pathogens have been commonly detected as members of the natural microbial community in many different environments, including groundwater. Thus, they do not have the impediment experienced by introduced microorganisms, which have to compete for nutrients and ecological niches with an established indigenous microbial population. Many opportunistic pathogen species are also capable of using a wide range of organic compounds for growth. Risks from opportunistic pathogens can be managed by engineered water treatment and are discussed further in the microbial health based targets (Chapter 8). Confined aquifers like the T1 and T2 aquifer in Adelaide, exclude the prospect of finding pathogens originating from recharge. The age of groundwater at the Parafield site exceeds several thousand years and the intact and extensive nature of overlying aquitards exclude the possibility of the presence of pathogens in native groundwater of human origin. Enterococci, Streptococci and *E. coli* were not detected in the ambient groundwater by Page *et al*. (2009).

Risks arise through MAR operations however (see catchment pathogen risks discussed in Section 6.3.1). Pathogen decay in the T2 aquifer are evaluated in this report (Appendix 15) but characterisation of the removal effectiveness taking account of net attachment, inactivation and decline in infectivity during ASR and ASTR remains to be validated. Inherent risks to public health from pathogens in native groundwater are low for drinking water and non-potable uses. Pathogen risks from stormwater sources are high for potable uses (section 6.3.1 and section 9.1). Pathogens can be attenuated within the aquifer, but validation is required for ASR and for ASTR if credit for removal is relied on to determine the level of disinfection treatment for recovered water. Public health risks for non-potable uses of recovered water without disinfection may be managed through exposure controls (e.g. withholding periods, restricted public access, spray drift control etc.).

6.4.1.2 Operational and Aesthetic

There were no identified operational or aesthetic risks arising from potential pathogen contamination of ambient groundwater.

6.4.1.3 Environmental

As discussed in relation to catchment risks, there is little information on microbial pathogen impacts of MAR on the environment (NRMMC-EPHC-NHMRC, 2009b). Pathogens are not included in the list of key identified MAR environmental risks (NRMMC-EPHC, 2006). Environmental risks arising from potential pathogen contamination of ambient groundwater were not identified.

6.4.2 Aquifer and groundwater inorganic chemical risks

Inorganic chemical risks can originate from the ambient groundwater, but can also arise from subsurface reactions between the injected water and the ambient groundwater or the aquifer sediments.

6.4.2.1 Public Health

The concentration of arsenic in the ambient groundwater can marginally exceed the health based Australian Drinking Water Guideline value. Arsenic remained below the guideline value during the flushing and injection phases of the ASTR operation, due to the lower concentrations present within the source water (Page *et al*., 2009).

Arsenic mobilisation can result from redox processes, including pyrite oxidation and reductive ferric iron dissolution. Arsenic is known to be present in the T2 aquifer and was quantified at 6-144 ppm in sediment from the Parafield ASTR site (Page *et al.,* 2009). Furthermore, arsenic mobilisation has previously been reported for the nearby Bolivar reclaimed water ASR scheme in the T2 aquifer (Vanderzalm *et al.* 2011). Less is known about arsenic within the T1 sediments. Pyrite, which may contain arsenic, was detected in T1 sediment from the Bolivar ASR site (Vanderzalm, 2004) and detection of arsenic in the T1 ambient groundwater also suggests an arsenic source within the aquifer. Arsenic mobilisation was consequently assessed as a high risk to public health but only for drinking water use. Elevated levels of arsenic can be managed through engineered drinking treatment in a similar way to iron removal.

Manganese is present within the T1 and T2 aquifer sediments and can be mobilised by redox reactions, ion exchange or mineral dissolution. However, in native groundwater the concentration was not detected in excess of the health based guideline for drinking water. Previous experience in the T2 aquifer suggests the concentration of manganese in recovered water is unlikely to exceed the health based guideline for manganese (Vanderzalm *et al.,* 2010) and was therefore assessed as a low risk to public health.

Boron was detected in ambient groundwater samples at levels below 0.6 mg/L (Appendix 7). The Australian Drinking Water Guidline health value is 4 mg/L therefore boron in ambient groundwater is unlikely to present human health risks.

6.4.2.2 Operational and Aesthetic

The concentrations of TDS, chloride, iron, sodium and sulfate in the ambient groundwater (Appendix 7) can exceed the Australian Drinking Water Guideline aesthetic guideline values. This will affect the recovered water quality if mixing between the source water and the ambient groundwater leads to recovery of a significant component of ambient groundwater. Page *et al*. (2009) reported that the concentration of TDS, chloride, sodium and sulfate in the groundwater was reduced to acceptable levels during the flushing and injection phases of the ASTR operation, due to the lower concentrations present within the source water. However, iron concentrations remained above the aesthetic guideline value (Vanderzalm *et al*., 2010).

The presence of iron within the aquifer sediments within a variety of mineral phases including pyrite, goethite, hematite and siderite, results in the potential for redox and mineral equilibrium processes to mobilise iron during aquifer storage. Ambient groundwater concentrations and reported data for iron in recovered water, suggest iron will continue to present a high aesthetic risk to drinking water arising from the aquifer (see Section 7.4.2).

As discussed above, manganese is also present in the aquifer and can be released from the sediments. Vanderzalm *et al.* (2010) reported that the manganese concentration in recovered water was more likely to exceed the aesthetic guideline value for ASR than for ASTR, due to redox processes that occur around the ASR well itself that are mitigated by recovery from a separate well. Manganese was assessed as a high aesthetic risk (see Section 7.4.2).

Hydrogen sulfide can be generated by redox processes in response to injection of source water containing organic matter and is an aesthetic concern related to the ‘rotten egg’ odour. Production results from sulfate reduction, which generally follows in sequence after consumption of oxygen, nitrate, manganese (IV) and iron (III). The sulfate concentration in the ambient groundwater suggests the ambient redox condition has not progressed to sulfate reducing. However, some localised sulfate reduction may occur in the immediate vicinity of wells used for injection due to accumulation of injected organic matter (Page *et al.,* 2009). Odour related problems related to hydrogen sulfide production in the aquifer were assessed as a high aesthetic risk. Odours can be managed by assuring sufficient aeration prior to use.

Sulfate in ambient T1 and T2 groundwater exceeded the drinking water aesthetic guideline related to taste (Appendix 7). Aesthetic risk is therefore high but only for drinking water use and can be managed in the same way as discussed later for salinity.

Carbonate dissolution will occur when the source water injected into the aquifer is not in equilibrium with the dominant carbonate minerals. Operational concerns arise when the extent of carbonate dissolution compromises the stability of the injection well. Injection of stormwater into the T2 aquifer does result in carbonate dissolution, but dissolution is not expected to limit the lifetime of injection wells based on expected injection volumes and organic carbon loadings (Vanderzalm *et al.,* 2010). Management options include inspection of calliper logs run during pump replacement to confirm that the dissolution is not excessive.

6.4.2.3 Environmental

Studies on the environmental risks arising from the aquifer and native groundwater are limited. Kumar *et al*. (2011) reported that the aquifer recovered water did not exhibit toxicity to the assessed alga, bacterium, duckweed, daphnia, and fish. Apart from boron, all metals in the T1 and T2 ambient groundwater were below short term irrigation guidelines (Appendix 7). Boron levels in the ambient T1 and T2 aquifer groundwaters therefore present an inherent environmental risk to sensitive irrigated plants. Dilution with injected stormwater with low levels of boron (Appendix 6) is apparent from the quality of recovered water (Appendix 8). Environmental risks for boron are therefore low, and remain lower than sodium risks which are managed by monitoring EC in recovered water at a critical control point with shutdown of recovery if EC exceeds the control limit. Carbonate dissolution also presents an environmental hazard, for example if aquitards were undermined and lost integrity, connecting aquifers with different water qualities and pressures. Management is discussed as an operational issue above.

6.4.3 Aquifer and groundwater salinity and sodicity risks

6.4.3.1 Public health

Unlike catchment water quality, there is an inherent risk to human health related to sodium in native groundwater, if this is inadequately diluted with fresh stormwater in recovered water. This is addressed by monitoring volumes recharged and recovered, to give advance warning on when salinity is expected to increase to a threshold value, and by maintaining a critical control point for electrical conductivity on recovered water as specified in the accompanying risk management plan (Page *et al.,* 2013).

6.4.3.2 Operational and Aesthetic

The Australian drinking water aesthetic guideline for salinity (as TDS) is 600 mg/L. The ambient groundwater salinity in the T2 and T1 aquifers is 1700-2500 mg/L and 2029-2284 mg/L TDS respectively (Appendix 7). Consequently the inherent aesthetic risk for ambient groundwater salinity is high. Freshening of the groundwater during injection improves the aesthetic quality and reduces the risk. However, mixing between the source water and the ambient groundwater and the implications for the salinity of the recovered water and recovery efficiency requires management (Miotliński *et al*., 2013). This can be managed through adjustments to injection and recovery cycles. To ensure the salinity of the recovered water remains low, a critical control point utilising on-line EC meters was proposed in the accompanying risk management plan (Page *et al*., 2013).

6.4.3.3 Environmental

Environmental risks (to irrigated soils and plants) are similar to aesthetic risks as the irrigation trigger value for sensitive plants is around 600 mg/L TDS (ANZECC-ARMCANZ, 2000). Management of MAR operations as discussed in Section 6.4.3.2 ensures risks are minimised.

6.4.4 Aquifer and groundwater nutrient risks

6.4.4.1 Public Heath

The nutrient levels in the ambient groundwater of the T1 and T2 aquifers are low compared with drinking water and irrigation guideline values (Appendix 7). There were no risks to public health identified for nutrients from ambient groundwater.

6.4.4.2 Operational and Aesthetic

As discussed in Section 6.4.4.1, the ambient groundwater of the T1 and T2 aquifers is low in nutrients. Organic carbon and nitrogen in injected water can be removed predominantly through redox processes, aerobic respiration and denitrification. During extended periods of ASR storage, degradation of accumulated injected organic matter can lead to inorganic risks e.g. mobilisation of metals through geochemical reactions (Vanderzalm *et al*., 2011).

Phosphorus is subject to removal via adsorption during injection, which can reduce injected concentrations to a level similar to that of the ambient groundwater. However, phosphorus desorption has been reported during the recovery phase of ASR in the T1 and T2 aquifers (Vanderzalm *et al*., 2013). Phosphorus concentrations in recovered water are generally lower for ASTR operations than for ASR (Vanderzalm *et al*., 2010).

6.4.4.3 Environmental

Ambient groundwater nutrient levels in the T1 and T2 aquifers were below environmental (irrigation) guideline values (Appendix 7). Consequently, no environmental risks were identified in relation to nutrient from ambient groundwater.

6.4.5 Aquifer and groundwater organic chemical risks

6.4.5.1 Public Health

Groundwater in the confined T1 and T2 aquifers has residence times of several millennia. The extensive and intact nature of the confining layers is such that there is no possibility for contamination of native groundwater by organic chemicals of anthropogenic origin. Organic chemicals were not detected in ambient groundwater samples (Appendix 7). No risks to human health as a result of organic chemicals in ambient groundwater or from interactions with injected stormwater within aquifers were identified.

6.4.5.2 Operational and Aesthetic

As discussed in Section 6.4.5.1, there have been no detections of organic chemicals in ambient groundwater (Appendix 7). There were no operational or aesthetic risks related to organic chemicals from ambient groundwater.

6.4.5.3 Environmental

As discussed in Section 6.4.5.1, there have been no detections of organic chemicals in groundwater (Appendix 7). Aquifer well samples from Parafield have not shown any toxicological effects to indicator organisms (Kumar *et al*., 2011). Consequently no environmental risks for organic chemicals in ambient groundwater or from interactions with injected stormwater within aquifers were identified.

Subsurface storage can provide a treatment step for organic chemicals (Ying *et al*., 2003; Pavelic *et al*., 2005; 2006). In addition aquifer passage through varying redox zones can provide exposure to the conditions required for degradation of multiple organic chemical hazards. Simazine has been reported to degrade in aerobic aquifers with a mean half-life of 60 days (ranging from 10–300 days) (EPHC–NHMRC–NRMMC, 2008a). A laboratory degradation study using aquifer material and groundwater from the ASTR site was undertaken to assess the simazine degradation rate under anoxic conditions comparable to those found in the T2 aquifer (Shareef *et al*. in press). Results indicated that while degradation rates are slower in anoxic environments there is still potential for attenuation of simazine, atrazine and diuron in anoxic aquifers.

6.4.6 Aquifer and groundwater turbidity risks

6.4.6.1 Public Health

There are no health-based limits for turbidity given in the Australian Drinking Water Guidelines though high turbidity may affect disinfection efficiency. Ambient groundwater was generally above the aesthetic guideline level for drinking water of 5 NTU ranging from 8.6 NTU at the Parafield ASR site to 27 at Parafield ASTR site (Appendix 7). There is a high inherent risk that turbidity in ambient groundwater could affect disinfection treatment (e.g. when supplied to the Mawson Lakes Recycled Water Scheme, end use Option 8) but this is reduced through management of MAR injection and recovery cycles.

6.4.6.2 Operational and Aesthetic

Ambient groundwater was generally above the aesthetic guideline level for drinking water turbidity of 5 NTU and colour of 15 HU. (Appendix 7). There is a high inherent risk to aesthetic water quality from turbidity and colour in ambient groundwater but this is reduced through management of MAR injection and recovery cycles. Turbidity and particulates can be removed by filtration in the aquifer. However particulate hazards can also be generated from mineral dissolution and particle mobilisation within the storage zone during pumping, which may lead to turbidity values above the aesthetic guideline level. Turbidity level controls in injection were proposed in the accompanying risk management report (Page *et al*., 2013) to manage turbidity of injected and recovered water.

6.4.6.3 Environmental

There were no environmental risks directly associated with turbidity in ambient groundwater or interactions between injected stormwater and ambient groundwater or aquifer sediments identified that would directly lead to risks to the environment.

6.4.7 Aquifer and groundwater radionuclide risks

6.4.7.1 Public Health

The T1 and T2 aquifers are considered a low risk lithology in relation the risk for release of radionuclides from the sediments, in the absence of granitic or coal deposits and with native groundwater having low organic carbon content. There is some potential for release of radium when organic matter present in the source water leads to reductive dissolution of iron oxides, which may contain radium on sorption sites. However, both gross alpha and beta (excluding potassium-40) activity remained below the 0.5 Bq/L screening levels recommended in the Australian Drinking Water Guidelines in water recovered from the T2 aquifer during aquifer flushing for the ASTR operation (Appendix 8; Page *et al*., 2009).

6.4.7.2 Operational and Aesthetic

There were no identified operational or aesthetic risks associated with radionuclides in ambient groundwater or interactions between injected stormwater and ambient groundwater or aquifer sediments.

6.4.7.3 Environmental

There were no identified environmental risks associated with radionuclides in ambient groundwater or interactions between injected stormwater and ambient groundwater or aquifer sediments.

7 Water quality monitoring

This section describes water quality monitoring data (where available) that were collected across the entire system and relate to hazards associated with the twelve stormwater use options. These water quality data include:

- catchment/wetland inlet
- weland outlet
- aquifer recovered water
- recycled stormwater distribution pipeline
- blended recycled water (Mawson Lakes)
- Little Para catchment and reservoir
- Treated drinking water from the Little Para Water Treatment Plant

Water quality monitoring was extended from the previous program of the ASTR-Reclaim Water project that did not include any monitoring of the Parafield stormwater catchment, Cobbler Creek stormwater catchment, recycled stormwater distribution pipline (ring main) or water quality from other stormwater harvesting sites. The full list of water quality monitoring points for the Parafield system is given in Table 13.

Sampling of the Greenfields Mixing Tank, Little Para Reservoir, Snake Gully (a tributary to Little Para Reservoir) and the Little Para Water Treatment plant final water quality was performed by SA Water. Sampling at Parafield, Kaurna Park, Greenfields, Unity Park and Paddocks stormwater harvesting schemes was conducted by the City of Salisbury. All water quality sampling and analyses were performed using methods consistent with standard methodologies in APHA–AWWA–WEF (2005) by accredited laboratories.

7.1 Catchment water quality monitoring at Parafield

A key objective with the stormwater quality monitoring program was to provide catchment stormwater quality data for use in the risk assessment and to evaluate the treatment performance of the harvesting facility, ASR and ASTR systems.

Previously, monitoring programs have been primarily focused on determining compliance with guideline values in accordance with EPA licence conditions. Other purposes include:

- Baseline stormwater quality monitoring – understanding the seasonal catchment system behaviour.
- Event-based water quality monitoring – where monitoring is enacted when recognised conditions occur that are known to cause source water quality problems such as high-flow events. Initially event-based monitoring would focus on understanding the *pollutograph* and how it changes between events.

The water quality data used in this report contains a mixture of different types, those from historical baseline monitoring, event-based programs, or specific research projects. In the case of stormwater risk assessment, water quality monitoring is a vital source of information as it indicates water quality characteristics in baseline (and potentially event conditions) and may also show the effect of specific catchment land uses on water quality. Since November 2011, stormwater flow rates were monitored at the Parafield data station concurrently with water quality to assess any catchment "first flush" effects and enable the calculation of load and event mean concentrations for the human health risk assessments.

Table 13 Description of water quality sampling points at the Parafield site monitored during the MARSUO project.

Code	Description	Rationale
CCk1	Cobbler Creek #1	To integrate all the Cobbler Creek catchment land use effects. Water sampled here reflects transfers of water from the Cobbler Creek catchment to the Parafield catchment.
CCk2	Cobbler Creek #2	To integrate all the Cobblers Creek catchment land use effects. Water sampled here reflects water flows from Cobbler Creek to the environment.
PC1	Parafield catchment #1	Parafield stormwater catchment reflecting a subcatchment comprised of mainly quarry land use.
PC2	Parafield catchment #1	Parafield stormwater catchment reflecting a subcatchment comprised of urban residential land use.
PC3	Parafield catchment #3	Parafield stormwater catchment reflecting a subcatchment comprised of urban residential land use.
PC4	Parafield catchment #4	Parafield stormwater catchment reflecting a subcatchment comprised of light industrial land use.
BC1	Beaconfield catchment #1	Parafield stormwater catchment reflecting a subcatchment comprised of urban residential land use with relatively high numbers of sewer chokes.
BC2	Beaconfield catchment #2	Parafield stormwater catchment reflecting a subcatchment comprised of urban residential land use with relatively high numbers of sewer chokes.
PDS	Parafield Data Station	Integrates the entire Parafield catchment and located at the same point as the Parafield gauging station. Links to the City of Salisbury SCADA system.
ISB1	In-stream basin inlet #1	Site moved to PDS. Data was collected here as part of the ASTR project.
ISB2	In-stream basin outlet #2	Site currently not sampled, data were collected here to evaluate the effects of the in-stream basin on water quality as part of the ASTR project. Links to the City of Salisbury SCADA system.
WE1	Wetland inlet #1	Site currently not sampled, data were collected here to evaluate the effects of the in-stream basin and holding storage on water quality as part of the ASTR project.
WE2	Wetland outlet #2	Integrates the entire Parafield stormwater harvesting system and is representative of the treated stormwater prior to aquifer injection. Links to the City of Salisbury SCADA system.
ASR1, 2	ASR Well #1, 2	ASR wells #1 and 2 recovered water quality.
PASR	ASR observation well	Parafield ASR observation well and site of the pathogen decay chamber and groundwater microbial ecology studies.
IW1-4	ASTR Injection Wells #1-4	ASTR injection wells water quality. Sampled as part of the ASTR project during the flushing phase.
P1-3	ASTR Piezometers #1-3	ASTR observation wells and site of the pathogen decay chamber, passive sampler and groundwater microbial ecology studies.
RW1, 2	ASTR Recovery Wells #1-2	ASTR recovery well water quality.
PHT	Holding Tank	The Parafield holding tank – site of the passive sampler study to determine the effect of aquifer treatment on organic chemicals in stormwater.
MW1	Ring Main	Salisbury Ring Main sampling site Rundle Road Reserve opposite Michell Wool Pty. Ltd. Final harvested water quality representative of the ring main network.

7.2 Source stormwater quality

This section addresses the seven water quality hazards discussed in section 6 (pathogens, inorganic chemicals, salinity, nutrients, organic chemicals, turbidity and radionuclides) in source stormwater identified in the Australian Guidelines for Water Recycling (NRMMC-EPHC–NHMRC, 2009a), drawing on data reported by Page *et al*. (2009); Barry (2010) and data collected during the MARSUO project. A one year time series of data has been collected at the Parafield Data Station (PDS) site since its commission in October, 2011. These turbidity, salinity and flow data are presented graphically in Appendix 4 and are overlaid with field sampling observations, in-stream basin depth and daily rainfall data where available. Source stormwater quality data for Parafield, Cobbler Creek, Greenfields, Kaurna Park, Paddocks and Unity Park catchments are presented in Appendix 5. The discussion of source stormwater quality hazards applies to all options considered in this report.

7.2.1 Pathogen numbers in the source water

The compiled pathogen and faecal indicator data collected at the Parafield site stormwater harvesting system are reported by sample point (in Appendix 5 with the specific data used for the calculation of microbial health based targets presented again in Table 14). All pathogens were sampled and analysed according to APHA–AWWA–WEF (2005).

Over the period 2006–2012 there were faecal indicators (thermotolerant coliforms, *E. coli*, Faecal Streptococci and Faecal Enterococci) detected in stormwater from all catchments. There was some differentiation between the catchments, for example Parafield had the highest median *E. coli* numbers (3,200 n/L), where n/L is the number of organisms per Litre, followed by Cobbler Creek with 1,950 n/L. All other wetland inlet sites were an order of magnitude below this (Appendix 5).

Faecal Sterols are chemical compounds excreted by animals and humans as by-products of digestion of dietary sterols. The particular distribution of sterols found in faecal matter is influenced by factors such as diet, intestinal microflora and the animal's ability to synthesise its own sterols. The combination of these factors determines 'the sterol fingerprint'. The most commonly known faecal sterol, coprostanol, is produced in the digestive tract of humans by microbial hydrogenation of cholesterol. By drawing on the differences in the sterol profile of humans and herbivores, it is possible to determine whether the source of faecal contamination is from humans and/or herbivores. Coprostanol was detected in 8 out of 25 samples within the Parafield catchment and 4 out of 10 samples in the Cobbler Creek catchment. However the detection limit for coprostanol varied between 40 ng/L and 267 ng/L due to variability in sample turbidity and volume over the sampling campaign. Coprostanol had a 95th percentile concentration of 426 ng/L in the Parafield catchment and a maximum of 400 ng/L in the Cobbler Creek catchment. By comparison, sewage effluent has Coprostanol concentrations > 10,000 ng/L (Cathum and Sabik 2001).

Table 14 shows that the Parafield stormwater harvesting system has lower 95th percentile numbers of *E. coli* (64,000 n/L), *Cryptosporidium* (14 n/L) and *Giardia* (83 n/L) than the values given for an untreated stormwater quality in Sydney. Conversely the Parafield stormwater harvesting system has higher estimated 95th percentile numbers of *Campylobacter* (11 n/L) and bacteriophages (1,800 n/L). This is despite the large differences in reported sewer overflows (Parafield 17 blockages/yr/100 km; Sydney >44 blockages/yr/100 km). Generally however, the data in Table 14 shows that the 95th percentile numbers of pathogens for the Parafield system are of the same magnitude as the compiled data in the stormwater guidelines. A more detailed explanation of this data is given in the section describing the microbial health-based targets.

7.2.2 Inorganic chemicals in the source water

Water quality data describing inorganic chemicals in the source stormwater focuses on metal and metalloid concentrations reported in Appendix 5. Major ion concentrations are included in the discussion of salinity. The level of detail in stormwater quality data varied between the catchments, with greater detail for the Parafield, Cobbler Creek and Unity Park catchments, than available for Kaurna Park, Greenfields and Paddocks catchments.

All median concentrations of inorganic chemicals in the urban stormwater remained below the Australian Drinking Water Guidelines (ADWG) with a few exceptions.

Iron: The 95th percentile measured total iron concentrations exceeded the ADWG of 0.3 mg/L for all samples collected in all stormwater catchments. Total iron of 11 mg/L in the Cobbler Creek catchment also exceeded the short term irrigation guideline value of 10 mg/L. The median total iron concentration was highest at 2.48 mg/L in Kaurna Park, followed by 1.8 mg/L in Cobbler Creek, 0.81 mg/L in Paddocks, 0.77 mg/L in Greenfields, 0.63 mg/L in Parafield and 0.57 mg/L in Unity Park, based on between 12 and 72 samples in each catchment. However soluble iron concentrations were considerably lower indicating that iron in stormwater was predominantly associated with particulates which can be settled out in the wetlands and stormwater harvesting systems. The 95th percentile soluble iron concentration only marginally exceeded the ADWG with values of 0.35 mg/L in Parafield and 0.88 mg/L in Cobbler Creek, the only two catchments with soluble iron concentration data. High iron concentrations also result in stormwater colour exceeding the 15 HU ADWG aesthetic quality value, as shown by median values of 50 HU in Parafield and 33 HU in Cobbler Creek catchments (colour was not measured in other catchments) (Appendix 5). High risk inorganic chemical land uses (Figure 11) and major arterial roads occur in all catchments consistent with the high concentrations of iron detected in the stormwater.

Aluminium, lead, manganese, chromium: The 95th percentile measured soluble aluminium concentrations reached 0.8 mg/L in the Parafield catchment 1.24 mg/L in the Cobbler Creek catchment and 8.84 mg/L in Kaurna Park catchments exceeding the ADWG of 0.2 mg/L (Appendix 5). 95th percentile concentrations of total aluminium, lead and manganese were in some instances above the ADWG. The lead and aesthetic manganese guideline values, both 0.01 mg/L, were exceeded in all catchments except Unity Park (Appendix 5). The Greenfields catchment had a 95th percentile total chromium concentration of 0.069 mg/L, but as the contribution from hexavalent chromium was not measured it cannot be compared with the ADWG of 0.05 mg/L Cr(VI).

7.2.3 Salinity in the source water

The location of the Greenfields wetlands, situated on low lying saline land, made this the highest inherent risk catchment for salinity. However the Greenfields site is used to obtain water injection credits for extraction elsewhere and is not used to recover injected stormwater. This is reflected in the quality of wetland inlet water where it has already had some residence time. Median and 95th percentile wetland inlet TDS were 940 mg/L and 3,700 mg/L respectively, well above ADWG values. Greenfields ASR injects into the T1 aquifer that has a background salinity below 1,000 mg/L TDS in the southern part of the Northern Adelaide Plains Prescribed Well Area (DEWNR, 2012b). High salinity injectant water poses environmental risks as defined in the EPA Licence (#2252) for the scheme.

Water quality at the Unity Park wetland inlet also shows occasional high salinity (95thpercentile value of 1,415 mg/L and median of 565 mg/L TDS). This could be due to soil types within the Dry Creek catchment or potential interaction with saline soils or ingress of saline groundwater in the wetland itself; median salinity raises to 860 mg/L TDS at the wetland outlet.

Analyses of data logged at the Parafield Data Station (PDS) on the Parafield Drain between 26th Oct 2011 and 30th Oct 2012 revealed that 7% (87 ML) of the total volume of potentially harvestable water (when flow rate was >5 L/s) exceeded the ADWG value for unacceptable salinity of 1200 mg/L TDS. This roughly coincides with the 95th percentile value (1,227 mg/L). About 8% (97 ML) of the total volume was over 600 mg/L TDS. The average and median salinity of this water was fresh (385 mg/L and 293 mg/L respectively). Pulses of high salinity water (sometimes > 1,300mg/L TDS) are occasionally seen at the commencement of flow events but quickly drop down to below 500 mg/L (see Appendix 4).

Electrical conductivity data collected by continuous monitoring at the PDS did not correlate well with independent grab or composite sampling. A weak linear relationship was seen with a poor fit (R^2<0.24; n = 13; Appendix 4). Results are potentially confounded through difference sampling methods (continuous and composite). Grab sampling directly from the drain should reflect continuous monitoring readings when matched by time. This was evident in 4 out of 5 grab sampling points (R^2>0.98) but when the outlying point was included this relationship decayed to an R^2 value of <0.1. This is an insufficient number of samples across the time series to allow valid statistical conclusions to be made about the linearity of the data.

Source water (catchment/wetland inlet) quality data for Parafield, Cobbler Creek, Kaurna Park and Paddocks have median and 95th percentile values well below the ADWG value of 600 mg/L TDS (Appendix 5 Catchment/Wetland Inlet Water Quality Data).

7.2.4 Nutrients in the source water

The 95th percentile nutrient concentrations of the urban stormwater were all below the Australian Drinking Water Guidelines with the exception of ammonia in the Parafield catchment. While the median nutrient concentrations were within the irrigation guidelines values, all stormwater catchments reported phosphorus concentrations above the 0.05 mg/L recommended to avoid bioclogging in irrigation equipment. The qualitative catchment land use risk assessment was inconsistent with the differences in nutrient water quality detected in the stormwater catchments. Nutrients in stormwater in urban areas are likely to be linked to over use of fertilizer common to many land uses. The temporal applications of fertilisers are largely unknown and as such there can be high variability both spatially and temporally, however available water quality data indicates that concentrations are low.

7.2.5 Organic chemicals in the source water

A comprehensive suite of organic chemicals was monitored within the Parafield stormwater harvesting system from 2006-2012. These included herbicides, pesticides, hydrocarbons, poly aromatic hydrocarbons (PAH), detergents, industrial solvents, pharmaceuticals and personal care products. The monitoring program was revised again in 2007 targeting those chemicals used and previously detected in the urban stormwater as part of the MARSUO project. This smaller suite was consistent with water quality monitoring associated with the other ASR stormwater catchments. Of the chemicals monitored, the herbicide simazine was the most frequently detected organic chemical in the source water and for Greenfields the 95th percentile was measured at 43.4 µg/L exceeding the Australian Drinking Water Guidelines value of 20 µg/L. There are no irrigation guideline values for simazine.

Methyl Blue Active Substances (MBAS) was detected at a 95th percentile concentration of 0.25 mg/L and is indicative of general surface active agents in the stormwater, which could come from use of detergents (e.g. car washing) as well as natural sources (e.g. leaching of tannins from gum trees). There are no drinking water, aesthetic or irrigation guideline value for MBAS.

A small number of organic chemicals were detected at least once in grab samples and via the targeted composite water quality monitoring in 2007 and 2008. Passive samplers deployed in 2006, 2007 and 2009 detected trace (ng/L) levels of organic chemicals, but again these were below the Australian Drinking Water Guideline values and could not be detected in grab sampling during the same study (Page *et al*., 2009). Those chemicals detected in at least one sampling in the stormwater catchments included: Phenanthrene; 2,4-D; Chlorpyrifos; Dicamba; Diuron; Heptachlor; MCPA; Triclopyr; Dalapon as well as the breakdown products from simazine and atrazine: Desethyl Atrazine and Desisopropyl Atrazine.

A small number of pharmaceuticals were detected once only in 2009 and included Caffeine; DEET and Paracetamol. These chemicals could not be detected in repeat sampling.

The land use risk assessments for organic chemicals (Figure 14) were consistent with the general findings of the water quality monitoring but no specific chemicals detected could be related to specific land uses. The exception to this being use of herbicides which were present at most of the sites and are ubiquitously used for many of the land use types analysed, e.g. residential, commercial, industrial, horticultural.

7.2.6 Turbidity in the source water

Turbidity was only measured in stormwater from the Parafield, Cobbler Creek and Unity Park catchments. Within these three catchments, turbidity was generally high in the urban stormwater, with median values exceeding the Australian Drinking Water Guidelines aesthetic value of 5 NTU.

Analyses of data logged at the Parafield Data Station (PDS) on the Parafield Drain between 26th Oct 2011 and 30th Oct 2012 revealed that only 0.2% (3 ML) of the total volume of potentially harvestable water (i.e. when flow rate was >5 L/s) exceeded 100 NTU (threshold under the DHA approval conditions for in-stream basin turbidity). Only 3% (44 ML) exceeded 20 NTU and this roughly coincides with the 95th percentile value (24 NTU). The average and median turbidity of this water 13 and 11 NTU, respectively.

Occasional spikes of high turbidity (up to 175 NTU) are seen in these data, however, turbidity was not significantly correlated to flow rate. When low/no flow data are included, the average, 95th percentile and maximum turbidity values are higher (18, 37 and 387 NTU, respectively).Both of these findings do not support the expectation of higher turbidity at faster, higher energy flow rates. Signals may be obscured by the occurrence of low flow rate (~30 L/s) releases of high turbidity water from the Cobbler Creek system. Turbidity data were extracted where flow was recorded and no rainfall occurred during or for at least 3 days prior to the flow event. This is likely to be flows induced by pumping from the Cobbler Creek system. The average and 95th percentile values (from a total of 21 readings, and total volume of 34 ML) were higher than over the entire dataset (23 and 52 NTU respectively).

Turbidity data collected by continuous monitoring at the PDS did not correlate well with independent grab or composite sampling. No linear relationship was seen (R^2<0.03; n = 11) (Appendix 4). Results are potentially confounded through difference sampling methods (continuous and composite). Grab sampling should reflect continuous monitoring readings when matched by time. Of the 4 such points to compare no correlation was evident although this is an insufficient number of samples across the time series to allow valid statistical conclusions to be made about the relationships between the data.

Regular diurnal fluctuations in turbidity independent of flow rate are apparent with higher values recorded during the day (12:00 pm) and lower at night (12:00 am). An increase in turbidity independent of flow is sometimes associated with algae or other organism cell growth and/or cell positions in the water column (rising and falling in-line with light/temperature cycles) (Reynolds *et al.,* 1987).

7.2.7 Radionuclides in the source water

Stormwater gross alpha and gross beta activity remained below 0.5 Bq/L within seven samples for the Parafield catchment, the screening level recommended within the Australian Drinking Water Guideline prior to analysis of individual radionuclide activity. No land uses that could be potential sources of radionuclides were identified within the catchment.

7.3 Wetland water quality

The water quality data from the wetland outlets in the Parafield, Greenfields, Kaurna Park, Paddocks and Unity Park catchments are presented in Appendix 6. Radionuclides were not measured as they were not present in the source stormwater (see Appendix 5).

7.3.1 Pathogen numbers in the wetland water

Faecal indicators: The water quality data for stormwater after wetland treatment (2006-2012) in Appendix 6 indicates the presence of faecal indicators (thermotolerant coliforms, *E. coli*, Faecal Streptococci and Faecal Enterococci) in considerably lower numbers than in the untreated stormwater samples. The 95th percentile *E. coli* concentration in the Parafield catchment was 588 cfu/100 mL in the wetland discharge, in comparison to 34,900 cfu/100 mL in untreated stormwater (approximately a 2.0 $\log_{10}$ reduction). Higher

95th percentile *E. coli* concentrations were measured at the discharge of wetlands in Paddocks (11,300 cfu/100 mL), Kaurna Park (1,898 cfu/100 mL) and Unity Park (4,280 cfu/100 mL), indicating lower or no removal through each of these wetlands. The wetland designs for these sites contrasted with the reed bed and basins in the Parafield stormwater harvesting facility, which were covered by netting to restrict access by birds, dogs and people. The Australian Drinking Water Guidelines state that faecal indicators should not be detected at the point of supply. The most abundant faecal sterol, coprostanol, had a 95th percentile concentration of 236 ng/L, approximately half that measured in the catchment, but again indicating the presence of sewage contamination as shown by the presence of faecal indicators.

7.3.2 Inorganic chemicals in the wetland water

All median concentrations of metals and metalloids assessed within this inorganic chemicals section in the urban stormwater remained below the Australian Drinking Water Guidelines (ADWG) with the exception of iron.

The 95th percentile measured soluble aluminium concentrations reached 1.12 mg/L in Kaurna Park catchment (*c.f.* 8.84 mg/L in the source water) and 0.21 mg/L in Unity Park catchment exceeding the ADWG aesthetic value of 0.2 mg/L. The high 95th percentile value in the Parafield source water was not evident in water exiting the wetland.

The median and 95th percentile total iron concentrations were greater than the drinking water guideline value of 0.3 mg/L for all wetlands, with the exception of a lower median concentration of 0.29 mg/L in the Unity Park catchment wetland. Soluble iron was only measured in the Parafield catchment wetland, but here the median was lower at 0.13 mg/L and only the 95th percentile of 0.49 mg/L was in excess of the ADWG. As discussed for the catchment water quality, high iron concentrations results in stormwater colour exceeding the 15 HU ADWG aesthetic quality value (measured in the Parafield wetland outlet (WE2) only; median 26 HU; Appendix 6). There were also some instances where 95th percentile concentrations exceeded the guideline values for arsenic, cadmium, lead and manganese.

7.3.3 Salinity of the wetland water

Median and 95th percentile values were above the guideline value of 600 mg/L TDS in the Greenfields and Unity Park wetland outlets. The 95th percentile value for Greenfields was also above the T2 ambient groundwater level of 1,900 mg/L. For the Unity Park wetland, the major ions contributing to salinity, sodium and chloride also had median and 95th percentile concentrations above the drinking water guidelines of 250 mg/L and 180 mg/L respectively, with sodium concentrations also above the long term threshold irrigation guideline value of 115 mg/L.

7.3.4 Nutrients in the wetland water

The 95th percentile nutrient concentrations of the wetland treated urban stormwater were all below the Australian Drinking Water Guidelines. However the 95th percentile total phosphorus concentrations remained above the 0.05 mg/L guideline value recommended to avoid bioclogging in irrigation equipment. In the Kaurna Park, Paddocks and Unity Park wetlands, the median phosphorus concentration was also in excess of this guideline value.

7.3.5 Organic chemicals in the wetland water

Of the extensive suite of organic chemicals monitored the herbicide simazine, which was the most frequently detected organic chemical in the source water, was detected in the highest concentration in wetland treated water. However the simazine concentrations measured in water discharged from the wetlands remained below the Australian Drinking Water Guidelines value of 20 µg/L. The 95th percentile value measured in the Greenfields catchment of 4.1 µg/L was considerably lower than the high value measured in the source water (44 µg/L). The 95th percentile simazine concentration measured in the Kaurna Park wetland discharge, 10.2 µg/L, was only marginally lower than that of the source water, 11.8 µg/L.

The presence of hydrocarbons in stormwater is commonly related to particulate matter (Hall and Anderson, 1988). Total petroleum hydrocabons (TPH) were measured for basin sediments at Parafield in 2006 for fractions ranging from C6 to C36. Sediment concentrations at the third basin (constructed wetland) were below 66 mg/kg, less than half the guideline value for soil health for recreational open space (180 mg/kg; NEPC, 1999).

Methyl Blue Active Substances (MBAS) was detected at a 95th percentile concentration of 0.10 mg/L in the water leaving the Parafield reedbed. While this can be indicative of the presence of general surface active agents, it indicates a significant reduction from 0.25 mg/L in the source water.

Most of the organic chemicals detected in at least one sample in the stormwater catchments were also measured at a concentration near or equivalent to the detection limit (<1 µg/L) in wetland treated stormwater. The organic chemical concentrations measured in water discharged from the wetlands did not exceed any guideline values.

7.3.6 Turbidity in the wetland water

Turbidity was reduced by wetland treatment, but there remained some instances of water quality from the wetlands in excess of the Australian Drinking Water Guidelines of 5 NTU. In the Parafield and Greenfields catchments, the median turbidity was within the guideline value but the 95th percentile value was above 5 NTU, at 13 and 27 NTU respectively. For the Parafield wetland this represents a considerable reduction from a 95th percentile turbidity in the untreated stormwater of 296 NTU. In the remaining catchments both the median and 95th percentile values were above the guideline, with a 95th percentile turbidity at the outlet of ~28-31 NTU.

High turbidity is not a direct risk to human health, though high turbidity may interfere with the efficacy of disinfection, and may contribute to clogging of injection wells. The risks for turbidity in treated stormwater remain high with respect to drinking water supply and aquifer injection and further preventative measures are required to reduce these risks to acceptable levels.

7.4 Aquifer recovered water quality

The Greenfields and Paddocks ASR schemes inject into the T1 aquifer while the Parafield, Kaurna Park and Unity Park schemes utilise the T2 aquifer. The recovered water from the ASR and ASTR systems were grouped based on the seven water quality hazards assessed for the source stormwater, both in native groundwater, and on recovery. While radionuclides were low within untreated stormwater, they are assessed for groundwater as aquifer storage can be a source of radionuclides. In general ASR operations showed lower removal of hazards than in ASTR operation, but direct comparison remains difficult due to the short operational timeframe of the ASTR system. This was truncated by reinjection in recovery wells to maintain the freshwater plume at the injection wells after abstraction had outpaced injection during the operational phase as a consequence of drought. Groundwater quality data for the Parafield site, which includes both ASR and ASTR are presented in Appendix 8. Additional groundwater quality data for the Kaurna Park, Paddocks and Unity Park ASR operations are in Appendix 9.

7.4.1 Pathogens in the groundwater

Prior to introduction of harvested stormwater into the aquifer, Enterococci, Streptococci and *E. coli* were not present in the ambient groundwater. There were no detections of Enterococci, Streptococci and *E. coli* in the groundwater collected from the Parafield ASTR recovery wells in 2008-2012. *E. coli* was detected in water recovered from the ASR wells at Parafield, Kaurna Park and Paddocks, while Enterococci and

Streptococci were detected from Kaurna Park only (Appendix 9). During commissioning of the ASTR system there was a single detection of pathogens in the RW wells, *Cryptosporidium* 21 n/ 10 L, *Giardia* 17 n/ 10 L and Adenovirus 7046 n/L (Appendix 8) and was attributed to the flushing operations (Page *et al*., 2009).

Microbial pathogens lose viability in groundwater and their survival is influenced by the pathogen type, source water type, temperature, redox conditions, activity of indigenous groundwater microorganisms and aquifer geochemistry. Pathogen decay in the T2 aquifer has been previously illustrated to marginally reduce the risk associated with stormwater recycling via ASTR up to 1.4 $\log_{10}$ for viruses (Sidhu *et al*., 2010).

Controlled experimentation was performed with the use of pathogen diffusion chambers to assess die-off rates under the conditions within the T2 aquifer. Rapid decay was evident for *Campylobacter* with a 1.0 $\log_{10}$ removal time (T90) of < 7 days. *Cryptosporidium* and rotavirus die-off was slower with T90 values exceeding the 90 day duration of the pathogen attenuation tests. The pathogen die-off rates measured in the T2 aquifer are and associated experiments on attachment are reported in Appendix 15 and Appendix 16. Studies on the microbial communities present in the aquifer system are also presented in Appendix 17.

7.4.2 Inorganic chemicals in the groundwater

The concentrations of arsenic, chloride, iron, sodium and sulfate in the ambient groundwater of the T2 aquifer can exceed the Australian Drinking Water Guideline values (Vanderzalm *et al*., 2010). Background groundwater quality from the Paddocks ASR operation in the T1 aquifer (22/8/1994) was also in excess of these values, (aside from chloride which was not measured). The ambient groundwater quality may affect the recovered water quality if mixing between the source water and the ambient groundwater leads to recovery of a significant component of ambient groundwater. Normally however, salinity will limit the fraction of ambient groundwater in recovered water for all intended uses.

Hydrogeochemical reactions are important influences on the quality of water that is recovered from a MAR scheme. The chemistry of the water stored in an aquifer is affected by the quality of the source water, the aquifer minerals, redox and temperature conditions within the aquifer and chemical reactions between the source water and the aquifer material or the ambient groundwater (NRMMC-EPHC-NHMRC, 2008). As a result, the aquifer can both treat and degrade water quality.

The total iron concentrations in water recovered from both ASR and ASTR at Parafield remained above the ADWG aesthetic value of 0.3 mg/L. The median concentration recovered from ASR was 0.38 mg/L and from ASTR was 0.36 mg/L, both marginally above the guideline value. The measurement of soluble iron from the ASTR operation indicated that iron in the groundwater of the MAR storage zone is predominantly dissolved. Similar median total iron concentrations were also reported for water recovered from the Kaurna Park (0.57 mg/L) and Unity Park (0.45 mg/L) ASR operations also in the T2 aquifer and the Paddocks ASR (1.0 mg/L) in the overlying T1 aquifer. The 95th percentile total iron of 11 mg/L from Paddocks ASR was also above the STV for irrigation use of 10 mg/L.

The 95th percentile manganese concentrations recovered from Parafield were above the aesthetic guideline of 0.1 mg/L, but the median values were lower with 0.04 mg/L from ASR and 0.06 mg/L from ASTR. This was also seen for Kaurna Park and Paddocks, but at Paddocks the 95th percentile manganese concentration of 1.2 mg/L was also in excess of the health based Mn guideline value of 0.5 mg/L.

Kaurna Park and Paddocks ASR operations also had 95th percentile arsenic above the ADWG value of 0.01 mg/L.

The data to date for Parafield do not show a significant influence of the type of MAR operation (ASR or ASTR) on the inorganic chemical concentrations in the recovered water. This may be influenced by the short time frame of operation for the ASTR scheme, following an extended period of aquifer flushing where the recovery wells had been used for injection.

It is expected that iron concentrations in water recovered from MAR will continue to exceed the aesthetic guideline value of 0.3 mg/L and in some cases (T1 aquifer) may also exceed the irrigation guideline value. Removal via aeration, such as through splash entry into a holding or mixing tank, may provide adequate treatment to allow Fe(2) to be oxidised to Fe(3) and form an insoluble iron oxide precipitate.

7.4.3 Salinity of the groundwater

The average ambient groundwater in the metropolitan Adelaide region of the T2 aquifer is brackish, with a total dissolved solid (TDS) concentration of approximately 1500 mg/L TDS whereas the T1 in the same area is fresher with an average ambient salinity around 1000 mg/L (ANRA, 2012). Mixing of fresh stormwater injectant with more saline native groundwaters was observed at all sites.

Median salinity (TDS) of recovered water from Kaurna Park, Paddocks and Parafield ASR and ASTR was below 300 mg/L and at Unity Park was 690 mg/L (see Appendix 8 and 9). 95th percentile TDS concentrations were below 400 mg/L for the Kaurna Park and Parafield ASTR sites and below 710 mg/L for the Parafield ASR, Unity Park and Paddocks sites.

Irrigation guidline values give a variety of salinity thresholds depending on the type of plants and soils being irrigated. The most stringent value for sensitive crops is 950 S/cm (~637 mg/L TDS) up to 1900 S/cm (~1273 mg/L TDS) for moderately sensitive crops (ANZECC-ARMCANZ, 2000).

Supply of recycled stormwater from the Parafield system to the Mawson Lakes Recycled Water Scheme is mainly for dilution of the reclaimed wastewater that has an average salinity of 1139 mg/L (n = 30; Appendix 11). For dilution, the recycled stormwater should be in the range of 300-650 mg/L TDS.

For direct injection of treated recycled stormwater into the drinking water mains supply, use the Australian Drinking Water Guideline aesthetic value of 600 mg/L applies. For indirect potable reuse (via Little Para Reservoir), the salinity of the reservoir must be considered. The 95th percentile TDS value for Loc. 9 in Little Para Reservoir is 407 mg/L (Appendix 12).

The salinity of aquifer recovered stormwater can be controlled through management of injection and recovery volumes. Salinity limits are optimised by leaving a residual of injectant in the aquifer in between recovery cycles which creates a buffer zone, containing a mixture of fresh stormwater injectant and brackish ambient groundwater. If demand increases substantially, more stormwater will need to be injected in order to meet both volume and salinity requirements.

7.4.4 Nutrients in the groundwater

The nutrient status of the ambient groundwater is low, and nutrient concentrations in native groundwater meet Australian Drinking Water Guidelines. The water recovered from ASR and ASTR operations generally remains below guideline values for nitrogen species, aside from the 95th percentile ammonia concentrations from Parafield ASTR and Kaurna Park, Paddocks and Unity Park ASR. Median phosphorus was below the long term value of 0.05 mg/L recommended to avoid bioclogging, aside from Paddocks ASR at 0.06 mg/L

During the flushing phase of the ASTR scheme, removal of organic carbon, nitrogen and phosphorus was evident along the flow-path between the recovery and injection wells. The TOC concentration at IW1 in September 2008 (end of flushing phase) was approximately 50% lower than expected from conservative mixing between the source and receiving waters, while total nitrogen and phosphorus reduction was ~70%.

The impact of injection on the recovery wells is evident during storage and in the first recovery from these wells through increased dissolved organic carbon (DOC), nitrogen (predominantly in the form of ammonia) and phosphorus. These wells had received the greatest flux of nutrients which can accumulate around the point of injection. For example, this is especially evident in groundwater sampled from the recovery wells in February 2009 within a day of the first recovery of water, where DOC reached 9.8 mg/L and ammonia (6.0 mg/L) and phosphorus (0.2 mg/L) concentrations were greater than measured in the WE2 source water. The next sampling from the recovery wells in March 2009 showed DOC, ammonia and phosphorus concentrations had dropped to 4.2, 0.2 and 0.035 mg/L respectively. These values are more representative of the quality of recovered water during ongoing operation. The elevated initial concentrations are associated with the reduced geochemical conditions occurring only in the immediate vicinity of injection wells due to entrapment of particulate organic matter. This can also occur in ASR operation, where the quality of water at the start of recovery may not represent the quality in the bulk of the storage zone when it is affected by the biofilm that develops around the injection well.

7.4.5 Organic chemicals in the groundwater

There has been little evidence for the presence of organic chemicals in the groundwater despite an extensive monitoring suite (Appendix 8). Detergents were identified in the Parafield ASTR recovery wells in February 2009. There was a single detection of 2,6-dichlorophenol in IW3 in 2008. This was thought to be caused by solvent residuals from the construction of the well. At the Parafield ASTR site, simazine was not detected in the injection or recovery wells despite being the most frequently detected organic chemical in the source water suggesting sorption or biodegradation during wetland and aquifer storage. Simazine has been reported to degrade in aerobic aquifers with a mean half-life of 60 days (ranging from 10–300 days) (NRMMC-EPHC-NHMRC, 2009b) however there are no data on simazine degradation rates in anaerobic aquifers. The studies involving passive samplers indicate generally low levels of organic micropollutants in the stormwater, as the contaminants detected were present at very low ng/L levels, generally two to four orders of magnitude below the drinking water guidelines. The efficiency of attenuation of these organic micropollutants during MAR was difficult to determine due to variations in the source water concentrations

Subsurface storage in anaerobic aquifers can provide a treatment step for organic chemicals, e.g. trihalomethanes and haloacetic acids as shown by Pavelic *et al.* (2005). In addition groundwater passage through varying redox zones can provide exposure to the conditions required for degradation of multiple organic chemical hazards.

7.4.6 Turbidity in the groundwater

Turbidity and particulates can be removed by filtration in the aquifer. However particulate hazards can also be generated from mineral dissolution and particle mobilisation within the storage zone during pumping, which may lead to turbidity values above the Australian Drinking Water Guideline aesthetic value of 5 NTU. The turbidity of the groundwater from the Parafield ASTR injection wells during the flushing phase varied between 3.9 - 22 NTU in 2007 and 1.5 - 3.1 NTU in 2008. The initial water recovered from the Parafield RW1 (March 2009) was also low in turbidity (1.2 NTU).

Overall the median turbidity of 0.7 NTU was below the ADWG aesthetic value of 5 NTU, while the 95th percentile remained marginally above this at 6 NTU (Appendix 8) for the Parafield ASTR system. The 95th percentile turbidity values were above the aesthetic guideline value for Parafield ASR (16 NTU), Kaurna Park ASR (78 NTU) and Paddocks ASR (27 NTU), while Unity Park ASR remained below 5 NTU. All median values however were below 3 NTU (Appendix 9). Occasional events of high turbidity in recovered water may result from well scouring (high flow rate pumping) peformed to manage clogging where particulates at the well interface are dislodged. This can be managed through adequate purging of wells following well scouring.

7.4.7 Radionuclides in the groundwater

Groundwater gross alpha and gross beta activity remained below the ADWG 0.5 Bq/L screening level within four samples recovered from the Parafield ASTR operation within the T2 aquifer. No samples for radioactivity were taken from the T1 aquifer.

7.5 Salisbury ring main water quality

The Salisbury ring main water quality is the mixture of water recovered from all the ASR systems and associated stormwater catchments that feed into the ring main (Figure 4). The water quality data for the ring main is presented in Appendix 10. The water quality is important to all the options, though generally Parafield dominates the hydraulic supply of stormwater to the Mawson Lakes third pipe system.

The ANZECC short term irrigation value was used to assess public open space irrigation and the third pipe system use options while the ADWG was used to assess potable water options. If recycled stormwater is transferred to the Little Para Reservoir, the ANZECC fresh water ecosystem protection trigger values for 80% species protection (ANZECC-ARMCANZ 2000) is the benchmark as the receiving environment is considered a highly modified ecosystem.

The 95th percentile value for colour (59 HU) for the ring main exceeded the third pipe network operational guideline of 15 HU used by SA water, but the mean value was below this. The median total iron of 0.38 mg/L was slightly above the ADWG aesthetic (taste threshold) value of 0.3 mg/L, while the median soluble iron was lower at 0.22 mg/L.

There was evidence of faecal contamination in the ring main system, with *E. coli* detected in 72% of samples (95th percentile 313 cfu/100 mL). *Campylobacter* was detected in 41% of samples with a 95th percentile value of 2,200 and *Cryptosporidium* with a maximum value of 9 n/L and adenovirus a maximum value of 407 n/L in 5% of samples (n=21).

The 95th percentile copper concentration of 0.008 mg/L (median 0.001 mg/L) was well below both long and short term irrigation guideline values of 0.2 and 5 mg/L respectively. Median and 95th percentile value were also well below ADWG health and aesthetic values of 2 and 1 mg/L respectively.

7.6 Recycled stormwater blended with reclaimed wastewater quality

Options 4, 7 and 8 (shown in Figure 3) describe urestricted municipal irrigation and domestic non-potable use via dual reticulation where reclaimed wastewater is mixed with recycled stormwater prior to distribution. For these options the waters are blended and chlorinated at the Greenfields Mixing Tank prior to distribution to the suburb of Mawson Lakes via dual reticulation. Water quality is monitored by SA Water and the results of the monitoring program are shown for different points across the Mawson Lakes distribution system (see Figure 16).

Figure 16 Mawson Lakes third pipe distribution sampling sites.

Electrical conductivity and TDS are consistently high and mean, median and 95th percentile values all exceed short term irrigation and ADWG aesthetic guideline values respectively (Appendix 11). Total iron and total manganese, colour and *E. coli* are all below irrigation guideline values (Appendix 11).

7.7 Little Para Reservoir water quality

Three options apply to potential drinking water supply augmentation via a reservoir and drinking water treatment plant (Figure 3) where water is;

- pumped directly from a wetland to a reservoir (option 10);
- pumped directly from an aquifer to a reservoir (option 11);
- pumped from an aquifer, undergoes an intermediate treatment step and is pumped to a reservoir (option 12).

Where urban stormwater is to augment the raw drinking water supplies consideration must be given to the quality of water in the reservoir. Treated urban stormwater from the Parafield, Edinburgh Park, Kaurna Park, Paddocks and Unity Park (with Globe Derby Park to follow once commissioned) stormwater harvesting schemes could be pumped via the interconnected ring main distribution system to the Little Para Reservoir. Water quality data were supplied by SA water for sampling locations (Loc 9) at the dam wall by the offtake structure and "Snake Gully" near the headwaters of the Little Para Reservoir (Figure 17).

Figure 17 Little Para Reservoir and catchment sampling locations (Snake Gully and Loc 9).

No differentiation was made between different sampling depths for Loc 9. Median and 95th percentile values for turbidity and colour at Loc 9 offtake structure exceeded ADWG aesthetic guideline (NHMRC–NRMMC, 2011) values (Appendix 12) for the period reported June 2000 to October 2010. *E. coli* and coliforms are found in samples from Loc 9 at 95th percentile concentrations of 24 and 3,775 cfu/100mL respectively. Confirmed *Cryptosporidium* oocysts have a 95th percentile concentration of 27 oocysts/10L in samples from Snake Gully. *Giardia* is also sampled for at Snake Gully and shows a 95th percentile concentration value of 74 confirmed cysts/10L. Loc 9 periodically has algal cell densities of up to 103,373 cell/mL and at Snake Gully this figure can be up to 56,063 cells/mL, however algae are not differentiated to the species level in the data supplied. 95th percentile total phosphorus concentrations at Loc 9 exceed the long-term irrigation value of 0.05 mg/L (ANZECC-ARMCANZ 2000) slightly. The total iron 95th percentile value (0.84 mg/L) for Loc 9 exceed both ADWG aesthetic guidelines and long term irrigation guidelines of 0.3 and 0.2 mg/L respectively (NHMRC–NRMMC 2011; ANZECC-ARMCANZ, 2000). Of the 30 trace organic compounds (including atrazine and simazine) tested for in 130 and 56 samples from Snake Gully and Loc 9 respectively, only Chlorthal-Dimethyl was detected twice in samples in May and June 2010 from Snake Gully at a maximum concentration of 0.43 µg/L (Appendix 12). Chlorthal-Dimethyl also known as DCPA is a phthalate pre-emergent herbicide used on annual grasses and annual broadleaf weed species in a wide range of vegetable crops. DCPA is also used in residential homes and gardens. It is not listed in the Australian Drinking Water Guidelines.

7.8 Little Para Water Treatment Plant treated drinking water quality

The same three options (10-12) apply to potential drinking water supply augmentation via a reservoir at the Little Para Reservoir and drinking water treatment plant (Figure 3). The Little Para Drinking Water Treatment Plant Little Para was the fourth of six filtration plants built to serve metropolitan Adelaide and was completed in 1984. The plant has a capacity of 160 ML per day and uses conventional coagulation/flocculation and chlorine disinfection to treat the water from the Little Para Reservoir. Five year average water quality data (1/7/2005-30/6/2010) from the Little Para Water Treatment Plant are shown in Appendix 13. None of the parameters exceeded the Australian Drinking Water Guidelines.

8 Calculation of microbial health-based targets

This section describes the setting of health-based performance targets for achieving microbial quality in recycled water derived from urban stormwater, and the measures that can be applied to meet compliance with the tolerable risk of 10^{-6} DALYs (Disability Adjusted Life Years) per person per year (NRMMC–EPHC–AHMC, 2006) for each use option. The basic principle of the DALY is to weigh each health impact in terms of severity within the range of zero for good health to one for death. The weighting is then multiplied by the duration of the effect and the proportion of people affected. In the case of death, duration is regarded as the years lost in relation to normal life expectancy.

Compiled pathogen and faecal indicator stormwater quality data for the Parafield site are reported in Table 14. Table 14 shows the extracted pathogen data numbers used in this risk assessment and includes the Parafield stormwater harvesting system and the compiled stormwater data from sewered catchments in Sydney with high sewer overflows frequency (>44 blockages per year per 100 km sewer) (NRMMC-EPHC–NHMRC–2009a; Table A2.4). The Parafield and Cobbler Creek catchments were within an area that had a five year (2005-2010) annual average of 15.6 overflows per 100 km sewer (see Section 6.3).

The Australian Guidelines for Water Recycling (NRMMC-EPHC-NHMRC, 2009a) recommend that the 95th percentile numbers of pathogens in source waters and the mean validated removal rates be used for each preventative measure when used in risk assessments. The data in the guidelines was transformed into a form suitable to support data analysis, by setting results that reported below detection limits to a value of one half the detection limit (for all relevant samples for all determinants) and by correcting results for the recovery efficiency of the methodology used for analysis (for protozoan parasite oocysts counts, as shown in Table 14) consistent with the approach recommended by the guidelines. The same approach was used to determine the pathogen numbers for the Parafield data set, an interpolated 95th percentile was carried forward based on a fitted log normal distribution to provide the summary statistic for the human health risk assessment.

This approach was adopted for deriving the *Cryptosporidium* protozoan parasite reference pathogen concentration in stormwater in the guidelines, which was based on the interpolated 95th percentile of the confirmed oocyst counts in samples containing either *C. parvum* or *C. hominis*: 18 oocysts per 10 L (Table A2.4, NRMMC-EPHC–NHMRC–2009a). The 95th percentile numbers of confirmed oocysts from the Parafield data station was lower, at 14 oocysts per 10 L (Table 13). The maximum observed value for *Cryptosporidium* at the Parafield data station was 19 per 10 L. However, in urban stormwater there is evidence that most samples do not contain human infectious oocyst genotypes; rather, they contain genotypes that infect other animals. For example, Jiang (2004) reported that in sewered urban stormwater systems only about 5% of around 100 *Cryptosporidium* oocyst types characterised were infective for humans.

Table 14 Summary of pathogen and faecal indicators from Australian urban stormwater data.

	Default values for reference pathogens (raw stormwater)*	Parafield stormwater harvesting system (PDS untreated stormwater only)**				Stormwater quality summary statistics from untreated sewered urban catchments in Sydney ***			
	Log normal 95th percentile	Number of samples	Detects (%)	Median	Log normal 95th percentile	Number of samples	Detects (%)	Median	Log normal 95th percentile
Adenovirus (n/L)	1	18	28	< 1	2				
Cryptosporidium (n/10L)	18 (= 1.8/L)	18	50	4	14	59	37	< 13	102
Campylobacter (n/L)	15	19	26	2	11	59	3	< 2	< 2
Giardia (n/10L)		18	50	12	83	59	19	< 25	220
E. coli (n/100mL)		21	95	9,600	64,000	58	100	1,700	240,000
Enterococci (n/100mL)		1	100	2,900		59	100	740	12,100
Bacteriophage (n/10mL)		20	100	140	1,800				

* Default values recommended for non-potable use risk assessment after Table A3.1 from NRMMC-EPHC–NHMRC–2009b

** Data set only includes sampling of untreated stormwater from the Parafield Data Station to 30/11/2012

*** Derived from Table A2.4, NRMMC-EPHC–NHMRC–2009b

In the guidelines where there were insufficient numerical data to derive an interpolated 95th percentile, or where the interpolated 95th percentile was below the detection limit, the maximum observed value was carried forward to provide the summary statistic for the health risk assessment. This approach was adopted for deriving the *Campylobacter* bacterial reference pathogen numbers for the Parafield catchment, which was based on the maximum observed value: 15 n/L (Table 14). The maximum observed value previously applied for *Campylobacter* at the Parafield system was also 15 n/L (Page *et al*., 2009), but greater numbers of detections allowed for an interpolated 95th percentile to be carried forward within this assessment, based on a fitted log normal distribution to provide the summary statistic for the human health risk assessment of 11 n/L.

Where no numerical data were reported due to all samples being reported as 'none detected', 10 times the detection limit for viruses was considered to represent a conservative summary statistic for the health risk assessment. This approach was adopted in the guidelines for deriving the infectious adenovirus viral reference pathogen concentration in stormwater (1 n/L), which was based on 10 times the assay detection limit (Table A2.4). For the Parafield system the maximum detected number of viruses were 420 n/L using a PCR based technique. A greater numbers of detections allowed for an interpolated 95th percentile to be carried forward based on a fitted log normal distribution to provide the summary statistic for the human health risk assessment of 194 n/L. The PCR based techniques used in the current study detect all viral DNA and make no distinction between infectious and non-infectious viruses and thereby tend to greatly over estimate numbers. For example, Choi and Jiang (2005) reported 7% detection of adenoviruses by real-time PCR, with numbers ranging from 10^2 to 10^4 viruses per litre from 114 environmental samples. However, a plaque assay using two human tissue culture cell lines yielded negative results, suggesting that adenoviruses detected by real-time PCR are likely non infectious. Similarly He and Jiang (2005) reported that for adenovirus numbers of 10^5 /L only 0.1% were infectious. In the current study a conservative number of 1% infectious viruses has been applied yielding a final 95th percentile of 2 viruses/L.

Previously in the absence of adequate data the default values from the Stormwater Harvesting and Reuse guidelines (NRMMC-EPHC–NHMRC–2009b) have been selected for use in all of the exposure scenarios, although it is acknowledged that the use for drinking water risk assessment is specifically excluded from the Stormwater Harvesting and Reuse guidelines and is dealth with in the Augmention of Drinking Water Guidelinges (NRMMC-EPHC–NHMRC–2009a). Note that the methods used are apparently inconsistent as drinking water is explicitly excluded from the Stormwater Harvesting and Reuse guidelines but the approach conforms to the current water recycling and drinking water guidelines. The new data collected from the Parafield data station allows for revised pathogen numbers to be utilised for the drinking water risk assessment which follows.

Microbial performance targets are usually expressed in terms of minimum required $\log_{10}$ reductions. The two parameters required for calculation of performance targets are *pathogen concentrations* in urban stormwater (Table 13) and *exposures* associated with identified uses of urban stormwater:

As shown in Table 13 pathogen and indicator concentrations can vary over a wide range. There was no observable direct correlation between pathogen and indicator numbers for the Parafield catchment. For the Parafield stormwater harvesting system the default assumption that urban stormwater contains 14 *Cryptosporidium*, 194 virus (before correction for infectivity) and 11 *Campylobacter* per litre (95th percentile) was used.

Indicative exposures associated with particular uses of recycled water are provided in Table 3.3 of the Australian Guidelines for Water Recycling Phase 1 (NRMMC–EPHC–AHMC, 2006) and repeated in Table 15.

These default values were used to determine the performance targets shown in Table 15, $\log_{10}$ reduction calculations and were performed as described below:

$\log_{10}$ reduction = Log (number of organisms in stormwater × exposure (L) × frequency ÷ dose equivalent to 10^{-6} DALY) where the dose equivalent to 10^{-6} DALY taken from NRMMC–EPHC–AHMC 2006, for*:*

- Rotavirus = 2.5×10^{-3} n/yr
- *Cryptosporidium* = 1.6×10^{-2} n/yr
- *Campylobacter* = 3.8×10^{-2} n/yr

System-specific data on pathogen concentrations can be used, as an alternative to the default values, to calculate performance targets using these same formulae. Specific exposure data can also be used as an alternative to the defaults shown in Table 15.

Table 15 shows that there are considerable differences in treatment removal requirements for different uses of stormwater. As expected, drinking water has the highest requirements; all uses required some form of treatment or exposure control.

Table 15 shows that viruses require the highest $\log_{10}$ reductions ranging from 5.8 $\log_{10}$ for drinking water to 2.7 $\log_{10}$ for open space irrigation. $\log_{10}$ reductions for bacteria were next highest follow by protazoa (Table 14). Table 15 also shows that the possibility of cross-connections represents a significant proportion of the exposure associated with dual-reticulation systems. The current risk assessment assumes a default cross connection rate of 1 in 1000. If the likelihood of cross connections was further demonstrated to be less, as for the Mawson Lakes development, this would further reduce the required $\log_{10}$ reductions.

Industrial use of stormwater has not been included in Table 15 because exposures will vary depending on the particular type of use. Potential occupational and public exposures need to be determined on a case-by-case basis, and used to calculate $\log_{10}$ reduction requirements (using the same approach described above). Potential preventive measures for addressing these risks are given in the next section below.

Table 15 $\log_{10}$ reductions for MARSUO options for priority uses of recycled water from Parafield stormwater harvesting system.

Option	**Route of exposure*****	**Exposure / event (L)***	**Frequency (events/yr)***	**----------- $\log_{10}$ reduction targets** ----------------**		
				Rotavirus	***Cryptosporidium***	***Campylobacter***
1 – 4 Restricted open space irrigation	Ingestion of sprays	0.001	50	1.6	0.6	1.2
5 -8 Non-potable domestic use and unrestricted irrigation	Ingestion of water and sprays	0.67	1	2.7	1.8	2.3
9 – 12 Drinking	Ingestion of water	2	365	5.8	4.8	5.3

* default assumptions (after NRMMC–EPHC–AHMC 2006)
** default assumption that Parafield raw urban stormwater contains 2 adenovirus 1.4 *Cryptosporidium*, and 11 *Campylobacter* per litre (95th percentile) was used
*** Total residential use (garden plus internal) after NRMMC–EPHC–AHMC (2006). Total consumption is assumed to be 2 litres per day, of which 1 litre is consumed cold. Affected individuals may consume water 365 days per year. A conservative estimate of 1 in 1,000 houses with cross-connections has been considered (NRMMC–EPHC–AHMC 2006).

8.1 Preventive measures to manage microbial risk

The Australian Drinking Water Guidelines (ADWG) (NHMRC–NRMMC, 2011) specifies the indicative $\log_{10}$ reductions of treatment processes for enteric pathogens. Table 16 (adapted from the ADWG and AGWR) gives indicative $\log_{10}$ removals for different treatment processes, provided that they are validated. The Australian Guidelines for Water Recycling (AGWR) (NRMMC–EPHC–AHMC 2006) present on-site controls to reduce exposure (Table 17) which were used to determine microbial removal for the provision of acceptable quality water for identified uses (Table 15).

Other specific treatments such as use of stormwater harvesting wetlands, bioretention basins, elements of water sensitive urban design and MAR require a case by case validation of the treatment efficacy which needs to be demonstrated by water quality monitoring as was shown for the Parafield wetland system by Page *et al.* (2008; 2009) and Sidhu *et al*. (2010). Similarly, treatment through aquifer storage (and transport during ASTR) require casewise validation for pathogen removal (see Appendix 15 and Appendix 16).

Employing on-site controls to reduce exposure augments or reduces the focus on more expensive treatment. Examples of controls, specific but not exclusive, to irrigation are given in Table 17 and can be used in combination with treatment processes to meet the required $\log_{10}$ reduction targets calculated in Table 15. For example, a withholding period, is currently used for options 1 – 4, public space irrigation of the MARSUO options evaluated in this report.

Table 16 Indicative $\log_{10}$ removals of enteric pathogens for different treatment processes*.

Treatment process	Virus	Protozoa	Bacteria*
Dual media filtration with coagulation	1.0	1.5	0.5
Ultrafiltration (membrane)	2.0	3.0	>4.0
Chlorine disinfection	3.0	0.0	>4.0
Ozonation	3.0	2.0	>4.0
UV disinfection	3.0	4.0	>4.0

*Adapted from the Australian Drinking Water Guidelines (Table A 1.8, p. A-15) (NHMRC–NRMMC 2011) and the Australian Guidelines for Water Recycling (NRMMC–EPHC–AHMC 2006).

Table 16 and Table 17 show how treatment processes can be used alone or in combination with on-site preventive measures to meet the minimum health-based $\log_{10}$ reduction targets. The required $\log_{10}$ reductions can be accumulated over sequential treatments and control measures. It is to be noted that a single treatment process (barrier) cannot be attributed a pathogen LRV greater than 4.0 $\log_{10}$. This is because validation of treatment barriers becomes problematic at > 4.0 $\log_{10}$ due to a lack of available surrogates for monitoring.

In general the following assessments of risk can be determined for the different stormwater use options:

Open space irrigation requires 1.3 $\log_{10}$ using the default Stormwater harvesting guidelines (or > 1.6 $\log_{10}$ using the Parafield specific data from Table 14) for reduction of viruses and *Cryptosporidium* and can potentially be managed using chlorination or UV disinfection and/or exposure controls.

Toilet flushing and washing machine require 2.7 $\log_{10}$ for viruses and aquifer treatment and chlorination would be sufficient. However, cross connections are the largest risk in dual reticulation systems. Exposure can be reduced using additional preventative measures such as certified plumbing schemes, staged inspections and audits. Other aesthetic risks such as colour and turbidity may dominate the acceptability for this end use.

Drinking water use requires the highest microbial health-based targets be met which would involve significant treatment, 5.5 $\log_{10}$ for viruses using the default values from the guidelines or 5.8 $\log_{10}$ using the Parafield data. The different potential end uses for stormwater harvesting and reuse are presented along with the associated microbial health-based targets in Table 18 also includes some example treatment trains to produce the required pathogen inactivation credits. Other treatment combinations are equally valid and in the "net benefits" part of this project, the selection of treatments to meet health, economic and environmental targets will be considered to optimise the treatment train for each option. In the interim, Table 18 shows indicative treatments to achieve the water quality targets to satisfy human health. Note that the treatments shown in Table 18 for use of stormwater in drinking water supplies are more strenuous that those reported by Page *et al.* (2010). This is due to the indicative $\log_{10}$ removals of different treatments being reduced in Table 16 due to process validation uncertainty from values previously published (NRMMC-EPCH-AHMC, 2006) cited and used by Page *et al.* (2010).

Table 17 Exposure reductions in $\log_{10}$ reduction provided by non-treatment measures (after NRMMC–EPHC–AHMC, 2006 p. 97).

Control measure	Reduction in exposure to pathogens
Cooking or processing of produce (eg cereal, wine grapes)	5-6 log
Removal of skins from produce before consumption	2 log
Drip irrigation of crops	2 log
Drip irrigation of crops with limited to no ground contact (eg tomatoes, capsicums)	3 log
Drip irrigation of raised crops with no ground contact (eg apples, apricots, grapes)	5 log
Subsurface irrigation of above ground crops	4 log
Withholding periods — produce (decay rate)	0.5 log/day[a]
Withholding periods for irrigation of parks/sports grounds (1–4 hours)	1 log
Spray drift control (microsprinklers, anemometer systems, inward-throwing sprinklers, etc.)	1 log
Drip irrigation of plants/shrubs	4 log
Subsurface irrigation of plants/shrubs or grassed areas	5-6 log
No public access during irrigation	2 log
No public access during irrigation and limited contact after (non-grassed areas) (e.g. food crop irrigation)	3 log
Buffer zones (25–30 m)	1 log

[a] Based on virus inactivation. Enteric bacteria are probably inactivated at a similar rate. Protozoa will be inactivated if withholding periods involve desiccation.

Table 18 groups the options in terms of exposure and required $\log_{10}$ reductions and indicates that for stormwater reuse applications. For example, for viruses 1.6 $\log_{10}$ reduction for open space irrigation, 2.7 $\log_{10}$ for dual reticulation systemsand 5.8 $\log_{10}$ for drinking water is required. This can be achieved either by combinations of aquifer (assuming a 4.0 $\log_{10}$ reduction if validated) or other treatments such as ultra filtration membranes and UV and chlorine disinfection and the existing conventional treatment at the Little Para Reservoir. Other treatment options from Table 16 may also be considered if total $\log_{10}$ reductions for each of the reference pathogens are met. Potentially other treatments and exposure controls could also be considered from Table 16 and Table 17.

Table 18 Calculated microbial health based targets (interim targets for drinking water), treatment options and exposure controls for stormwater reuse.

Option	Target log_{10} removal from Table 15			Log_{10} removal achieved with suggested *exposure controls* (at right)			Log_{10} removal achieved with suggested *treatments* (at right)			Total log_{10} reduction			Example of treatment / exposure controls to meet target removals
	V	P	B	V	P	B	V	P	B	V	P	B	
1 – 4 Open space irrigation	1.6	0.6	1.2	3.0	3.0	3.0	0.0	0.0	0.0	3.0	3.0	3.0	No public access during irrigation, withholding period
5 -8 Dual reticulation - internal and external plus municipal irrigation	2.7	1.8	2.3	0.0	0.0	0.0	7.0	4.0	>8.0	7.0	4.0	>8.0	Aquifer treatment†, blending with recycled water; and chlorine disinfection with cross connection monitoring.
9 - 12 - Drinking	5.8	4.8	5.3	0.0	0.0	0.0	10.0	8.0	>12.0	10.0	8.0	>12.0	Aquifer treatment†, UV disinfection, dual media filtration with coagulation, chlorination*

V virus, P protozoa, B bacteria; † Aquifer treatment assumed to be 4 log_{10} but would require validation; *dual media filtration with coagulation, chlorination are already installed at the Little Para treatment plant

9 Summary of human health and environmental risks and preventative measures for different options

This section integrates the catchment land use assessments and water quality data and combines them with preventative measures in a final risk assessment for each of the options. The integrated risk assessment results for each of the options were incorporated into the twelve risk groups given in the MAR guidelines (NRMMC-EPHC–NHMRC, 2009a) and are shown in the following sections. The first seven risks (pathogens, inorganic chemicals, salinity, nutrients, organic chemicals, turbidity and radionuclides) are related to water quality and assessments are given for human health, aesthetic water quality and the environment. The last five risks (pressure, contaminant migration, aquifer dissolution, groundwater dependant ecosystems and energy considerations) relate only to the environment.

The results are presented in a series of figures similar to Figure 3. All risks are coded in terms of a traffic light approach:

- green indicates a low risk;
- yellow an unknown or poorly understood risk and
- red a high risk.

In each of the figures, circles refer to human health risks and triangles refer aesthetic and environmental risk.

The assumed treatment trains and use controls in Table 17 are considered to apply. The water quality risk assessment depended upon the option selected: Option 1 utilised wetland treated stormwater and water; Option 2, 3, 5, 6, 9 water extracted from the ASR systems and ring main; Option 4, 7, 8 the final blended water quality at the Greenfields mixing tank; Option 10, 11, 12 water from the Little Para Water Treatment Plant. Where a parameter was not assessed for the final treated water, the sampling point upstream was used.

9.1 Pathogens

Pathogen risks to human health and the quality of harvested stormwater may arise from untreated sewage entering the stormwater system. The Australian Drinking Water Guidelines state that faecal indicators should not be detected. Faecal indicators are likely to originate from human and animal sources within the catchment. These could arise from sewerage contamination e.g. overflows (Figure 8) or runoff from land contaminated with domestic animal or livestock faeces and septic tank failures (Table 7).

Faecal source tracking can be used to differentiate between the different sources of faecal contamination in stormwater. By exploiting the differences in the sterol profiles of humans and animals, it is possible to determine the source of the faecal contamination. Faecal sterols, such as coprostanol, are produced in the digestive tract of humans by microbial hydrogenation of cholesterol. The most abundant faecal sterol, coprostanol, has been detected in the majority of surface waters and sediments contaminated with sewage. The presence of coprostanol is primarily a consequence of anthropogenic input into a system and hence represents the presence of sewage contamination.

The coprostanol /epicoprostanol index is used to differentiate between human and non-human faecal inputs (Leeming *et al*., 1996). Studies by Nichols *et al*. (1996) confirmed values of >0.7 as indicative of urban sewage pollution and concluded that this ratio is a very useful tool for the elucidation of sources of faecal pollution. However, the faecal sterol data collected does not permit the accurate determination of ratios as coprostanol or epi-coprostanol or both were not detected in all samples, indicating an overall low level of faecal contamination in the Parafield stormwater. Presence of cholestanol at a 95th percentile concentration for Parafield of 491 ng/L and for Cobblers Creek of 3,026 ng/L indicates the presence of diffuse quantities of non-human faecal pollution. Based on the low concentrations of faecal sterols detected, the primary sources of faecal contamination to the stormwater were unlikely to be from human sources. This suggestes that the microbial health-based targets adopted in this study are appropriate and the associated preventative measures are sufficient to be able to manage pathogen risks.

Pathogens in stormwater require the adoption of specific microbial health-based targets as risk management strategies which have been evaluated quantitatively in Section 8. The results of the risk assessment have been represented for each of the twelve options in Figure 18.

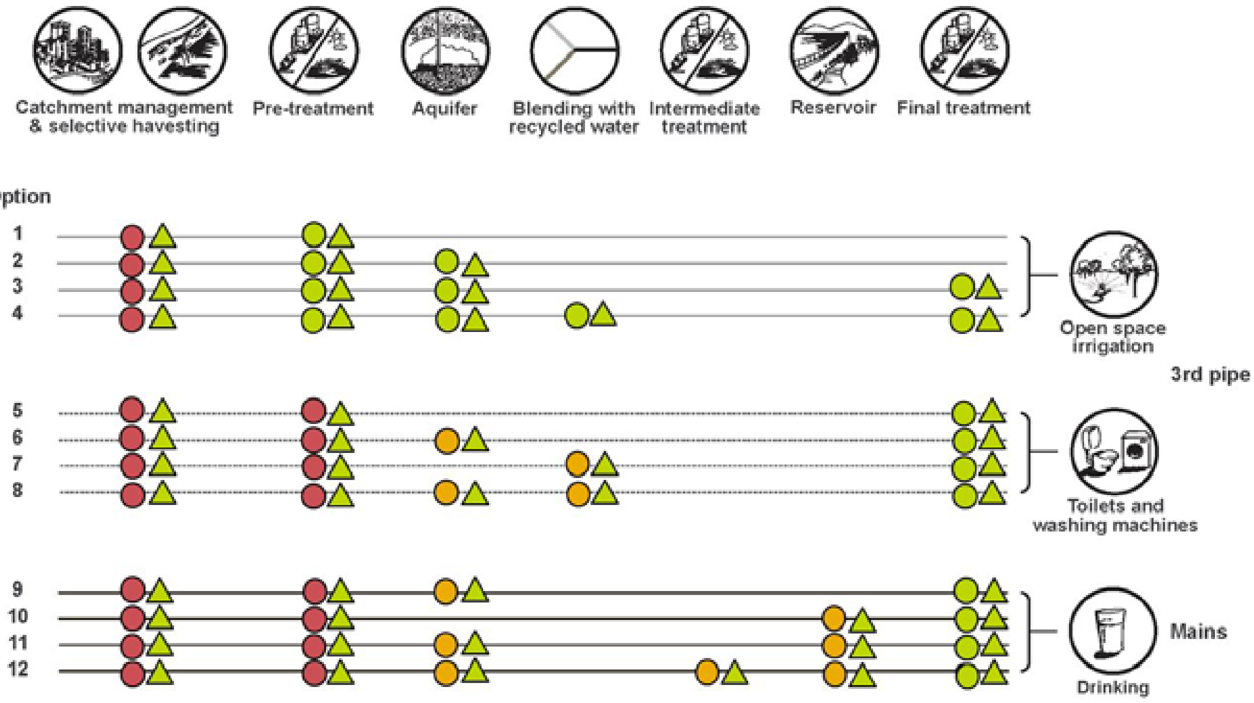


Figure 18 The twelve MARSUO options and pathogen risks (circles represent human health, triangles represent environmental risks; red represents high risks, yellow represents uncertain risks and green represents low risks).

Figure 18 shows that initially the untreated stormwater (inherent risk) was considered as a high risk to human health and additional management activities were identified for each of the options. Pathogen risks to the environment and aesthetic water quality were assessed as being low for all options.

In the stakeholder workshops it was identified that a number of stormwater catchment risk management activities could also be performed to manage the risks. The management options identified included:

- the use of buffer strips around streams;
- the adoption of a livestock exclusion program (especially juvenile animals) from water courses;
- removal of dog faeces by dog walkers;
- continuance of SA Water's active sewer maintenance program with enhanced (higher priority) response times and bunding/treatment of overflows with the catchment in line with ESCOSA approved 'best practices';
- development of an improved sewer chokes reporting system where the stormwater is intended for drinking. This is also identified in a CSIRO report to the WSAA as 'best practice guidance' controls with improvements to preventative maintenance and avoidance (planning and design) practices; and

- improvements to septic tank maintenance schemes as suggested by Alexander *et al*. (2010) with a view to move toward community based wastewater treatment or sewered systems are also recommended for the currently unsewered areas.

Risks from viruses require the highest microbial inactivation credits and hence have the highest health-based targets for options of stormwater reuse. With sufficient treatment or exposure controls all of the options could be made safe for human exposure. The microbial inactivation credits section groups the options in terms of exposure (i.e. open space irrigation, toilet and washing machine use and drinking water) and determines the required $\log_{10}$ reductions and indicates that for stormwater reuse applications.

For open space irrigation: a minimum 1.6 $\log_{10}$ reduction is required (NRMMC-EPHC–NHMRC–2009b). This could be achieved simply by restricting public access during irrigation and use of a withholding period, a practice that largely occurs already, and gives a 3.0 $\log_{10}$ reduction through reduced exposure (NRMMC–EPHC–AHMC 2006).

For dual reticulation systems: a minimum 2.7 $\log_{10}$ reductions for viruses are required to meet the microbial health-based targets. This could be achieved through combinations of either aquifer or UV treatment and chlorination disinfection. However, aquifer treatment would need to be validated prior to the 4.0 $\log_{10}$ inactivation credits being applied.

For drinking water: the minimum microbial health-based target is 5.8 $\log_{10}$ for viruses. This can be achieved either by combinations of aquifer or membrane filtration and UV followed by chlorine disinfection. The greatest value in removing pathogens would be to incorporate further treatment options at the Water Treatment Plant, as opposed to the intermediate steps. Chlorination as an intermediate step prior to pumping to Little Para Reservoir has not been recommended as the water quality of the stormwater is comparable to that of the reservoir. Pathogen attenuation in the reservoir is not credited / considered as there is potential for short circuiting. Ultrafiltration membrane treatment can achieve at least 2.5 $\log_{10}$ removal for viruses, UV disinfection can achieve 1.0 $\log_{10}$ removal at 50 mJ/cm^2 and chlorine disinfection can achieve up to 4.0 $\log_{10}$, depending upon the chlorine contact time (CT) as a function of pH and turbidity. With these barriers, the risks from pathogens may be acceptable.

9.2 Inorganic chemicals

The results of the risk assessment for inorganic chemicals for each of the 12 use options are shown in Figure 19.

A variety of catchment land uses are associated with potential contamination of various metal compounds that may constitute a risk to the environment (mainly the tertiary 2 aquifer) (Table 8). Untreated stormwater had low concentrations of inorganic chemicals with the exception of iron (and aluminium in Parafield, Cobbler Creek and Kaurna Park); see Appendix 5. Iron imparts a yellow colour to stormwater that is an aesthetic risk and also a risk to the environment. Given the ubiquitous nature of iron within the stormwater catchment (in the form iron in colloidal clay and rusted materials present in the stormwater detention basins) catchment management activities are unlikely to be able to reduce iron to an acceptable level for any of the required end uses. Iron concentrations in Little Para Reservoir are similarly high but again do not represent a risk to human health.

Arsenic has the potential to be mobilised during storage of harvested stormwater in the aquifer. However to date there has been no evidence of elevated arsenic concentrations in the recovered water that would be a risk to human health.

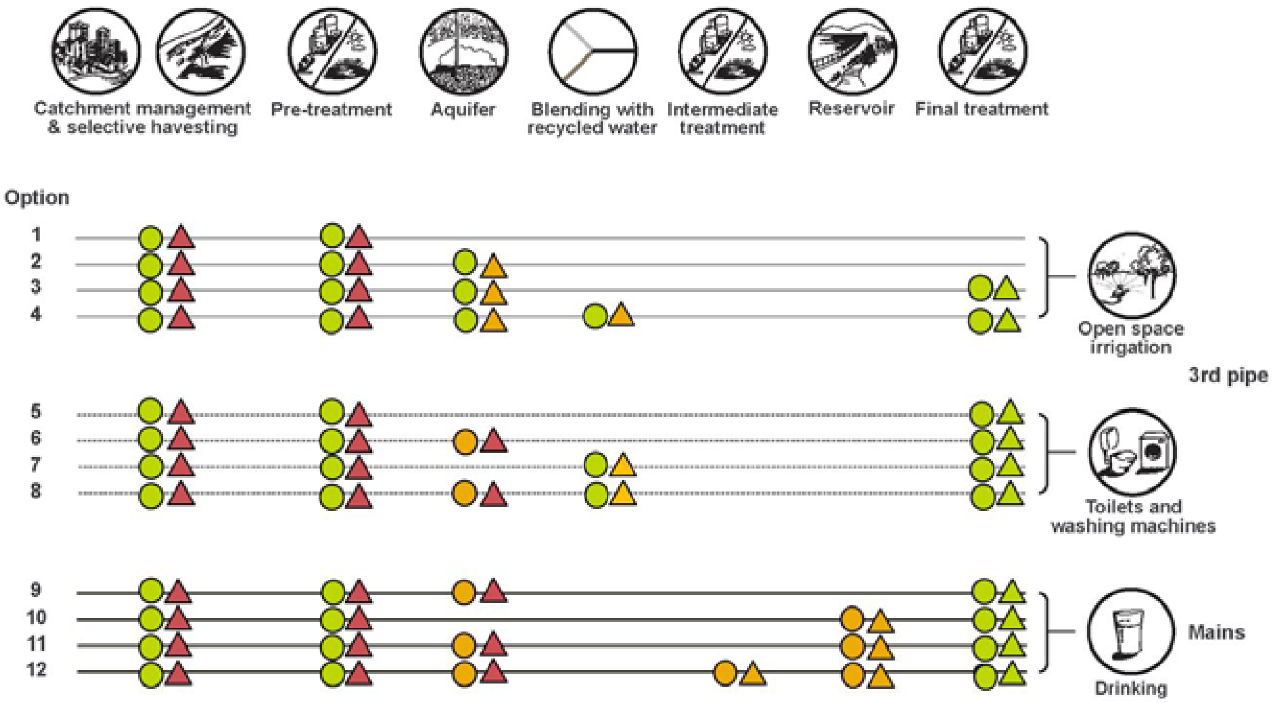


Figure 19 The twelve MARSUO options and inorganic chemical risks (circles represent human health, triangles represent environmental risks; red represents high risks, yellow represents uncertain risks and green represents low risks).

The risk management activities identified for managing aesthetic iron (and thereby also colour) are to implement a treatment process which could include chlorination/oxidation (as currently occurs for blending with recycled water) or a specialised engineered treatment technology such as aeration for iron removal such as splash entry to a tank prior to water reticulation in pipes. With the addition of these additional treatments for the options the risks to human health and the environment from inorganic chemicals are acceptable.

9.3 Salinity and sodicity

Salinity and sodicity are not risks to public health. The risks are observed where stormwater is blended with more saline recycled water or the aquifer storage and treatment options are used (Figure 20).

Aside from low lying saline land, there were no land use risks identified for salinity and sodicity. The main risk is to the T1 aquifer injected into at the Greenfields ASR site as the Greenfields wetlands are located on former salt plains/marshes. Water is not recovered here but a risk to the target aquifer remains (see Section 6.3.3.3). The environmental risk caused by salinity can be managed by monitoring the electrical conductivity of the injected water. When the salinity of the injectant is above the ambient groundwater value (e.g. 1,000 mg/L TDS for the T1 aquifer) injection should discontinue. With the addition of these additional preventative measures for the aquifer storage and blending options the environmental risk from salinity and sodicity is acceptable. Historically, the salinity of recycled stormwater from the City of Salisbury's MAR schemes for use in irrigation is not an issue for protecting irrigated plants and soils (see Section 7.4.3). The importance of protecting the Munno Para clay acquitard and preserving the lower salinity T1 aquifer from the T2 is discussed below in Section 9.8.

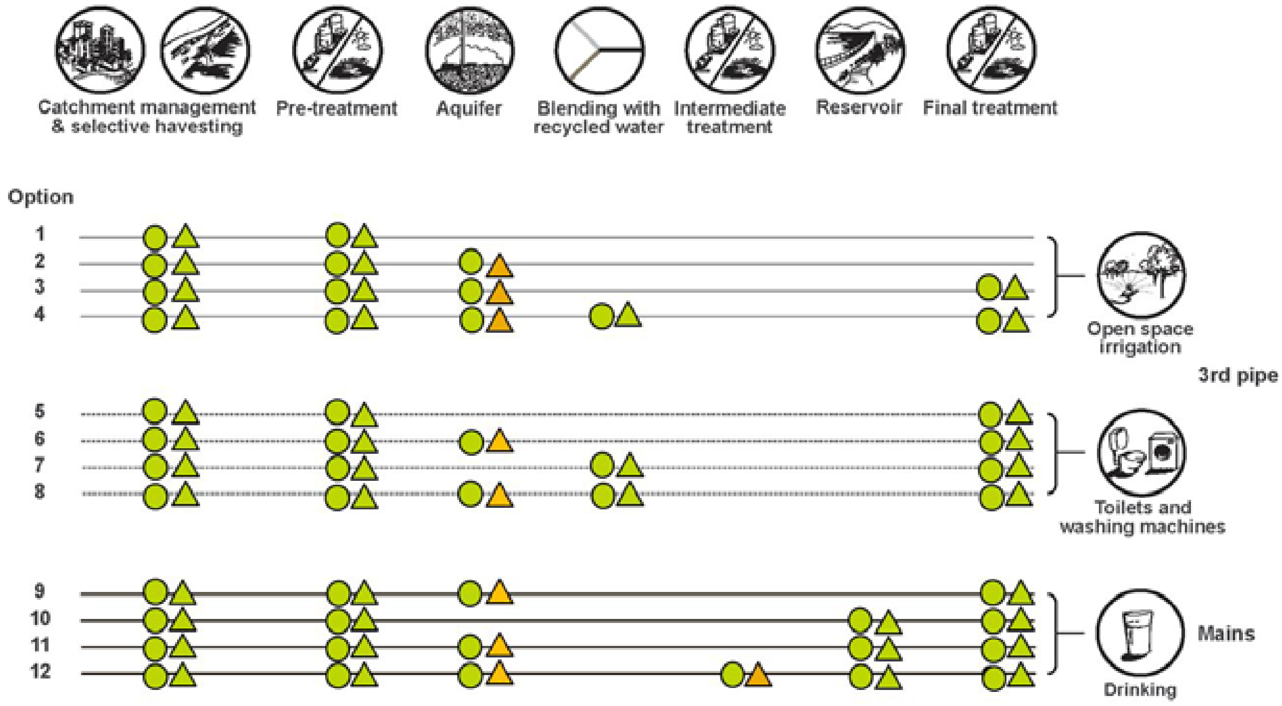


Figure 20 The twelve MARSUO options and salinity risks (circles represent human health, triangles represent environmental risks; red represents high risks, yellow represents uncertain risks and green represents low risks).

No other risk management activities are required for the stormwater except for blended options 4, 7 and 8 where the aquifer mixing ratio of injected stormwater to native groundwater must be managed to ensure the recycled stormwater meets the salinity requirements for dilution of reclaimed wastewater. This applies only to the Parafield system as the Mawson Lakes Recycled Water Scheme is supplied only by Parafield recycled stormwater. Based on historical data, salinity of Parafield recycled stormwater presents a moderate risk for use in blending with reclaimed wastewater and distribution for non-potable domestic use via dual reticultation and unrestricted irrigation.

9.4 Nutrients

Nutrients in urban stormwater are not a risk to human health. High concentrations of nutrients may be a risk to the environment and also cause operational issues such as bioclogging of injection wells. The risks from nutrients for each of the options are shown in Figure 21.

The risks from nutrients to water quality are centred on environmental risks (i.e. groundwater and irrigated land contamination) but can also include operational risks to harvesting infrastructure irrigation equipment through clogging. A number of catchment land uses were identified as risks for nutrients (Table 10). Injectant water however showed generally low nutrient levels (Appendix 6). Operational risks relating to open space irrigation (options 1-4) can be managed through irrigation management practices such as flushing to ensure sprinkler systems do not become clogged and so the risk was classified as acceptable. No other catchment management or other specific risks were identified. For all other options the risks from nutrients were low. With the addition of this additional preventative measure the risks from nutrients are acceptable.

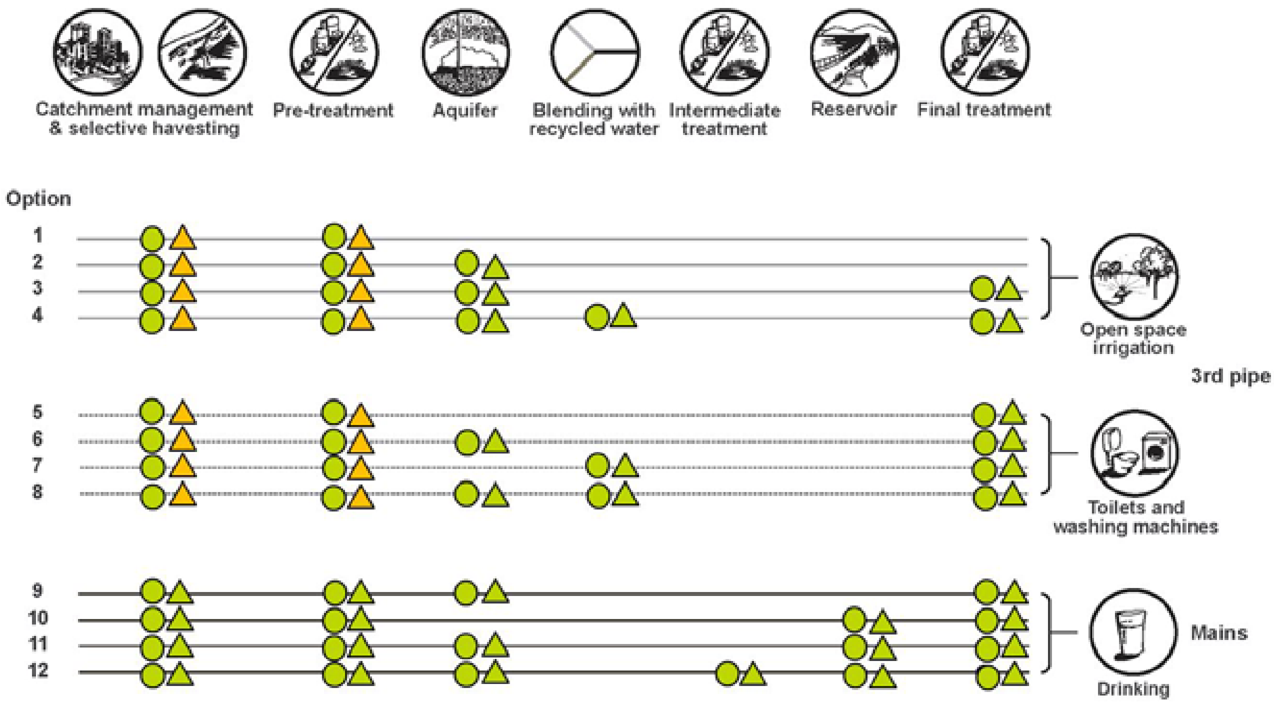


Figure 21 The twelve MARSUO options and nutrient risks (circles represent human health, triangles represent environmental risks; red represents high risks, yellow represents uncertain risks and green represents low risks).

9.5 Organic chemicals

Raw stormwater quality data suggests that organic chemicals are generally too low in concentration to be of real risk to public health (Appendix 5) perhaps with the exception of simazine. Benzene is carcinogenic in low concentrations but was measured in raw stormwater. Trigger values (95% freshwater ecosystem species protection) for environmental end-points, e.g. aquifer and irrigated land, are about one order of magnitude lower than health protection values (ANZECC-ARMCANZ, 2000). A wide variety of organic chemicals are associated with different land uses with the potential to contaminate stormwater and present environmental risks (Table 11). Figure 22 shows the human health and environmental risk assessment for organic chemicals across the various options. Notably, organic chemicals are only considered an uncertain human health risk for drinking water options (9-12) due to the low exposures of open space irrigation and third pipe systems.

The human health risks from organic chemicals were assigned an uncertain risk as current monitoring does not preclude the potential for future higher risk incidents to occur such as chemical spills. For low likelihood events, current sampling programs are likely to miss spikes in contaminants coming through the system. Similarly, the risks in the reservoir from organic chemicals are uncertain as at times algal blooms may occur potentially releasing cyanobacterial toxins. To date however, no human health risks from organic chemicals have been identified in the recovered stormwater from the aquifer and final treatment for the reservoir options include use of powdered activated carbon to remove chemicals in the final product water.

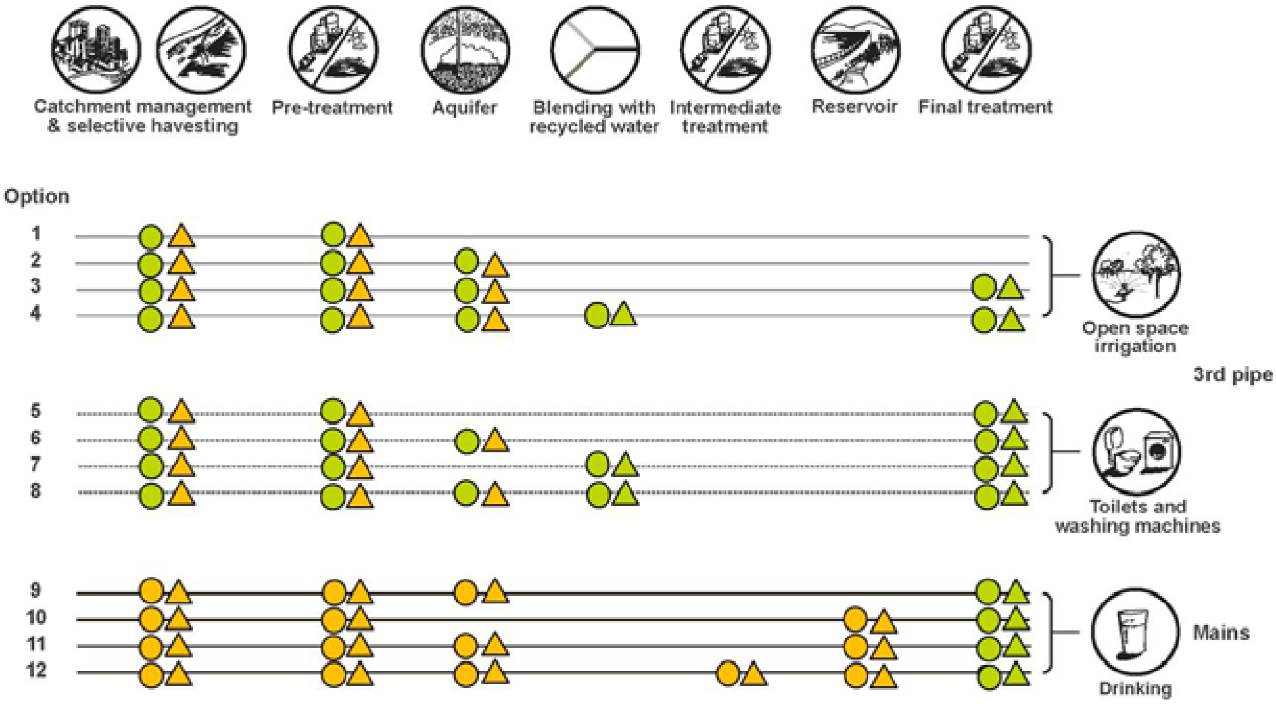


Figure 22 The twelve MARSUO options and organic chemical risks (circles represent human health, triangles represent environmental risks; red represents high risks, yellow represents uncertain risks and green represents low risks).

Any human consumption of stormwater destined for irrigation or washing machine use or toilet flushing will be restricted to sporadic, isolated incidental consumption of small amounts of water. Therefore the total exposures and risks are likely to be low, and adverse outcomes are likely to be limited to those associated with acute-acting hazards. Under the Phase 1 guidelines, health risks from organic chemicals arising from stormwater recycling were considered to be low, not requiring targeted treatment.

Environmental risks from organic chemicals can occur when stormwater reaches environmental receptors such as the aquifer, irrigated soils or plants. The environmental risks were also deemed to be uncertain due to the low likelihood of detecting the chemicals with water quality monitoring programs. To date however, no environmental health risks from organic chemicals have been identified in the recovered stormwater from the aquifer.

Management options to address the risks from chemicals include an enhanced spill management program (in case of a car accident or tanker spill) to minimise the transfer of organic chemicals to the stormwater system and the existing EPA licensing program for businesses that store quantities of chemicals. This regards the provision of appropriate storage facilities for hazardous chemicals, supply of spill kits and maintenance of response plans, and training of staff in chemical handling and spill prevention and clean up. These are legislated principally in South Australia by the *Environment Protection Act 1993* and the *Dangerous Substances Act 1979* and policies contained within these Acts through the EPA licensing for commercial and industrial activity. In addition, dangerous substances (e.g. class 8 chemicals) need to be maintained according to the Australian Standards and facilities must be licensed through Work Safe SA. No further preventative measures were identified and the risks from organic chemicals are acceptable.

9.6 Turbidity and particulates

High turbidity is not a direct risk to human health, though high turbidity increases the risk of transport of other contaminants, may interfere with the efficacy of UV and chlorine disinfection, and may contribute to clogging of injection wells. The main risk is to operations predominantly through potential clogging of injection wells. The threshold for efficient and sustainable injection rates is approximately equal to the aesthetic drinking water guideline values of 5 NTU for many of the schemes in Salisbury (City of Salisbury pers. comm.).

A risk assessment of turbidity for the various options is given in Figure 23.

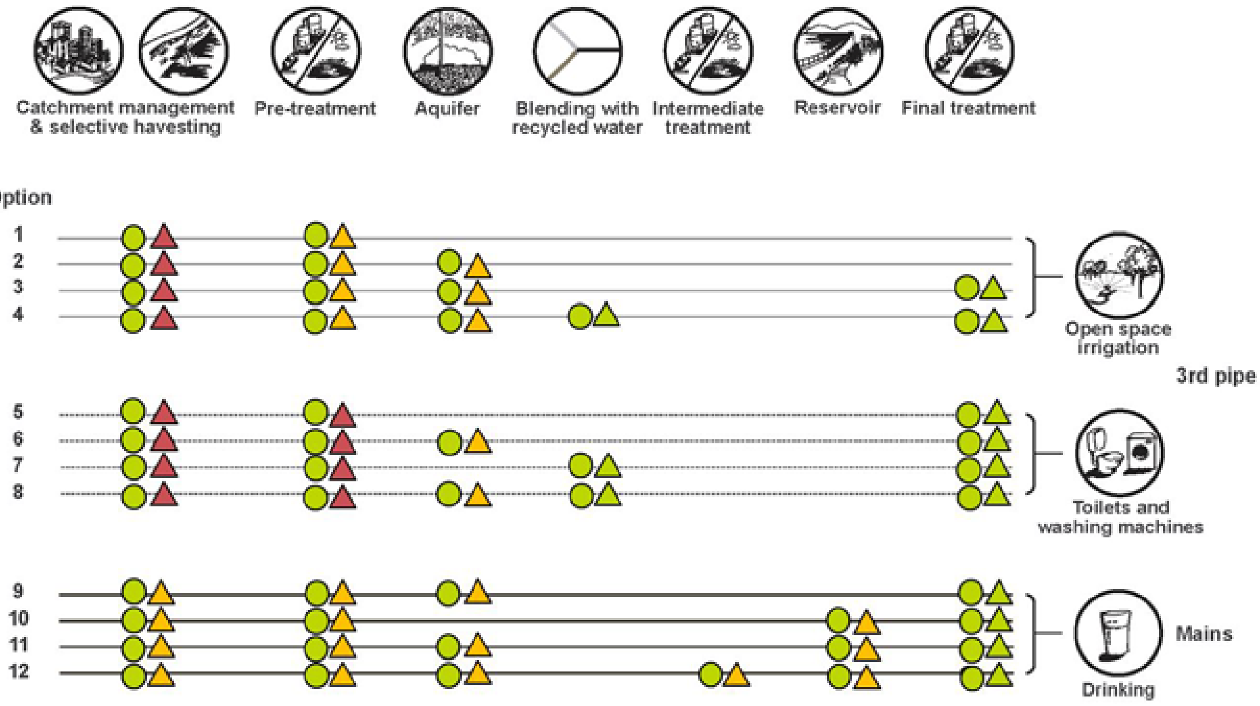


Figure 23 The twelve MARSUO options and turbidity risks (circles represent human health, triangles represent environmental risks; red represents high risks, yellow represents uncertain risks and green represents low risks).

For SA Water's use of the recycled stormwater from the Parafield scheme in the Mawson Lakes Recycled Water Scheme, the Department of Health Ageing (DHA) set approval conditions for turbidity. Turbidity must be monitored continuously at the inlet to the pump that transfers water from the in-stream basin to the holding basin. This must be set up with remote alarm and automatic pump shut-off should turbidity exceed 100 NTU.

The main land use risks for turbidity were extractive industries, cement and building supply industries and agriculture (cropping and grazing) (Table 12). Cobbler Creek, Kaurna Park and Parafield stood out as containing large areas of high land use risks (Figure 16). This was also reflected in the water quality; total suspended solids (TSS) median and 95th percentile values from Cobbler Creek were 58 and 502 mg/L, higher than the second highest risk catchment with respect to turbidity, Kaurna Park and Parafield had a 95th percentile value of 155 mg/L (see Appendix 5).

For all options the risks are acceptable if additional preventative measures are employed. Management of turbidity in the catchment could be improved with stricter adherence to the South Australian EPA codes of practice e.g. building and construction industry (EPA, 1999). These are discussed in detail in Section 6.3.6.2. Planting, restoration and maintenance of riparian zones around creek lines in the Parafield and particularly the Cobbler Creek catchment may also provide an improvement in water quality. NSW State legislation covering mining and quarrying activities has provisions for sediment and erosion control measures under the *Environmental Planning and Assessment Act 1979*, and the *Protection of the Environment Operations Act 1997* (DECC, 2008). Adoption of similar regulations in South Australia could improve runoff water quality for extractive industries.

9.7 Radionuclides

There were no identified land uses within the stormwater catchment that posed a radionuclide risk to water quality. Similarly, water quality monitoring demonstrated that all samples were below the drinking water guideline for radiological quality. No risk management actions were identified or required for radiological hazards in the Parafield and Cobbler Creek stormwater catchments.

9.8 Pressure, flow rates, volumes and groundwater levels

Over pressurisation resulting from injection in confined aquifers could lead to overflow of nearby existing wells, cross contamination of aquifers, failure of poorly completed wells and/or rupturing of the aquitard (Munno Para Clay). Conversely, groundwater pressure reduction induced by extraction can lead to diminished access for nearby groundwater users, consolidation of compressible aquifer media and land subsidence.

The environmental risk assessment shows that the ASR and ASTR wells have been correctly constructed and cemented, as per the *Well Completion Permit* (available at https://des.pir.sa.gov.au/page/desHome.html). Pump tests and down-hole profiling were performed at each well to characterise the hydraulic properties of the aquifer, to evaluate aquitard vulnerability, and to assess any well interferences, or flow, volume and pressure-related hazards. As such the environmental risk is deemed to be acceptable.

Further observations of drawdown in nearby wells during pump testing at the ASTR site indicated that no leakage from or to the overlying aquifer occurred (AGT, 2007). Flow rates at the ASTR wells should be set to ~5 L/s during injection and ~10 L/s during extraction to limit the impact of the leakage to and from the T2c sub-aquifer. In the vicinity of the existing ASR site wells become artesian seasonally as a result of injection. This artesian zone will not extend to other existing wells as a result of the ASTR operation.

To prevent injection pressure from rupturing the aquitard, the injection pressure should not exceed 15*d kPa, where d is the depth (metres) to the base of the aquitard (NRMMC-EPHC-NHMRC, 2009b). The depth of the Munno Para Clay is about 160 m below ground, leading to a maximum allowable injection pressure of 2,400 kPa. Therefore, injection pressures at ASTR of ~500 kPa cannot induce over pressurisation and rupturing of the aquitard. Similarly, due to placement of pumps in wells, drawdown will not be capable of dewatering the aquitard so consolidation of compressible aquifer media and subsidence is unlikely to occur.

Comparison of water levels in the ASTR wells between May 2006 and January 2007 showed water level fluctuations of approximately 6 m (AGT, 2007), with the water level varying from ~4 to 10 m below ground across the well-field. These water level variations result from a regional hydraulic gradient of about 0.0015 from east to west occurring within the T2 aquifer (Pavelic *et al*., 2004); and from a strong local gradient induced by the Parafield ASR well scheme situated about 300 m north-east of the study using two injection-extraction wells completed over the entire T2 aquifer. The local gradient can be as high as 0.03, either towards the northeast during extraction or the southwest during injection at the ASR site (Kremer *et al*., 2008). Despite the transfer of fluid pressure occurring between the Parafield ASR and the ASTR systems, monitoring and background data at the ASTR site suggested that no transfer of fluid constituents occurs (Kremer *et al*., 2008).

Modelling tools can be used to assess the impacts of injection and extraction flow rates and volumes on pressures and water levels in the T2 aquifer close to the ASTR site. Conceptual models defined in Kremer *et al*. (2008) showed that an area of 800 m radius, including the Parafield ASR scheme, is likely to be affected by drawdown during operations at the ASTR site; and therefore wells situated within this area can potentially become artesian during injection at the ASTR site. Results from simulation of injection and recovery at the four outer ASTR wells showed a maximum drawdown of less than 10 m within the ASTR site, and less than 4 m at the Parafield ASR site.

Based on groundwater monitoring, modelling and observations from MAR operations in the T2 aquifer, the residual risks are acceptable for pressure, flow rates, volume and water levels.

9.9 Contaminant migration in fractured rock and karstic aquifers

Preferential flow paths induced either by fractures or high conductivity layers allow recharged water to travel faster than the average flow rate through the porous media. As a result the residence time in the aquifer is reduced, potentially impacting on the treatment capacity of the aquifer. This is particularly of concern where aquifer treatment capacity may contribute to the pathogen inactivation credits such as in an ASTR system.

The target T2 aquifer of the ASTR project was investigated and characterised as a sandy-limestone aquifer known to be heterogeneous with respect to depth. The lithological log and core samples collected from piezometer P2 show no evidence of fractures; despite irregular well diameters observed from calliper logs run at the ASTR wells before the casing was installed. Evidence from pumping tests suggests that the flow is more likely to be through porous media than through fissures or karstic features. Therefore the risk of contaminant migration in fractures was assessed to be acceptable for this T2 aquifer.

Further evidence from pump tests and electro-magnetic (EM) flow-meter analysis showed higher hydraulic conductivity in the bottom part of the T2 aquifer, suggesting that preferential flow paths would occur if T2c was intercepted by the ASTR wells (Kremer *et al*., 2008). To avoid low recovery efficiency of the ASTR scheme and shorter travel time within the aquifer, the best system configuration defined in Pavelic *et al*. (2004) involving six wells screend over the entire T2 aquifer, with inter-well distance of 75 m, was revised into a 50 m-spacing system intersecting only the upper part of the T2 aquifer. Details of the modelling process used for the revision are described in Appendix 1 in Kremer *et al*. (2008). Field observations in T2c and three dimensional flow and solute modelling based on field data suggest that the environmental risk of contaminant migration in preferential flow paths induced by higher conductive layers in the heterogeneous T2 aquifer is acceptable.

9.10 Aquifer dissolution and stability of well and aquitards

The environmental risk assessment indicates that wetland treated stormwater water may react with the aquifer matrix material, resulting in dissolution of minerals or reduction in the aquifer's bulk volume or strength. The reedbed-treated urban stormwater is not in equilibrium with carbonate minerals. Therefore injection of this source water into the T2 aquifer will result in dissolution of carbonate minerals, predominantly calcite.

Aquifer dissolution may increase the effective diameter of a well, consequently increasing yield, and inhibit chronic clogging problems. However, aquifer dissolution can have many negative effects, including collapse of uncased wells, production of turbid water or water containing a lot of sand, mobilisation of clay particles that may become trapped further within the aquifer matrix and development of preferential flow paths that alter aquifer residence time. Remobilisation of sand may also dislodge larger aggregates/ rocks which may impede pump operation or reduce well yield.

The impact of aquifer dissolution on the stability of the overlying clay aquitard was considered in the environmental risk assessment by assuming that dissolution of a 2 m radius around the injection well would result in stability concern. With estimated dissolution rates of 0.3 and 0.5 mmol/L, the calculated time required for dissolution of the calcite in a 2 m radius around the open interval of an injection well ranged from 120 to 200 years. This was based on a total annual injection volume of 172 ML/year expected under average rainfall conditions (Kremer *et al*., 2008), with 43 ML/year injected into each IW well.

These calculations indicate that aquifer dissolution is not a risk to the lifetime of the injection wells and hence the risk for aquifer dissolution and stability is acceptable.

9.11 Aquifer and groundwater-dependent ecosystems

Managed aquifer recharge can affect groundwater dependent ecosystems such as stygofaunal assemblages, and connected rivers and wetlands by raising or lowering the water table, changing nutrient cycles, and introducing contaminants to the system.

The environmental risk assessment reveals that there are no surface water ecosystems connected to the T2 aquifer. Furthermore, there are unlikely to be populations of stygofauna in the T2 aquifer due to the depth, anoxic conditions and lack of karst features. Previous sampling of a number of T2 wells on the Northern

Adelaide Plain has failed to detect stygofauna (pers. comm. Colin Pitmann, City of Salisbury). Low connection to recharge leads to low nutrient availability, and hence low stygofauna populations (Tomlinson and Boulton, 2008). Hence the residual risk to groundwater dependent ecosystems is also deemed to be acceptable.

9.12 Energy and greenhouse gas considerations

Energy consumption and resultant greenhouse gas emissions contribute to global warming, and as such should be minimised. Energy consumption in the provision of water supplies comes from both the treatment of water and pumping from source to treatment site to end user and is discussed by ATSE (2012). Pumping water long distances and against gravity is an energy-intensive process (Kenway *et al*., 2008). Consequently, for the environmental risk assessment, the sourcing of stormwater close to the MAR site and end users will consume less energy than pumping water from a long distance away.

For the environmental risk assessment, each of the options is required to be compared to other potential sources of water such as the River Murray or desalination of sea water. As the ASR and ASTR systems currently operate, the only energy required for treatment is to pump the water from the in-stream basin to the holding basin, from the reedbed outlet into the injection wells, and out of the recovery wells. High injection pressures increase the energy consumption, especially if the aquifer becomes artesian (however, the risk of this is low). Furthermore, fixed speed bore pumps may also waste energy as the drawdown in a well is subsequently controlled by throttling using a valve.

Page *et al*. (2009) reported that volume and energy consumption data at the Parafield stormwater harvesting system and ASTR well field, and a recovery efficiency of 90%, the ASTR scheme consumes ~2,700 MJ/ML of water produced (including distribution to end users). This compares with the energy cost of water supply from the River Murray and Mount Lofty Ranges catchments with conventional treatment (coagulation, filtration and disinfection) and distribution by SA Water, which varies from 3,500 MJ/ML (50% River Murray water) to 6,900 MJ/ML (90% River Murray water) (Kenway *et al*., 2008). Seawater desalination typically consumes more than 14,400 MJ/ML (Kenway *et al*., 2008). The environmental risks from excess energy consumption and greenhouse gas emissions are considered acceptable.

10 Conclusions

The approach used in this report for human health and environmental risk assessment of the twelve Managed Aquifer Recharge and Stormwater Use options is consistent with the Australian Guidelines for Water Recycling series of documents. Each of the options was grouped according to exposure scenarios: open space irrigation; third pipe systems and drinking water and risk assessments based on water quality monitoring and assessment of human health based targets. Some of these options such as public open space irrigation and blending with treated sewage have already been successfully in operation for a number of years. As such the risk assessment for these options verified that the risks had been managed. Other options, such as third pipe systems only utilising recycled urban stormwater and the drinking water options have not before been assessed.

Urban stormwater catchments that supply the City of Salisbury recycled stormwater ring main were subjected to a geographical information systems analysis of the land uses. A stakeholder workshop was used to develop a semi-quantitative risk assessment of land use influences on water quality and included diffuse sources of pollution as well as hazardous events such as tanker spills. The methodology developed was used to assess each of the catchments, influence the water quality monitoring program and is now ready to be transferable for stormwater catchment risk assessments.

Water quality monitoring was performed across stormwater catchment to the end use for all options. Pathogens, organic chemicals, inorganic chemicals, turbidity, salinity, nutrients and radionuclides were all monitored in the catchment, wetland harvesting systems and recycled stormwater recovered via the ASR or ASTR systems. Water quality tended to improve across the harvesting systems. For recycled stormwater recovered from an aquifer pathogen risks for human health, colour and turbidity risks to aesthetic quality and salinity risks to the environment were identified.

A targeted event-based monitoring of pathogens (adenovirus, *Cryptosporidium* and *Campylobacter*) in stormwater was undertaken to allow for a quantitative microbial risk assessment (QMRA) of urban stormwater for drinking. The untreated stormwater quality was found to have 95th percentile numbers for pathogens of 2 n/L for viruses, 1.4 n/L for *Cryptosporidium* and 11 n/L for *Campylobacter*. This allowed for determination of health based targets for the drinking water end uses and to suggest suitable water treatment technologies for each of the options. Viruses are considered to be the highest risk pathogen to human health.

For open space irrigation: exposure controls such as restricted access during irrigation is sufficient to meet the 1.6 $\log_{10}$ health based target of viruses for municipal irrigation. However salinity of the recovered water needs to be monitored to ensure that environmental risks are also managed.

For third pipe systems and blending with reclaimed wastewater: 2.7 $\log_{10}$ health based target for viruses was required. This could be met using chlorination. For this option other aesthetic water quality considerations such as colour caused by high iron concentrations and turbidity would also need to be managed but do not pose a risk to human health.

For drinking: a total of 5.8 $\log_{10}$ health based target for viruses is required for drinking water options. This could be achieved through a mixture of treatments including membrane filtration, UV disinfection and chlorine disinfection. No provision is currently made for pathogen removal in the aquifer. The potential for aquifer treatment was assessed using colloid filtration theory and a series of pathogen decay studies. There is good potential for pathogen removal, 4.0 $\log_{10}$ for the ASTR system (compared to the ASR systems) where the residence time in the subsurface has a guaranteed minimum and aquifer treatment has been validated. Regardless of treatment technology employed it would need to be fully validated to the satisfaction of regulatory agencies.

However, it is important to note that in addition to meeting the requirements of the risk assessment, a *water safety plan* would need to be developed and adopted for any option considered. This would need to be accepted by stakeholders, regulators and the general community.

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Appendix 1 Parafield ASR and ASTR operational data

Table A19.1 Quantities of water injected and extracted in Parafield ASR well system from February 2003 to October 2012.

Month	Injected (ML)			Extracted (ML)		
	Monthly Totals		Cumulative	Monthly Totals		Cumulative
	ASR1	ASR2	volume injected	ASR1	ASR2	volume extracted
Jun-03	20	0	20	0	0	0
Jul-03	60	27	107	0	0	0
Aug-03	45	47	199	0	0	0
Sep-03	35	19	253	0	0	0
Oct-03	1	2	256	0	0	0
Nov-03	0	0	256	0	0	0
Dec-03	0	0	256	0	0	0
Jan-04	0	0	256	1	0	1
Feb-04	1	0	257	26	0	27
Mar-04	0	0	257	9	0	36
Apr-04	0	0	257	0	0	36
May-04	3	22	282	0	0	36
Jun-04	34	45	361	0	0	36
Jul-04	55	58	474	0	0	36
Aug-04	46	61	581	0	0	36
Sep-04	60	50	691	0	0	36
Oct-04	4	0	695	0	0	36
Nov-04	0	53	748	1	0	37
Dec-04	0	28	776	0	1	38
Jan-05	0	0	776	0	0	38
Feb-05	0	0	776	15	0	53
Mar-05	0	3	779	26	9	88
Apr-05	1	2	782	20	6	114
May-05	0	0	782	30	0	144
Jun-05	38	36	856	0	2	146
Jul-05	48	19	923	0	0	146
Aug-05	46	20	989	0	0	146
Sep-05	47	30	1066	0	0	146
Oct-05	51	52	1169	0	0	146
Nov-05	36	26	1231	0	0	146
Dec-05	0	0	1231	0	0	146
Jan-06	0	0	1231	1	0	147
Feb-06	0	0	1231	21	1	169
Mar-06	0	0	1231	0	0	169
Apr-06	0	2	1233	7	6	182
May-06	0	0	1233	0	0	182
Jun-06	0	0	1233	0	0	182

Month	Injected (ML) Monthly Totals ASR1	ASR2	Injected (ML) Cumulative volume injected	Extracted (ML) Monthly Totals ASR1	ASR2	Extracted (ML) Cumulative volume extracted
Jul-06	0	0	1233	0	0	182
Aug-06	0	0	1233	2	11	195
Sep-06	0	0	1233	0	0	195
Oct-06	0	0	1233	55	12	262
Nov-06	0	0	1233	31	12	305
Dec-06	0	0	1233	26	43	374
Jan-07	0	0	1233	1	35	410
Feb-07	0	0	1233	20	33	463
Mar-07	0	1	1234	30	23	516
Apr-07	1	0	1235	3	28	547
May-07	44	26	1305	0	0	547
Jun-07	32	31	1368	0	0	547
Jul-07	26	14	1408	0	0	547
Aug-07	7	0	1415	0	11	558
Sep-07	0	0	1415	0	24	582
Oct-07	0	0	1415	0	13	595
Nov-07	13	0	1428	3	18	616
Dec-07	0	0	1428	51	13	680
Jan-08	0	0	1428	57	14	751
Feb-08	0	0	1428	41	49	841
Mar-08	0	0	1428	29	36	906
Apr-08	0	0	1428	8	21	935
May-08	29	25	1482	0	0	935
Jun-08	6	0	1488	1	0	936
Jul-08	34	30	1552	0	0	936
Aug-08	49	24	1625	1	0	937
Sep-08	4	2	1631	0	0	937
Oct-08	0	0	1631	38	34	1009
Nov-08	0	0	1631	20	34	1062
Dec-08	0	0	1631	17	18	1097
Jan-09	0	0	1631	33	35	1165
Feb-09	0	0	1631	31	39	1234
Mar-09	0	0	1631	11	12	1257
Apr-09	4	3	1638	1	19	1278
May-09	29	29	1696	0	0	1278
Jun-09	56	55	1807	0	0	1278
Jul-09	90	89	1986	0	0	1278
Aug-09	13	9	2008	0	0	1278
Sep-09	30	42	2080	0	1	1279
Oct-09	53	0	2133	0	0	1279
Nov-09	0	14	2147	5	25	1309
Dec-09	0	0	2147	5	1	1316
Jan-10	0	0	2147	5	27	1347

Month	Injected (ML)			Extracted (ML)		
	Monthly Totals		Cumulative	Monthly Totals		Cumulative
	ASR1	ASR2	volume injected	ASR1	ASR2	volume extracted
Feb-10	0	0	2147	18	35	1400
Mar-10	0	0	2147	53	51	1504
Apr-10	0	0	2147	15	9	1527
May-10	0	0	2147	3	0	1530
Jun-10	21	1	2169	8	3	1541
Jul-10	38	50	2257	6	4	1551
Aug-10	45	42	2344	1	0	1552
Sep-10	55	54	2453	0	0	1552
Oct-10	11	12	2476	10	5	1568
Nov-10	0	0	2476	0	0	1568
Dec-10	4	3	2483	12	11	1590
Jan-11	5	13	2501	18	18	1626
Feb-11	0	0	2501	17	18	1661
Mar-11	4	7	2512	5	5	1671
Apr-11	2	5	2519	21	21	1713
May-11	17	16	2552	0	0	1713
Jun-11	5	6	2563	7	8	1728
Jul-11	26	20	2609	2	2	1732
Aug-11	48	49	2706	1	9	1741
Sep-11	0	0	2706	15	8	1764
Oct-11	32	30	2768	4	0	1768
Nov-11	0	0	2768	21	13	1802
Dec-11	0	0	2768	21	19	1843
Jan-12	22	15	2805	21	19	1882
Feb-12	0	0	2805	38	42	1962
Mar-12	4	6	2815	15	0	1977
Apr-12	31	15	2861	1	10	1988
May-12	30	9	2900	0	4	1992
Jun-12	34	30	2964	0	0	1992
Jul-12	38	31	3033	2	1	1995
Aug-12	22	41	3096	5	0	2001
Sep-12	56	11	3163	1	14	2015
Oct-12	9	0	3172	14	12	2042
Nov-12	0	0	3172	43	39	2124
Dec-12	0	0	3172	35	30	2189

N.B. Well unit numbers are : ASR1 6628-20743; ASR2 6628-20943.

Table A1.20 Quantities of water injected and extracted in Parafield ASTR well system from September 2006 to October 2012.

Month	Injected (ML)								Extracted (ML)		
	Monthly Totals		Cumulative volume injected - RW	Monthly Totals				Cumulative volume injected - IW	Monthly Totals		Cumulative volume extracted
	RW1	RW2		IW1	IW2	IW3	IW4		RW1	RW2	
Sep-06	3.6	2.9	6.6	0	0	0	0	0	0	0	0
Oct-06	9.4	7.8	23.8	0	0	0	0	0	0	0	0
Nov-06	14.1	11.9	49.8	0	0	0	0	0	0	0	0
Dec-06	13.9	13.0	76.7	0	0	0	0	0	0	0	0
Jan-07	2.1	0.0	78.8	0	0	0	0	0	0	0	0
Feb-07	0.0	0.0	78.8	0	0	0	0	0	0	0	0
Mar-07	0.0	0.0	78.8	0	0	0	0	0	0	0	0
Apr-07	0.0	0.0	78.8	0	0	0	0	0	0	0	0
May-07	9.2	7.6	95.6	0	0	0	0	0	0	0	0
Jun-07	11.0	9.2	115.8	0	0	0	0	0	0	0	0
Jul-07	12.2	13.2	141.1	0	0	0	0	0	0	0	0
Aug-07	16.1	11.4	168.6	0	0	0	0	0	0	0	0
Sep-07	6.5	5.9	181.0	0	0	0	0	0	0	0	0
Oct-07	0.0	0.0	181.0	0	0	0	0	0	0	0	0
Nov-07	8.7	7.6	197.2	0	0	0	0	0	0	0	0
Dec-07	15.7	13.8	226.7	0	0	0	0	0	0	0	0
Jan-08	20.1	17.5	264.3	0	0	0	0	0	0	0	0
Feb-08	11.9	11.7	287.9	0	0	0	0	0	0	0	0
Mar-08	14.6	0.7	303.1	0	0	0	0	0	0	0	0
Apr-08	4.5	9.4	317.0	0	0	0	0	0	0	0	0
May-08	8.8	21.9	347.6	0	0	0	0	0	0	0	0
Jun-08	14.9	14.3	376.9	0	0	0	0	0.0	0	0	0
Jul-08	0	0	376.9	0	0	0	0	0.0	0	0	0
Aug-08	0	0	376.9	0	0	0	0	0.0	0	0	0
Sep-08	0.1	0	377.0	3.3	3.6	0.5	3.0	10.3	0.3	0.7	1.0
Oct-08	0	0	377.0	1.7	1.9	0.1	1.7	15.6	0	0	1.0

Month	Injected (ML)								Extracted (ML)		
	Monthly Totals		Cumulative volume injected - RW	Monthly Totals				Cumulative volume injected - IW	Monthly Totals		Cumulative volume extracted
	RW1	RW2		IW1	IW2	IW3	IW4		RW1	RW2	
Nov-08	0	0	377.0	0	0	0.1	0	15.8	0	0	1.0
Dec-08	0	0	377.0	4.1	12.6	2.3	4.1	38.9	0	0	1.0
Jan-09	0	0	377.0	0	0	0.2	0	39.1	0	0	1.0
Feb-09	0	0	377.0	0	0	0	0	39.6	12	10	22.2
Mar-09	0	0	377.0	0	0	0.7	0	40.3	20	17	59.1
Apr-09	0	0	377.0	0	0	1.0	0	41.4	25.9	20.7	105.7
May-09	0	0	377.0	4.2	3.6	3.4	3.9	56.5	0	0.1	105.8
Jun-09	0	0	377.0	9.2	8.0	6.5	8.7	88.9	0	0	105.8
Jul-09	0	0	377.0	5.6	5.0	4.9	5.5	110.0	0	0	105.8
Aug-09	0	0	377.0	4.2	3.7	3.8	4.0	125.7	2.8	3.7	112.3
Sep-09	0	0	377.0	7.6	6.1	4.8	6.4	150.6	3.3	6.5	122.1
Oct-09	0	0	377.0	6.2	6.6	3.1	7.0	173.6	1.4	1.9	125.4
Nov-09	0	0	377.0	0	0	0	0	173.6	16.5	21.2	163.1
Dec-09	0	0	377.0	0	0	0	0	173.6	0.1	0.3	163.5
Jan-10	0	0	377.0	0	0	0	0	173.6	16.6	24.6	204.6
Feb-10	0	0	377.0	0	0	0	0	173.6	5.1	23.0	232.7
Mar-10	0	0	377.0	0	0	0	0	173.6	0.3	0.7	233.8
Apr-10	0	0	377.0	0	0	0	0	173.6	2.6	5.4	241.7
May-10	0	0	377.0	0	0	0	0	173.6	2.6	6.2	250.4
Jun-10	2.1	2.0	381.1	2.9	0.3	1.9	1.2	179.9	0	0	250.4
Jul-10	0	0	381.1	6.8	9.4	5.7	6.7	208.4	0	0.4	250.9
Aug-10	0	0	381.1	12.8	12.8	11.1	9.4	254.5	0.1	0.4	251.4
Sep-10	1.2	1.1	383.4	26.9	25.9	14.6	23.7	345.7	0.6	0.1	252.1
Oct-10	0	0	383.4	0.3	0.3	0.1	0.3	346.7	9.6	18.1	279.9
Nov-10	0	0	383.4	0	0	0	0	346.7	0	0	279.9
Dec-10	0	0	383.4	0	0	0	0	346.7	13.4	22.1	315.4
Jan-11	0	0	383.4	0.7	0.7	0.8	0.6	349.5	13.4	23.0	351.7

Month	Injected (ML)								Extracted (ML)		
	Monthly Totals		Cumulative volume injected - RW	Monthly Totals				Cumulative volume injected - IW	Monthly Totals		Cumulative volume extracted
	RW1	RW2		IW1	IW2	IW3	IW4		RW1	RW2	
Feb-11	0	0	383.4	0	0	0	0	349.5	10.4	16.3	378.4
Mar-11	4.3	4.0	391.7	11.1	17.0	17.6	9.0	404.1	2.9	4.9	386.2
Apr-11	3.2	3.0	397.9	0	7.9	7.9	0	419.9	0.2	0.2	386.7
May-11	0	0	397.9	5.2	2.9	3.9	1.0	432.9	0	0	386.7
Jun-11	0	0	397.9	1.7	1.7	1.8	0.0	438.1	0.3	0.3	**387.3**
Jul-11	0	0	397.9	9.0	9.0	10.8	0.0	467.0	0.0	0.0	387.3
Aug-11	0	0	397.9	15.0	15.0	0.0	0.0	497.0	0.0	0.0	387.3
Sep-11	0	0	397.9	0.0	0.0	0.0	0.0	497.0	1.0	1.3	389.6
Oct-11	0	0	397.9	10.0	6.9	10.0	0.0	523.9	0.1	0.1	389.8
Nov-11	0	0	397.9	0.0	3.0	-0.1 [1]	0.0	526.9	10.9	17.9	418.6
Dec-11	0	0	397.9	0.0	-0.2 [1]	-0.2 [1]	0.0	526.9	2.3	2.6	423.5
Jan-12	0	0	397.9	0.1	-0.5 [1]	-0.6 [1]	0.0	525.9	0.6	1.8	425.9
Feb-12 [2]	0	0	397.9	0.0	-0.1 [1]	-0.1 [1]	0.0	525.8	0.3	0.5	426.7
Mar-12 [2]	0	0	397.9	0.0	0.0	-0.1 [1]	0.0	525.6	9.7	10.4	446.7
Apr-12 [2]	0	0	397.9	0.0	0.0	-1.0 [1]	0.0	524.7	16.9	21.5	485.1
May-12 [2]	0	0	397.9	0.0	0.0	-0.2 [1]	0.0	524.4	12.5	19.3	517.0
Jun-12	0	0	397.9	7.3	6.0	6.8	3.8	548.3	1.5	11.5	530.0
Jul-12	0	0	397.9	14.3	12.1	12.7	9.9	597.4	5.2	14.1	549.2
Aug-12	0	0	397.9	0.0	0.0	0.0	0.0	597.4	0.0	0.0	549.2
Sep-12	0.025	0	397.9	25.1	19.6	23.2	13.7	679.0	10.1	11.6	570.9
Oct-12	0	0	397.9	0.0	-0.7 [1]	-2.6 [1]	0.0	675.7	23.8	24.3	619.1
Nov-12	0	0	397.9	1.5	-3.1	-6.1	3.3	671.4	18.1	20.9	658.0
Dec-12	0	0	397.9	1.7	-1.0	-2.0	1.4	671.5	2.5	4.8	665.3

N.B. Well unit numbers are: IW1 6628-23047; IW2 6628-23053; IW3 6628—22535; IW4 6628-23045; RW1 6628-22533; RW2 6628-22532.
[1] negative value indicates there has been periodic purging of well required to reduce well clogging; [2] approximately four month period with no injection at the ASTR site due to new pipe installation from Parafield wetland.

Table A1.3 Quantities of water injected and extracted in City of Salisbury ASR operations from July 2009 to December 2011.

	Kaurna Pk (T2 aquifer)				Greenfields (T1 aquifer)				Paddocks (T1 aquifer)				Unity Park/Pooraka (T2 aquifer)			
	Injected (ML)		Extracted (ML)		Injected (ML)		Extracted (ML)		Injected (ML)		Extracted (ML)		Injected (ML)		Extracted (ML)	
	Monthly total (2 wells)	Total Cum.	Monthly total	Total Cum.	Monthly total (4 wells)	Total Cum.	Monthly total	Total Cum.	Monthly total	Total Cum.	Monthly total	Total Cum.	Monthly total	Total Cum.	Monthly	Total Cum.
Prior to Jul-09		**2005**		**769.7**		**300.0**		**0.0**		**516.1**		**480.4**		**213.0**		**176.4**
Jul-09	152.3	2157	0.0	770	45.2	345	0.0	0.0	26.2	542	0.0	480	25.5	236	0.0	176
Aug-09	46.8	2204	2.7	772	68.8	414	0.0	0.0	4.6	547	0.0	480	6.3	245	0.6	177
Sep-09	44.9	2249	3.5	776	51.3	465	0.0	0.0	20.0	567	0.0	480	25.6	270	0.0	177
Oct-09	77.0	2326	8.3	784	42.9	508	0.4	0.4	6.4	573	0.6	481	6.8	277	0.0	177
Nov-09	4.3	2330	29.6	814	0.0	508	7.6	8.0	0.0	573	8.4	489	0.0	277	3.0	180
Dec-09	0.0	2330	17.6	832	0.0	508	0.0	8.0	0.0	573	5.8	495	0.0	277	2.6	183
Jan-10	0.0	2330	34.1	866	0.0	508	5.4	13.4	0.0	573	14.9	510	0.0	277	10.9	193
Feb-10	0.0	2330	28.0	894	0.0	508	8.6	22.0	0.0	573	13.7	524	0.0	277	10.4	204
Mar-10	0.0	2330	22.4	916	0.0	508	1.7	23.7	0.0	573	8.4	532	0.0	277	6.9	211
Apr-10	0.0	2330	28.5	945	0.0	508	0.0	23.7	0.0	573	4.7	537	0.0	277	3.7	214
May-10	0.0	2330	13.9	959	0.0	508	0.0	23.7	0.0	573	2.2	539	0.0	277	1.7	216
Jun-10	0.0	2330	0.0	959	12.4	521	0.1	23.8	0.0	573	0.0	539	0.0	277	0.0	216
Jul-10	0.0	2330	34.2	993	37.4	558	0.0	23.8	22.2	596	0.0	539	0.0	277	1.2	217
Aug-10	35.6	2366	1.3	994	45.8	604	0.0	23.8	16.1	612	0.0	539	0.0	277	0.0	217
Sep-10	147.1	2513	0.0	994	81.0	685	0.0	23.8	14.9	627	0.0	539	0.0	277	0.4	218
Oct-10	46.4	2559	12.4	1006	32.3	717	0.0	23.8	0.0	627	5.8	545	0.0	277	5.4	223
Nov-10	0.0	2559	0.0	1006	0.0	717	0.0	23.8	0.0	627	0.0	545	0.0	277	0.0	223
Dec-10	4.7	2564	26.9	1033	4.7	722	0.0	23.8	0.0	627	10.4	555	0.0	277	13.4	237
Jan-11	36.2	2600	38.9	1072	0.5	722	0.0	23.9	0.0	627	13.7	569	0.0	277	17.5	254
Feb-11	0.0	2600	18.0	1090	0.0	722	0.0	23.9	0.0	627	5.8	575	0.0	277	8.0	262
Mar-11	66.6	2667	0.8	1091	54.0	776	2.3	26.1	6.0	637	4.2	579	0.0	277	3.4	265
Apr-11	24.8	2692	10.7	1102	42.2	819	0.9	27.0	3.3	636	2.3	581	0.0	277	2.6	268
May-11	0.0	2692	10.2	1112	20.7	839	0.0	27.0	1.2	637	0.6	582	5.7	283	2.0	270
Jun-11	42.7	2735	6.0	1118	38.4	878	0.0	27.0	0.8	638	0.1	582	4.8	288	0.1	270

	Kaurna Pk (T2 aquifer)				Greenfields (T1 aquifer)				Paddocks (T1 aquifer)				Unity Park/Pooraka (T2 aquifer)			
	Injected (ML)		Extracted (ML)		Injected (ML)		Extracted (ML)		Injected (ML)		Extracted (ML)		Injected (ML)		Extracted (ML)	
	Monthly total (2 wells)	Total Cum.	Monthly total	Total Cum.	Monthly total (4 wells)	Total Cum.	Monthly total	Total Cum.	Monthly total	Total Cum.	Monthly total	Total Cum.	Monthly total	Total Cum.	Monthly	Total Cum.
Jul-11	90.1	2825	6.2	1124	76.2	954	0.0	27.0	13.6	652	0.0	582	34.9	323	0.0	270
Aug-11	84.9	2910	4.7	1129	61.7	1015	0.0	27.0	18.6	670	0.0	582	23.3	346	0.0	270
Sep-11	42.8	2952	9.0	1138	11.2	1027	0.0	27.0	0.0	670	0.0	582	6.2	352	0.0	270
Oct-11	29.8	2982	28.1	1166	57.2	1084	0.0	27.0	5.3	676	1.2	583	14.2	366	1.3	271
Nov-11	0.0	2982	34.0	1200	30.0	1114	0.9	27.9	0.0	676	7.8	591	2.5	369	4.1	276
Dec-11	0.0	2982	18.8	1219	0.0	1114	0.9	28.8	0.0	676	5.6	597	0.0	369	4.6	280
Jan-12	0.0	2982	18.8	1219	27.7	1225	1.8	30.6	0.1	676	9.3	606	0.0	369	12.6	293
Feb-12	0.0	2982	18.8	1219	0.1	1225	1.7	32.3	0.0	676	10.3	616	0.0	369	14.8	307
Mar-12	0.0	2982	18.8	1219	8.7	1234	3.6	35.9	0.0	676	4.8	621	0.2	369	10.0	317
Apr-12	0.0	2982	18.8	1219	10.7	1244	0.0	35.9	0.0	676	5.9	627	7.0	376	8.1	326
May-12	0.0	2982	18.8	1219	47.0	1291	0.0	35.9	3.0	679	1.3	628	20.4	396	1.3	327
Jun-12	0.0	2982	18.8	1219	53.9	1345	0.0	35.9	12.2	691	0.0	628	20.8	417	0.0	327
Jul-12	0.0	2982	18.8	1219	96.1	1441	0.0	35.9	20.6	711	0.0	628	18.0	435	0.0	327
Aug-12	0.0	2982	18.8	1219	106	1547	0.0	35.9	24.1	735	0.0	628	29.4	465	0.0	327
Sep-12	0.0	2982	18.8	1219	41.0	1588	0.0	35.9	3.4	739	0.7	629	12.2	477	0.0	327
Oct-12	0.0	2982	18.8	1219	95.1	1683	0.0	35.9	1.6	740	5.0	634	12.1	489	1.4	328
Nov-12	0.0	2982	18.8	1219	1.7	1685	0.0	35.9	0.0	740	9.9	644	0.0	489	14.3	343
Dec-12	0.0	2982	18.8	1219	0.0	1685	0.0	35.9	0.0	740	3.5	637	0.0	489	8.0	351

N.B. Well unit numbers are: Kaurna Park 6628-18545, 6628-20392; Greenfields 6628-16624, 6628-16625, 6628-22567, 6628-23635; Paddocks 6628—16623; Unity Park 6628-20765.

Appendix 2 GIS Methodology

Data sources

Stormwater catchment boundaries were delineated using a combination of stormwater infrastructure and modelled flow layers, aerial imagery, roads and land parcel data and a digital elevation model in a geographic information system (GIS) (ESRI ArcGIS Version 10). Sources and descriptions for layers used in the delineation of the stormwater catchments are detailed in Table A2.1.

Table A2.1 Source and description of GIS data used in the stormwater catchment delineations.

Layer Name	Description	Source
Generalised_Landuse	Property boundaries coded with general land uses	Dept. of Planning and Local Government
ALUM_Landuse	Land tenure boundaries classified using the Australian Land Use and Management system	Australian Government Department of Agriculture, Fisheries and Forestry
Specific_Landuse	Property boundaries coded with detailed land uses at landholder scale	City of Salisbury
Mini_Catchments	Polygons of stormwater sub-catchments	City of Salisbury
Stormwater_Pipes	Polylines of stormwater pipe network	City of Salisbury, City of Playford & Dept. For Water
Stormwater_Pits	Points of stormwater pits/drains	City of Salisbury/City of Playford/Dept. For Water
Sub-catchments	Polygons of hydrological sub-catchments in South Australia	Dept. For Water
1_Sec_DEM	1 second resolution digital elevation model (pixels ~30m)	Geoscience Aust.
Salisbury_Aerial	Ortho-rectified 0.5m resolution aerial image of Salisbury council area	City of Salisbury
Water_Features	Polygons of wetlands and detention basins in Salisbury	City of Salisbury
ASR_Bores	Points of ASR/ASTR bores in Salisbury	City of Salisbury
Rewater_Pipes	Polylines of Salisbury dual reticulation network	City of Salisbury
Bing_Maps	High resolution aerial imagery	Bing Maps for ESRI ArcGIS10
LGA_Boundaries	Polygons of local council boundaries	Dept. of Planning and Local Government
Streams	Polylines of streams and rivers covering study area	City of Salisbury/Geoscience Aust./manual digitising
Sewer_Overflows	Points of sewer chokes across metropolitan Adelaide region	United Water
Sewer_Mains	Polylines of sewer pipe mains network within Parafield and Cobbler Creek catchments	United Water
Sewage_Infrastructure	Points of sewage pumping stations & WTPs across Adelaide metropolitan area	United Water

Stormwater catchment delineation

A broadly applicable method for stormwater catchment delineation in urban areas was developed through this study only requiring widely available GIS datasets to increase transferability of methodology. This began with defining the stormwater harvesting inflow point and overlying it onto a digital elevation model (DEM). Hydrological GIS models using the spatial analyst extension of ESRI ArcGISTM were run on the 1-second DEM to delineate terrain-based catchment areas following the principles given in Jenson and Domingue (1988).

The DEM of the area was conditioned for flow routing by removing depressions using the 'fill' tool to create a 'depressionless' surface. Tarboton *et al*. (1991) suggest that 0.9 to 4.7% of a DEM are sinks (2.7% in the DEM tile used in this study). While some sinks represent the actual landscape, the majority are spurious features and are a fundamental problem for analyses as coherent flow paths are interrupted.

Following this, the flow direction tool was run to code each cell with flow direction in one of 8 directions, this is the direction water will flow out of a cell based on its elevation in relation to its 8 closest neighbours (Jenson and Domingue, 1988). From this, flow paths were determined using the 'flow accumulation' tool to build a raster image where cells were coded for the number of neighbouring cells that flow into them based on the flow direction dataset (Jenson and Domingue, 1988). This gave a layer showing the topographic flow paths of surface runoff.

The flow accumulation raster was used to manually define specific pour points (points above which a catchment was to be defined e.g. points along Parafield Drain that feed into the harvesting system (wetland). A point feature class was created with a 'VALUE' field to input the flow accumulation values of the underlying cells. It is important to select the point overlying the cell with the highest flow accumulation value near the pour point location for specific catchment delineation (Jenson and Domingue, 1988). The 'snap to pour point' tool was applied to automatically locate this cell within a search distance of the original pour point and re-plot the pour point. Raster images of the catchments were then generated using the 'watershed' tool. This tool was run using the flow direction raster as the input dataset and the pour point layer as the 'starter' dataset (Jenson and Domingue, 1988). Pour points were created at each flow accumulation junction to generate sub-catchments starting at the lowest elevation point near the harvesting inflow location and working up.

As the stormwater drainage network generally flows following the terrain relief the DEM derived sub-catchments were used to guide the delineation of stormwater catchments based on stormwater pipe flow direction, property boundaries, roads and rail lines. Stormwater pipes were symbolised with 'arrow at end' to show flow direction. Rules were established to guide the refinement the DEM-based sub-catchments based on tracing the stormwater pipe network back through the system from the pour point and digitising lines features around areas where:

- Land parcel polygons intersected with stormwater pits and pipe flow was directed toward the pour point.
- Roads (from aerial photography or gaps in land parcel polygons) intersected with stormwater drains and pipe flow was directed toward the pour point.
- Road centre lines were used to divide areas where one side drains toward the pour point and the other drains away (assuming negative camber on roads).

Stormwater catchments within the Salisbury Council area were refined using a manual process of on-screen digitising. The City of Salisbury had commissioned the creation of stormwater 'mini-catchments' in 2004 and a further spatial extent in 2008 for stormwater modelling purposes (Cardno Willing, 2008). These data were supplied to CSIRO for the project along with various other data sets as detailed in Table A2.1. City of Salisbury mini-catchments were manually defined polygons based on available elevation data, aerial imagery, and road centreline and property boundaries. A detailed description of the creation of these polygons is given in Cardno Willing (2008).

The mini-catchments contained a field for the unique ID of the stormwater pit that was the drain point for each polygon. Stormwater pipes were symbolised with arrows to indicate flow direction and pits were labelled with their unique IDs. This was used to either include or exclude each mini-catchment polygon by tracing back flow paths from the harvesting point (e.g. weir on Parafield Drain, inlet to Paddocks wetland). This method is illustrated in Figure A2.1. This was applied specifically to local catchment runoff areas where the stormwater pipe system channelled water to wetlands. Stream catchments where inflow to wetlands was through creek diversion, e.g. Dry Creek to the Greenfields wetlands, were left as the DEM-based watershed delineation.

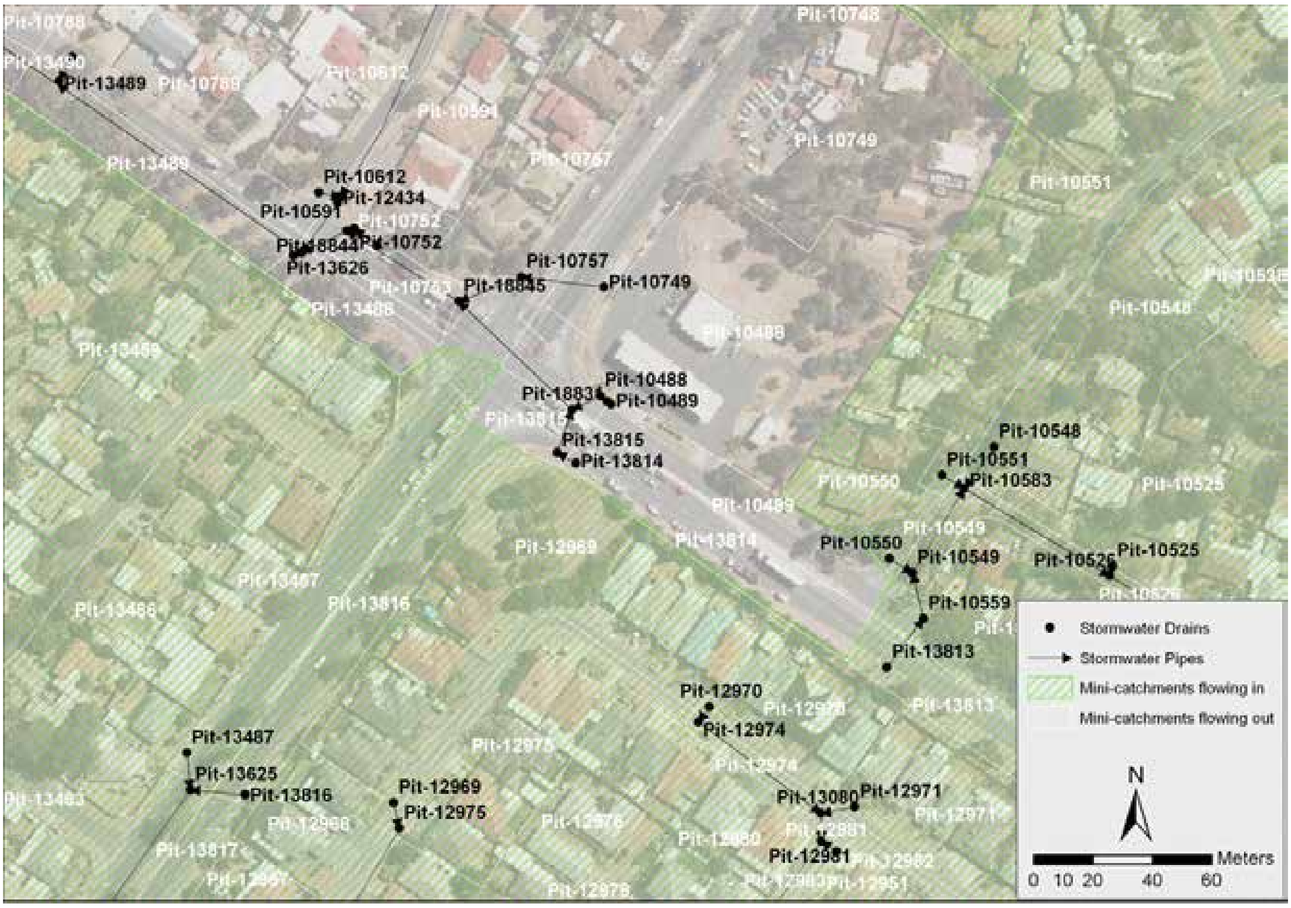


Figure A2.1 Example of stormwater catchment boundary refining using stormwater pipes, drains and modelled min-catchment data (all data shown sourced from City of Salisbury). Areas hatched in green flow into the harvesting point. Mini-catchment drain point IDs labelled with white text, drain IDs labelled in black text.

The boundaries of the hydrological sub-catchments draining to Little Para Reservoir were sourced from publicly available spatial database server (DEWNR, 2012a). These included the Little Para Reservoir, Gould Creek and Upper Little Para sub-catchments. These 3 sub-catchments were merged into a single polygon for subsequent spatial processing of other layers e.g. land use.

Generalised Land Use Assessment

Land use spatial data covering the extent of South Australia were sourced from a publicly available on-line database (DPLG, 2011) administered by the Department for Planning and Local Government. Property boundaries were based on property valuation cadastre data. Land use was categorised into nineteen broad classes using a system based on valuation records (DPLG,2011). This layer focused on metropolitan areas and lacked spatial accuracy and precision and attribute detail in rural regions. Coverage of rural areas in the Little Para Reservoir and Unity Park catchments were sourced from publicly available land use data (based on the Australian Land Use and Management (ALUM) classification system) from the Australian Bureau of Agricultural and Resource Economics and Sciences web server (ABARES, 2012). The ALUM classification system provides a nationally consistent land use data set but is focussed on rural regions at the catchment scale and metropolitan areas are unmapped. These data contain 3 levels of land use classification, primary, secondary and tertiary. For example, the primary key could be 4.0 - Production from irrigated agriculture; secondary key 4.4 – Irrigated perennial horticulture; tertiary key 4.4.4 – Irrigated vine fruits. These keys were also used to assign specific land use codes according to the ANZSIC based system. These data were re-coded in line with methods applied to the DPLG sourced layer for generalised categories using a GIS routine.

Table A21 DPLG generalised land use classification re-coding.

Original	Recoded
Non-private residential	Residential
Residential	
Food industry	Industrial
Utility industry	
Commercial	Commercial
Retail Commercial	
Education	Institution
Public institution	
Recreation	Recreational
Golf	
Vacant	Vacant
Vacant Residential	
Forestry	Forestry
Horticulture	Horticulture
Livestock	Livestock
Mining	Mining
Reserve	Reserve
Rural residential	Rural residential

A spatial model was created in ArcGIS to clip the generalised land use layer to the stormwater catchment boundaries and recode the clipped layers into a customised classification system. Definition queries were inserted using Structured Query Language (SQL) statements to recode the existing land use classifications into broader groups within the model for the purposes of characterising catchments for informing hazard identification stakeholder workshops for the MARSUO project. This grouped the land use codes into 12 categories from an original 19 (of which only 18 applied to the study area). A summary of the classes and changes is given in Table A2.2 and Table A2.3.

A spatial model was built to calculate descriptive statistics for land use using the Summary Statistics tool. This totalled the number of land parcels and area occupied for each land use class within each catchment and output summary table for each catchment.

Table A2.3 ALUM land use classification re-coding.

Original ALUM Category	Re-coded Generalised Category	Re-coded Specific Land Use Code
1.1.4 Natural feature protection	Reserve	4500
1.2.2 Surface water supply		
1.3.3 Residual native cover	Forestry	9400
3.1.3 Other forest production		
3.2.0 Grazing modified pastures	Livestock	9800
4.2.4 Irrigated sown grasses		
5.2.6 Aquaculture		9290
3.3.3 Hay & silage	Horticulture	9700
3.4.2 Oleaginous fruits		
4.4.0 Irrigated perennial horticulture		
4.4.1 Irrigated tree fruits		
4.4.2 Irrigated oleaginous fruits		
4.4.4 Irrigated vine fruits		
4.4.5 Irrigated shrub nuts fruits & berries		
5.1.0 Intensive horticulture		
5.1.2 Glasshouses		9730
5.3.0 Manufacturing and industrial	Industrial	*manually coded
5.6.1 Electricity generation/transmission		6170
5.4.1 Urban residential	Residential	1100
5.4.2 Rural residential	Rural Residential	0100
5.5.1 Commercial services	Commercial	*manually coded
5.5.2 Public services	Institution	*manually coded
5.6.0 Utilities		*manually coded
5.7.5 Navigation and communication		*manually coded
5.8.2 Quarries	Mining	8250

* Specific land use was manually coded through interrogation of internet mapping (Google Maps) and business locality databases (True Local, Yellow Pages).

Specific Land Use Assessment

Specific land uses (e.g. automotive repair workshops) and activities pose certain water quality hazards (e.g. assessment by Swierc *et al*., 2005). When reviewing land uses within a catchment, it was important to recognise the water quality hazards they may pose (e.g. sources of oils and hydrocarbons), and the specific hazardous event conditions (e.g. a container spill) under which the hazard may become a risk. The generalised land use GIS layer from DPLG in this regard was insufficient. Detailed land use layers at a scale that identified individual land holdings were sourced from the City of Salisbury and the City of Playford.

These specific land use data were at a similar spatial scale as the DPLG generalised land use data but recorded details of land use at the individual landholder scale. These data are based on property valuation cadastral data and classified based on the Australian and New Zealand Standard Industrial Classification (ANZSIC, 2006).The City of Salisbury and City of Playford contained a total of 342 and 320 different land use classes respectively but not all featured within the stormwater catchment boundaries. Some land uses were subsequently grouped into single classes where the nature of the water quality risk was similar. For example, nutrient risks from fertiliser application of different recreation/sports grounds including football ovals, soccer pitches, golf courses, school ovals, cricket grounds etc. were grouped into one land use code. This represented the level of detail in the risk assessment table and simplified the relationship with the land use layer.

For metropolitan catchment areas outside the spatial extent of the City of Playford and City of Salisbury land use data, specific land use was manually coded using the generalised land use property boundaries and performed through field surveys and interrogation of internet mapping (e.g. Google Maps) and business locality databases (e.g. True Local, Yellow Pages). For catchment areas in rural regions (e.g. Unity Park and Little Para Reservoir), specific land use was derived from the ALUM layer. The ALUM classes were re-coded according to the classification system used in the City of Salisbury and City of Playford layers (see Table A.24) using a GIS routine, or manually coded following business locality research where the secondary or tertiary key in the ALUM layer did not identify the land use with the precision required for the land use risk assessment.

The land use codes and schemas for the City of Salisbury, City of Playford and recoded generalised and ALUM specific land use layers across the extent of the stormwater catchments were matched. The layers were then merged into one seamless layer to enable extraction (clipping) analysis of land use within stormwater catchments that overlapped spatial extents of different land use datasets.

Major roads and rail lines were digitised from aerial imagery and roads were coded according to annual average daily traffic volumes sourced from DPTI (2011).

Validation of the land use layers for each catchment was performed using a combination of field based GPS data collection and observations, aerial image interpretation and cross referencing with internet mapping (e.g. Google Maps) and business locality databases (e.g. Yellow Pages, True Local). This led to recoding of some polygons. Spatial editing of polygons was also performed (e.g. to separate buildings from sports fields and vacant land) and were coded to reflect the change.

Risk assessment spatial referencing and geostatisitcs

The risk assessment table was incorporated into a GIS by importing the original MS Excel spreadsheet to MS Access, reformatting and exporting to a database file format (.dbf) that was incorporated into a GIS model. The table contained the assessed risk for each MAR water quality group for different land use codes e.g. Industrial (cement production) - 3692; Horticulture (crops fields and market gardens) – 9700. Textual descriptions of the risk level were given a numeric risk 'value' in ascending order of risk (low = 1; moderate = 2; high =3; extreme = 4). Land use codes were the relational field upon which the risk 'value' was associated with the spatial data. Spatial data associations with the risk assessment table and spatial statistics were generated using another series of GIS models.

The first model created a 'risk' look up table (LUT) for each of the MAR water quality groups by extracting the maximum risk 'value' for each land use code from the original risk database table. This model used the structured query language (SQL) statements to create a temporary table of land use risks for each MAR water quality group. The Summary Statistics tool then created a geodatabase table (the LUT) for each water quality group containing the maximum risk for each land use code.

The second model made copies of the specific land use polygon layers for each catchment. The hazard descriptions, likelihood and severity scores, and the textual and numeric risk value fields for each of the MAR water quality groups (from the LUTs) were then joined to the polygon layer based on the land use codes.

The third model generated summary tables for each catchment containing the number of properties and total areas of each land use type for each of the water quality groups.

Sewer Overflows & Sewage Pump Stations

Sewerage infrastructure (sewer pipes and sewage pump stations) and failure (chokes and overflows) data were sourced from the water utility company (United Water); see Table A.22. Sewerage mains pipe network data within the Parafield and Cobbler Creek catchments were provided as a polyline shapefile. Sewer overflow data were provided to the project as a point shapefile that gave the location, time and details of sewer chokes across the Adelaide metropolitan region over a 7 year period from 2003 to 2010.

The average annual number of sewer overflows per 100 km of sewer for the five year period from 2006 to 2010 was calculated using a GIS routine to clip the sewer mains shapefile to the catchment boundaries, sum the length of pipes within catchments, clip the sewer overflows points within the catchments and calculate the average annual number of overflows per 100 km of sewer across the five years. The number of overflows within each catchment was summed using a simple GIS routine that intersected and summed the number of overflow points occurring within each catchment.

A spatial model was built to categorise sewage pump stations (SPS) based on distances to streams and open water courses. A proximity analysis was conducted using the ‘generate near table’ tool to calculate distances of SPSs from water courses and attach these distance back to the point feature class objects using unique identifiers. Symbology rules were then applied to display SPSs within 20 m of a water course as an extreme risk, 20-30 m as high risk and over 30 m as a moderate risk.

Appendix 3 Literature review on transport and fate of pathogens in aquifers

The processes that affect the fate of pathogen and viruses include:

- inactivation in both mobile and immobile phases;
- sorption to aquifer material; and
- dilution with ambient groundwater (Schijven and Hassanizadeh, 2000).

The effects of particular factors that control the processes are discussed in the literature (Schijven and Hassanizadeh, 2000; Tufenkji, 2007). Most studies on pathogen fate assume that inactivation rate might be estimated in independent tests, while total removal is the net removal by attachment and inactivation. The colloid transport approaches (McCarthy and McKay, 2004) are often useful in predicting physical transport of pathogens, although shape of bacteria and viruses is not comparable with shape of colloids. The complexities in transport phenomena rendered most studies to be carried out in a one-dimensional set up, e.g. in column experiments.

The modelling approaches for pathogen and virus transport consider inactivation, sorption and dilution (Figure A3.1). Inactivation may be regarded as a process occurring in the aqueous (mobile) and on the solid (immobile) phases. Different inactivation rate coefficients may be assigned to different phases.

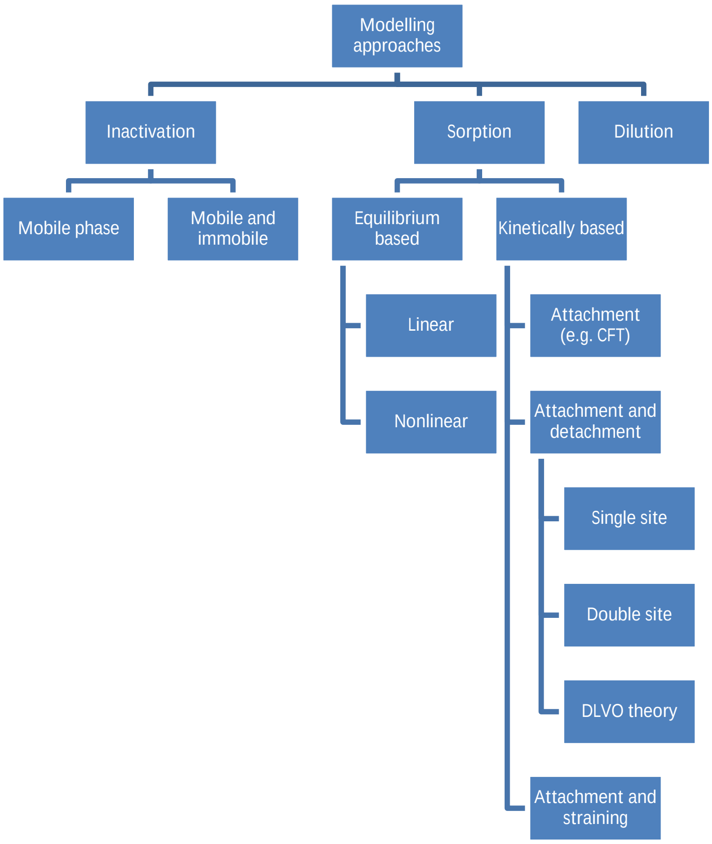


Figure A3.1 Modelling approaches in pathogen transport in aquifers (explanation in the text)

Prediction of sorption to the aquifer material is by far the most challenging issue when considering pathogen transport in aquifers. To some extent, the colloid transport approaches (McCarthy and McKay 2004) might be useful in predicting physical transport of pathogens, although shape of bacteria and viruses is not comparable with shape of colloids. The simplest approach in predicting sorption is the assumption of linear or nonlinear sorption to the aquifer material (Yates and Yates, 1988; Dillon *et al*., 2005, Tufenkji, 2007). The transport is governed by the equation known from solute transport of non-conservative in porous media (e.g. Appelo and Postma, 2005; Bear and Cheng, 2010):

$$R\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - v\frac{\partial C}{\partial x}, \qquad \textbf{(A.1)}$$

Where R is the retardation factor, C is the concentration of pathogen, t is time, D is the longitudinal coefficient of hydrodynamic dispersion, x is the distance, and n is the average pore water flow velocity. The retardation factor indicates the extent to which the transport velocity of the pathogen differs from the transport velocity of a conservative tracer (which does not undergo sorption, degradation and reaction with aquifer material). The retardation factor of a conservative tracer equals 1, whereas R>1 indicates slower transport of the contaminant, or retardation.

It has been emphasised, however, that the nature of pathogen transport differs from that of other contaminants where behaviour could be explained by linear sorption. First of all, the peaks of pathogens occur concurrently with conservative tracers, which do not point to the retardation effect known from transport of most inorganic and organic contaminants in aquifers. Secondly, there is a distinct tailing over time observed in the observation wells, which implies that part of the introduced contaminant is transported at much lower velocity than average groundwater flow.

A more elaborate equation of pathogen transport incorporates attachment of pathogens and viruses to aquifer material (Schijven, 2001, Chp 5; Schijven *et al*., 2006):

$$D\frac{\partial^2 C}{\partial x^2} - v\frac{\partial C}{\partial x} - (k_{att} + \mu_l)C = 0 \quad \textbf{(A.2)}$$

Where k_{att} is the attachment rate coefficient and μ_I is the inactivation rate coefficient. This approach is based on the Colloid Filtration Theory (CFT), the concept associated with the removal of colloidal particles during packed-bed filtration in water treatment applications (Yao *et al*., 1971). The k_{att} is evaluated during column or field experiments and is linked with the collision efficiency.

Schijven *et al*. (2006) proposed the following relationship between k_{att} and α:

$$k_{att} = 6\frac{(1-n)}{d_c}\alpha A_s^{1/3}\left(\frac{D_{BM}}{d_c n v}\right)^{2/3} v \quad \textbf{(A.3)}$$

where d_c is the average diameter of the single collector (grain of sand), n is porosity, A_s is the Happel porosity dependent parameter, and D_{BM} is the diffusion coefficient. These parameters are assumed to be constant. Once k_{att} is evaluated through an experiment, α can also be estimated.

Attachment of viruses, due to their very small dimensions, is assumed to be governed by Brownian diffusion solely (Penrod *et al*., 1996). More specifically, in the Smoluchowski-Levich approximation Brownian diffusion dominates the transport of particles in the immediate vicinity of the collector surface while colloidal and hydrodynamic interactions between the virus and collector surface are negligible (Penrod *et al*., 1996). Both k_{att} and α in the CFT are considered to decline with increasing transport distances (Hendry *et al*., 1999; Dong *et al.,* 2006). In the field experiment (Schijven, 2001, Chp 4) α decreased with distance from 0.0014 to 0.00027 for MS-2 bacteriophage and from 0.0024 to 0.00043 for PRD1. They suggested that low α values in the sand dune aquifers are due to the relatively high pH values (7.3-8.3). Dong *et al*. (2006) who studied distribution of bacteria along the flow path found that in the field studies α decreased with distance, while in the lab studies it increased with distance. The reason for α decrease with increased transport distance is variability in the cell surface properties within a monoclonal bacterial population; it seems that 'stickier' bacteria within the population are selectively removed at short transport distances yielding a progressively less-sticky population with increased transport distance (Dong *et al.,* 2006). Hence laboratory-based models tend to overestimate α values (predict lower mobility of bacteria). Larger attachment of bacteria in the laboratory tests when compared with field experiments were also found by Bales *et al.* (1997). Some authors (Bradford *et al*., 2003) use two parameters controlling physical straining in lieu of the inactivation rate coefficient.

To improve the fit between observed and modelled values, a two sites kinetic attachment/detachment models with exponential decay were proposed (Bales *et al*., 1991; 1997; Schijven *et al*., 2002). The inactivation rates as well as attachment and detachment coefficients were assigned to aqueous phase and two sorption site phases.

$$D\frac{\partial^2 C}{\partial x^2} - v\frac{\partial C}{\partial x} = \mu_l C + \mu_{s1}\frac{\rho_B}{n}S_1 + \mu_{s2}\frac{\rho_B}{n}S_2 \quad \textbf{(A.4)}$$

$$\frac{\rho_B}{n}S_1 = \frac{k_{att1}}{\mu_{s1} + k_{\det 1}}C \text{ and } \frac{\rho_B}{n}S_2 = \frac{k_{att2}}{\mu_{s2} + k_{\det 2}}C \quad \textbf{(A.5)}$$

Where S is the adsorbed concentration, and k_{det1} and k_{det2} are the detachment rate coefficients in first and second sorption sites. In this kind of models the k_{att1} mainly affects the peak value of a breakthrough curve while the k_{att2} chiefly influences the level of the tail of the breakthrough curves (Bales *et al*., 1997).

Another modelling approach includes the concept called DLVO (Derjaguin-Landau-Vervey-Overbeek) interactions. The reason for that was that in the laboratory experiments on *C. Parvum* the removal by CFT was largely overestimated due to secondary minimum deposition and surface charge heterogeneities (Tufenkji and Elimenech 2005). The authors found that *C. Parvum* transport was controlled by “slow” deposition in the primary energy well as well as the two mechanisms of “fast” secondary minimum deposition and retention due to charge heterogeneities. As such Tufenkji and Elimenech (2005) proposed a dual deposition mode mechanism which refers to two groups of particles (heterogeneous in terms of population) that behave differently in terms of deposition.

More advanced models of pathogen transport can be developed using numerical codes like PHREEQC (Parkhurst and Appelo, 1999) and HYDRUS (e.g. Pang and Simunek, 2006). These programs are capable of incorporating surface charge of particles (pathogens), the influence of water chemistry (e.g. monovalent/divalent ions concentration ratios) on solute transport and dual porosity transport effects. Nevertheless, much work has yet to be done to create a reliable database for pathogen transport. The results of laboratory experiments might still not be reliable when upscaled to the field conditions.

Most authors suggest that there is a need for improvement in existing modelling techniques (McCarty and McKay, 2004, Schijven *et al*., 2006, Engesgaard *et al*., 2006; Tufenkji, 2007). The most important issues are:

- The equilibrium adsorption mechanism is inadequate,
- CFT is not valid under ‘unfavourable’ (repulsive) conditions for deposition (McCarthy and McKay 2004; Tufenkji and Elimenech, 2005; Tufenkji, 2007). These conditions broadly refer to the presence of repulsive electrostatic interactions (Tufenkji, 2007),
- Determination of attachment efficiency is very complex,
- The influence of cell/cyst surface biomolecules is not well understood,
- Physical straining can be important for larger microorganisms,
- Microbial growth and inactivation are difficult to predict,
- Detachment of microorganisms is often not considered.

The summary of modelling approaches for pathogens transport in aquifers with relevant references is shown in Table A3.1.

Table A3.1 Modelling of bacteria and viruses in aquifer material

Model	Parameters	Limitations	Reference
Equilibrium retardation and 1st order kinetic decay	R (K_d) – retardation factor (distribution coefficient) α – time of 1.0 $\log_{10}$ removal	- Bacterial transport rarely undergoes retardation similar to inorganic/organic contaminants - sorption is modelled using the local equilibrium assumption - tailing can not be modelled using this concept	Yates and Yates (1988); Dillon (2005)
1st order attachment and decay	α - collision efficiency k – attachment rate coefficient μ_l – inactivation rate coefficient (inverse of τ)	detachment is neglected (irreversible attachment) assumes decrease in attachment with distance (empirical assumption) assumption of steady state hydrodynamic dispersion negligible	Schijven *et al*. (2006)
Single site kinetic sorption	k_r –coefficient of reversible attachment k_{ir} –coefficient of irreversible attachment (excluded by Dong *et al*., 2006) k_f –coefficient of detachment μ_l, μ_S, – inactivation rate coefficients	Too simple in some cases - Schijven *et al*. (2002) were not able to fit the parameters using one-site model Some investigators neglected bacterial inactivation (very low in a column experiment; Stumpp *et al*., 2011)	Harvey and Garabedian (1991), Penrod *et al*. (1996), Hendry et al. 1999 Schijven et al. 2002, Mallen *et al*. (2005) Dong *et al*. (2006) Stumpp *et al*. (2011)
Double site kinetic sorption	k_{att1} –coefficient of attachment in the 1st sorption site k_{det1} –coefficient of detachment in the 1st sorption site k_{att2} –coefficient of attachment in the 2nd sorption site k_{det2} –coefficient of detachment in the 2nd sorption site μ_l, μ_{S1}, μ_{S2} – inactivation rate coefficients	a couple of parameters that might be difficult to fit observed values unless a well constrained laboratory experiment is conducted has not been applied in the field studies	Bales *et al.* (1991),(1997) Schijven *et al*.(2002)
Attachment, decay and straining	k_{att} – the attachment coefficient k_{str} – the straining coefficient Ψ_{str} – a dimensionless depth-dependent straining function $\mu_{adsorbed}$ – *inactivation rate coefficient in adsorbed phase (attached/strained)* μ_{solute} – *inactivation rate coefficient in aqueous phase*	- the parameters are difficult to determine	Bradford *et al*. (2003)
Advanced	μ_l = f(solution composition (including nutrient availability), pH, temperature, presence of other bacteria) α = f(solution composition (including nutrient availability, monovalent divalent cations ratio), mineralogical composition, pH of groundwater, presence of other bacteria) - colloid transport can be modelled using PHREEQC in 1D code with kinetic sorption to mobile and immobile phases (double layer diffusive model) – This has not been published yet (extension to virus transport possible?)	a number of parameters that are hard to be determined, lack of a wide range of input data makes modelling very difficult	Elimenech *et al*. (2000) (effect of patchwise heterogeneity), Pang and Simunek (2006) (bacteria facilitated Cd transport in a column) Jewett *et al*. (1995)

Model	Parameters	Limitations	Reference
	- HYDRUS – similar as above but includes 2 and 3 dimensional transport in both unsaturated and saturated zones		Cao *et al*. (2010)

Considerations of the application of pathogen transport model in the risk assessment studies

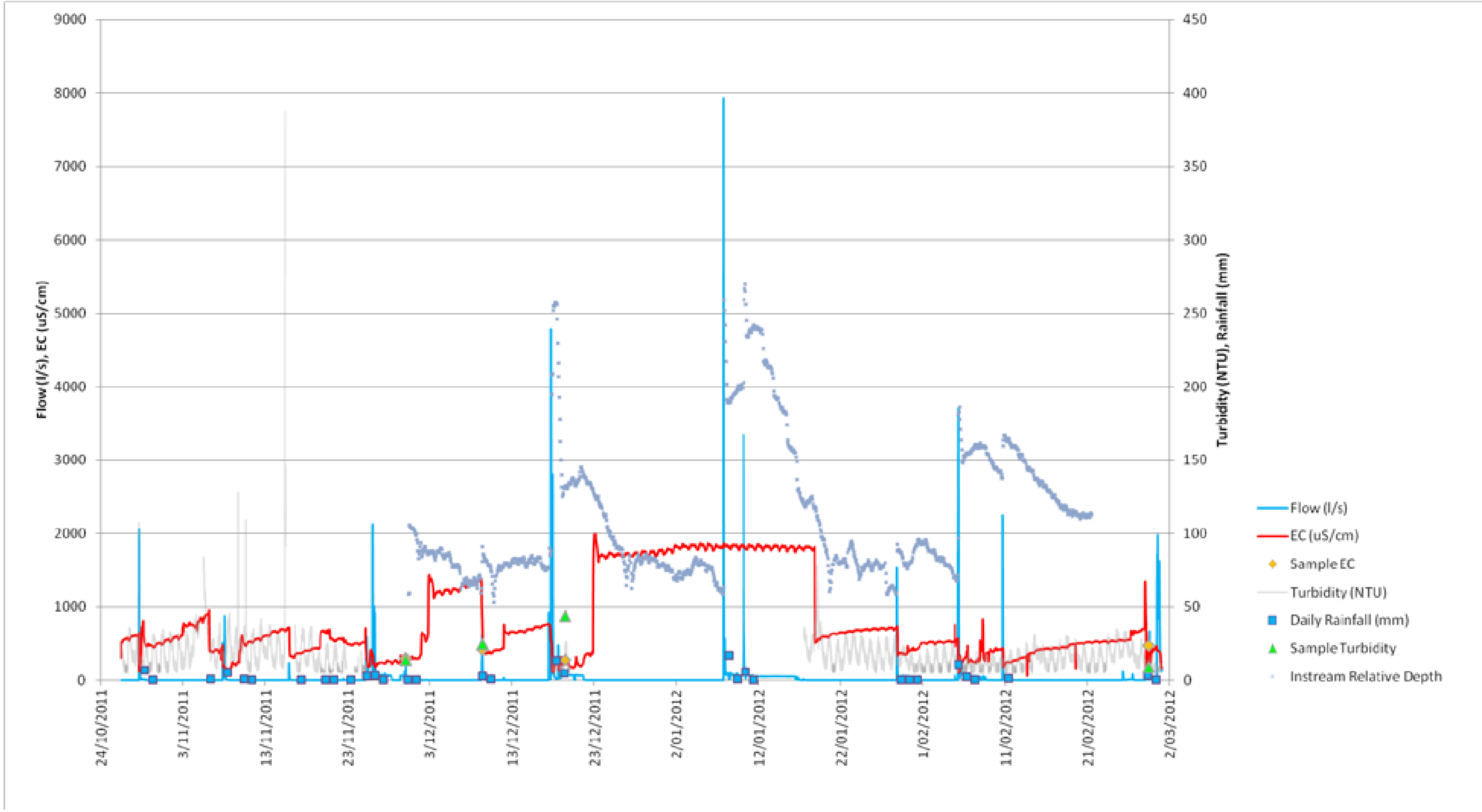
A simplified approach of risk assessment for ASR and ASTR systems was presented by Dillon *et al*. (2005) and is summarised in Table A3.2 Parameters and processes controlling pathogen behaviour in aquifers under ASR and ASTR schemes The authors assumed a conservative (the worst case) scenario based on the calculation of minimum residence time of injected water in an aquifer. In ASR systems the minimum residence time is the storage period between injection and recovery. In ASTR systems two cases are presented for wells that are operated continuously at the same rate: 1) if no ambient flow is considered and 2) with ambient groundwater flow where the extraction well is situated directly down-gradient of the injection well. In both scenarios for risk assessment in ASTR schemes, the minimum residence time is a function of the distance between the wells, thickness and porosity of an aquifer and rate of pumping. If ambient groundwater flow is of importance a natural groundwater velocity is included. The attenuation of a contaminant potentially injected to an aquifer is subsequently evaluated if degradation rate and retardation factor are known (Dillon *et al*., 2005).

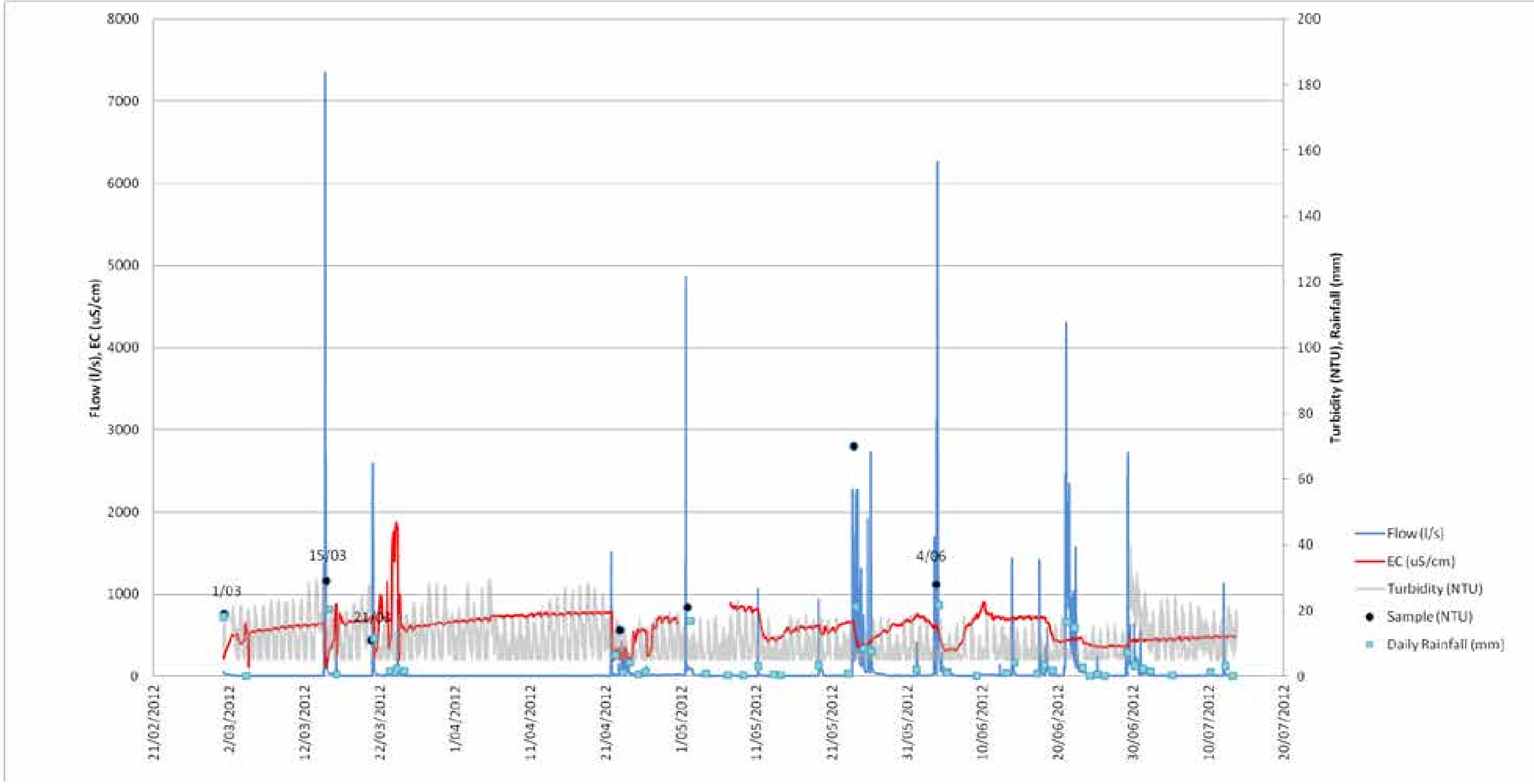
Table A3.2 Parameters and processes controlling pathogen behaviour in aquifers under ASR and ASTR schemes

Parameter/process	ASR	ASTR	Remarks
Residence time	Uneven. The minimum residence time is assumed to be equal to the length of storage period	Relatively even. May be controlled by adjusting rates of pumping and length of storage period	Dillon *et al.* (2005)
Length of storage period	Must be long enough to provide sufficient residence time of water injected to an aquifer	Might be shorter than in ASR, but its length will be affected by the separation distance, aquifer thickness and porosity, pumping rate, and natural groundwater velocity	Dillon *et al*.(2005)
Pathogen straining	May be reversible under reversed flow	May not me reversible if flow is not reversed	No published literature to date
The influence of bioclogging on pathogen transport	Might influence both attachment and detachment rates under intermittent divergent and convergent flow. Pathogen attachment around an ASR well might be diminished	An injection well may be affected by bioclogging formation, but separation distance in an ASRT scheme provides many sorption sites for pathogen uptake	No published results to date on bioclogging development reversed flow The importance of this process could be revealed by performing lab experiment – column (reversed flow) or sand box study (radial flow)

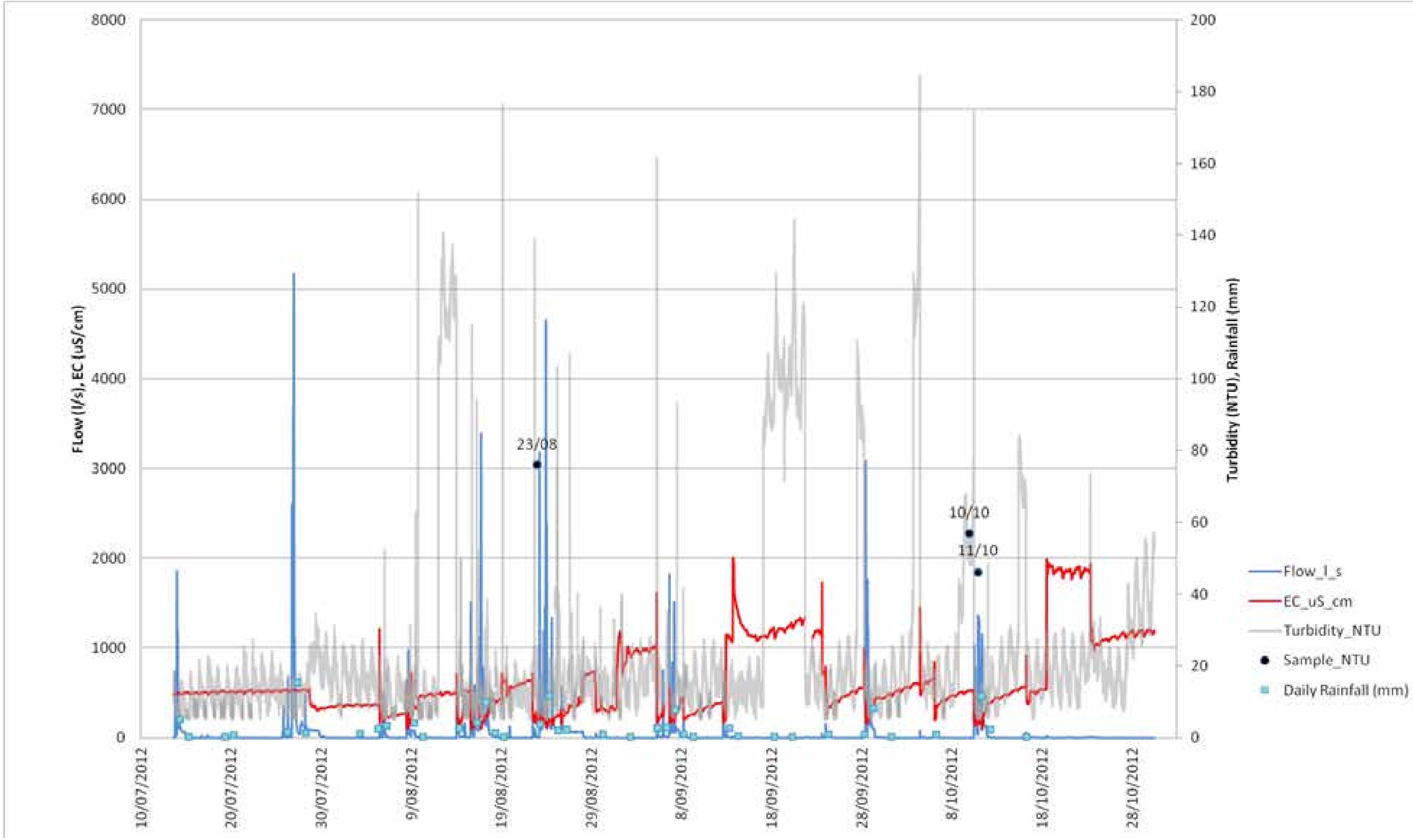
Most studies on pathogen transport in aquifers have been conducted so far in 1-D configurations. An intriguing scientific issue would be determination of pathogen transport in a reversed flow as well as 2-D and 3-D systems. Those kinds of experiments, carried out both in the laboratory and field conditions, will be warranted in order to assess relative efficiency of ASR and ASTR systems (Table A3.2). Engesgaard *et al*. (2006) who studied biomass growth in a 2-D sand box experiment found that a pattern of successive decline in hydraulic conductivity from the source of injection was caused by detachment of bacteria close to the inlet and attachment further downstream. If a similar feature occurs in an aquifer-scale environment, one would anticipate that ASR system in which the groundwater flow is reversed would behave different in terms of pathogen uptake compared to ASTR system in which solely radial divergent flow around an injection well takes place.

Appendix 4 Flow, salinity and turbidity recorded at Parafield Drain Station (PDS)





8000
7000
6000
5000
4000
3000
2000
1000
0
FLow (l/s), EC (uS/cm)
200
180
160
140
120
100
80
60
40
20
0
Turbidity (NTU), Rainfall (mm)
1/03
15/03
21/03
4/06
21/02/2012
2/03/2012
12/03/2012
22/03/2012
1/04/2012
11/04/2012
21/04/2012
1/05/2012
11/05/2012
21/05/2012
31/05/2012
10/06/2012
20/06/2012
30/06/2012
10/07/2012
20/07/2012
Flow (l/s)
EC (uS/cm)
Turbidity (NTU)
Sample (NTU)
Daily Rainfall (mm)



8000
7000
6000
5000
4000
3000
2000
1000
0
200
180
160
140
120
100
80
60
40
20
0
FLow (l/s), EC (uS/cm)
Turbidity (NTU), Rainfall (mm)
23/08
10/10
11/10
10/07/2012
20/07/2012
30/07/2012
9/08/2012
19/08/2012
29/08/2012
8/09/2012
18/09/2012
28/09/2012
8/10/2012
18/10/2012
28/10/2012
Flow_l_s
EC_uS_cm
Turbidity_NTU
Sample_NTU
Daily Rainfall (mm)

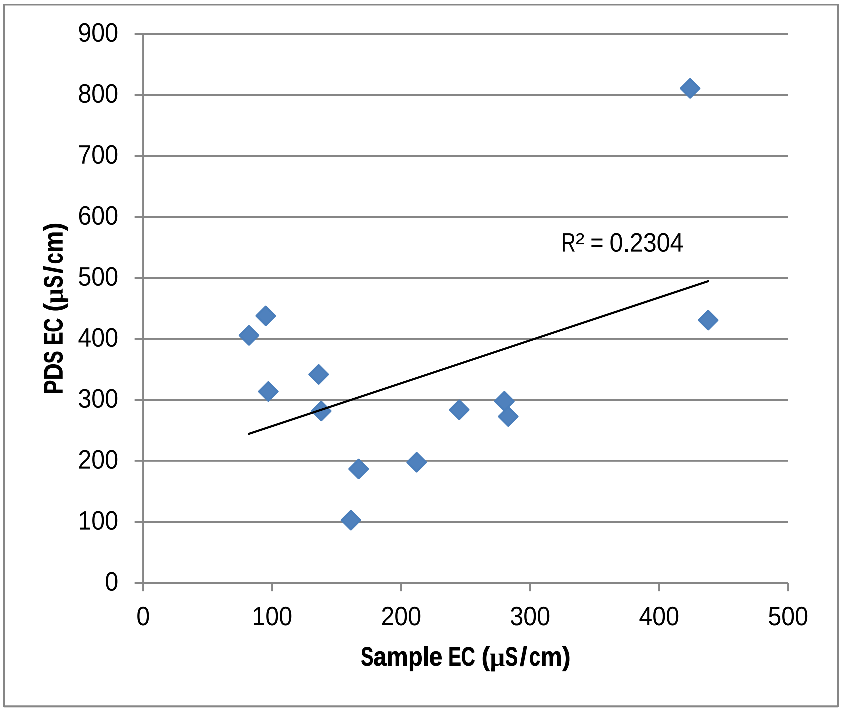


Figure A4.2 Grab and composite sampling (sample EC) versus continuous monitoring (PDS EC) observations of electrical conductivity at the Parafield Drain site.

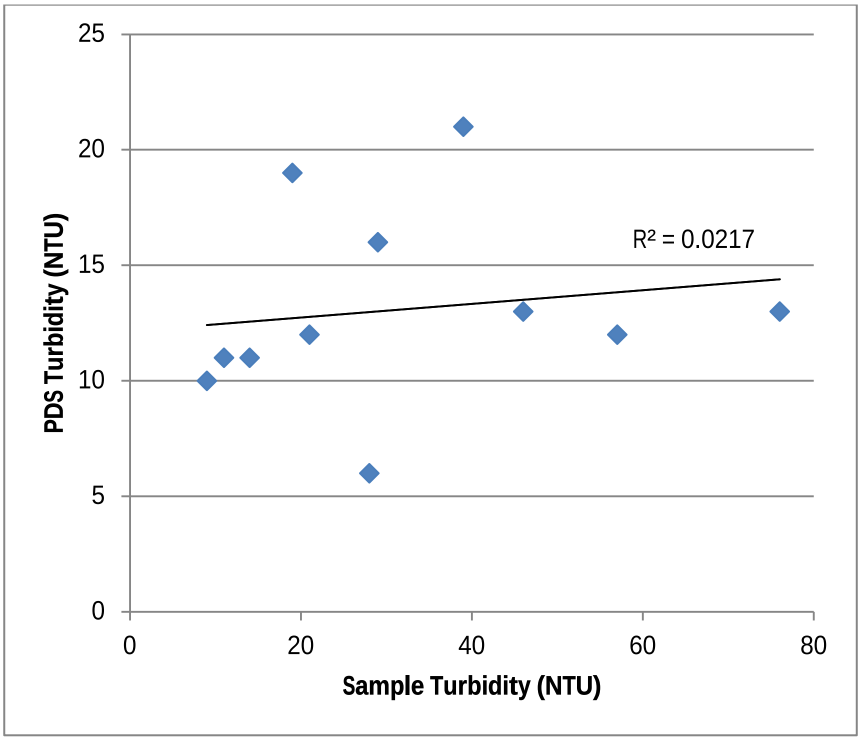


Figure A4.3 Grab and composite sampling (sample turbidity) versus continuous monitoring (PDS turbidity) observations of turbidity at the Parafield Drain site.

Appendix 5 Catchment/Wetland Inlet Water Quality Data

	Guidelines		Parafield			Cobbler Creek			Greenfields			Kaurna Park			Paddocks			Unity Park		
	DWG	STV	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile
Field Readings																				
EC (mS/cm)			35	159	491	10	293	664												
Temperature (°C)			31	16	24	10	13	21												
pH (pH units)	6.5-8.5 [a]	6.5-8.5	36	7.8	9.0	10	8.1	**8.7**												
DO (mg/L)			34	7.3	10.3	10	10	13												
Eh (mV SHE)			36	383	493	10	383	414												
Physical Characteristics																				
EC (mS/cm)			85	222	1634	12	314	664	52	1750	6776	35	266	494	35	224	478	14	1028	2566
pH (pH units)	6.5-8.5 [a]	6.5-8.5	85	7.7	**8.8**	12	7.9	8.1	52	8.0	**8.6**	35	7.9	**8.8**	35	7.5	8.0	14	8.3	**8.7**
Suspended Solids (mg/L)			78	26	155	12	58	502	52	18	130	35	44	167	35	6	99	14	10	66
Total Dissolved Solids (mg/L; by EC)	600 [a]		79	130	**975**	12	175	365	50	**940**	**3700**	33	150	274	33	120	264	14	565	**1415**
Turbidity (NTU)	5 [a]		69	**20**	**296**	12	**70**	**405**										13	**17**	**56**
True Colour (HU)	15 [a]		48	**50**	**121**	8	**33**	**47**												
Particle size - d_{10}			41	3	12	8	2	8												
Particle size - d_{50}			41	12	52	8	10	21												
Particle size - d_{90}			41	45	211	8	52	755												
Major Ions (mg/L)																				
Alkalinity as $CaCO_3$			49	53	132	12	63	181										13	148	257
Bicarbonate			64	67	155	12	76.5	221										13	180	314
Bromide			53	0.11	1.33	12	0.17	0.29												
Sulphate	250 [a] (500 [b])		66	13	65	12	11.1	31				1	155	155				13	47	197
Chloride	250 [a]		73	29	192	12	39	91				6	38	46				13	189	**444**

	Guidelines		Parafield			Cobbler Creek			Greenfields			Kaurna Park			Paddocks			Unity Park		
	DWG	STV	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile
Cyanide	0.08 [b]		6		<0.05															
Fluoride	1.5 [b]		670	0.26	0.87	12	0.26	0.39										13	0.31	0.43
Calcium			71	17	54	12	20.4	44				6	37	48				13	44	75
Magnesium			71	3.7	20	12	8.76	20				6	7	10				13	27	60
Potassium			68	3.5	11	12	2.81	3.71										13	5	7
Sodium	180 [a]	115 [c]	68	20	106	12	23.2	65										13	112	**246**
Microbiological (cfu/100 mL)																				
Colony Count (20° C) Aerobic			9	150,000	354,000															
Coliforms - Presumptive			9	33,000	222,500															
Coliforms			9	37,000	219000													12	10,400	41,950
E. coli/F Coliforms - Presumptive			47	5,600	104,000	12	2,100	16,700												
Faecal coliforms	0 [b]		47	**5,400**	**102,600**	**12**	**2,100**	**16,700**												
E. coli	0 [b]		66	**3,200**	**34,900**	**12**	**1,950**	**16,700**	50	**520**	**5,740**	33	**91**	**1,559**	33	**210**	**4,380**	14	**710**	**10,230**
Ent/F.Strep - Presumptive			14	300	39,000	5	2,700	8,100												
Enterococci	0 [b]		15	**650**	**37,750**	5	**2,700**	**8,100**										7	**450**	**17,740**
Faecal Streptococci	0 [b]		14	**300**	**39,000**	5	**2,700**	**8,100**										6	**360**	**18,500**
Sulphite reducing Clostridia			3	790	3,049															
Clostridium - presumptive			3	790	3,049															
Clostridium perfringens			3	400	2,740															
Campylobacter (cfu/L)	0 [b]		22	**4**	**110**															
Cryptosporidium - confirmed (oocytes/10 L)			16	**5**	**14**															
Giardia - confirmed (cysts/10 L)			**15**	**<6**	**58**															
Bacteriophage (/10 mL)			35	74	907	8	53	122												
Rotavirus (PDU/L)			3		<1															
Adenovirus (gene copies /L)			18	<10	1,216															
Nutrients (mg/L)																				

	Guidelines		Parafield			Cobbler Creek			Greenfields			Kaurna Park			Paddocks			Unity Park		
	DWG	STV	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile
Nitrate + Nitrite as N	11.3 [b] (NO_3-N)		81	0.17	0.98	12	0.26	0.50	51	0.01	0.51	34	0.01	0.20	33	0.02	0.30	14	0.15	0.79
Ammonia as N	0.4 [a]		72	0.04	**0.60**	12	0.01	0.07										13	0.01	0.03
TKN			79	0.77	2.94	12	0.555	2.1	51	0.65	1.9	34	0.84	2.3	33	0.64	2.9	14	0.43	0.76
Total Nitrogen		25	70	1.05	5.65	12	0.81	2.4				1	2.0	2.0				13	0.65	1.4
Filterable Reactive P			54	0.04	0.15	12	0.009	0.023	34	0.01	0.03	34	0.01	0.04	33	0.02	0.07	1	0.02	0.02
Total Phosphorus		0.8 (0.05 LTV [d])	85	0.14	0.44	12	0.079	0.36	52	0.06	0.18	35	0.11	0.27	34	0.09	0.29	14	0.04	0.11
Biodegradable Dissolved Organic Carbon			17	6.2	15.1	3	1.1	1.5												
Dissolved Organic Carbon			54	8.0	24.0	8	4	6.1												
Total Organic Carbon			74	10.9	26.4	12	6	12				4	6.9	13	2	4.6	5.3	13	5.9	13
Silica	80 [a]		45	2	7	8	4	6				4	6.0	7.9						
UV_{254} Filtered (cm^{-1})			12	0.40	0.72	4	0.13	0.14												
UV_{254} Unfiltered (cm^{-1})			5	0.39	0.45	4	0.43	0.79												
Metals and metalloids (mg/L)																				
Aluminium - Soluble	0.2 [a]		48	0.12	**0.80**	12	**0.28**	**1.24**				6	**5.90**	**8.84**				4	0.02	0.03
Aluminium - Total		20	46	0.89	5.83	12	1.62	11.3												
Antimony - Soluble			6		<0.01	4	0.001	0.002												
Antimony - Total	0.003 [b]		5	0.001	0.002	4	0.001	0.001										3	0.001	0.001
Arsenic - Soluble			34	0.001	0.006	9	0.001	0.004												
Arsenic – Total	0.01 [b]	2	74	0.001	0.006	12	0.001	0.003	51	0.002	0.004	35	0.002	0.004	34	0.004	0.007	14	0.001	**0.014**
Barium - Soluble						4	0.04	0.05												
Barium - Total	2 [b]		6	0.03	0.04	4	0.04	0.06										3	0.05	0.06
Beryllium - Soluble						4		<0.0005												
Beryllium - Total	0.06 [b]	0.5	5		<0.0005	4		<0.0005										3	0.001	0.001
Boron - Soluble	4 [b]	0.5 [e]	45	0.04	0.14	12	0.05	0.07										4	0.14	0.16
Cadmium - Soluble			7		<0.0001	4		<0.0005												

	Guidelines		Parafield			Cobbler Creek			Greenfields			Kaurna Park			Paddocks			Unity Park		
	DWG	STV	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile
Cadmium - Total	0.002 [b]	0.05	63	0.0002	0.002	12		<0.0005				3	0.0002	0.0002				13	0.001	0.001
Chromium - Soluble			6		<0.05	4	<0.003	0.004												
Chromium (VI) – Soluble	0.05 [b]	1	7		<0.03													2	0.010	0.010
Chromium - Total	0.05 as Cr (VI) [b]		46	0.003	0.009	12	0.003	0.015	8	0.010	0.069	3	0.008	0.008	3	0.028	0.028	4	0.003	0.005
Cobalt - Soluble			6		<0.05	4	<0.0005	0.0005												
Cobalt - Total		0.1	5	0.001	0.001	4	<0.0005	0.0009										4	0.001	0.002
Copper - Soluble			9	0.003	0.005	4	0.002	0.006												
Copper - Total	1 [a] (2 [b])	5	72	0.007	0.029	12	0.004	0.016	51	0.03	0.07	35	0.03	0.04	34	0.03	0.05	14	0.003	0.007
Iron - Soluble			50	0.113	**0.351**	12	0.27	**0.88**												
Iron - Total	0.3 [a]	10	72	**0.634**	**4.63**	12	**1.77**	**11**	51	**0.77**	**3.68**	35	**2.48**	**7.0**	34	**0.81**	**3.49**	14	**0.57**	**1.0**
Lead - Soluble			9	<0.0005	0.0007	4	<0.0005	0.0016												
Lead - Total	0.01 [b]	5	77	0.004	**0.028**	12	0.004	**0.02**	51	0.003	**0.025**	35	**0.012**	**0.022**	34	0.005	**0.024**	14	0.002	0.005
Lithium – Soluble						4	0.004	0.005												
Lithium - Total		2.5	6	0.002	0.003	4	0.004	0.006										4	0.004	0.005
Manganese - Soluble			34	0.012	0.053	4	0.01	0.04												
Manganese - Total	0.1 [a] (0.5 [b])	10	74	0.038	**0.225**	**12**	0.053	**0.22**	51	0.04	**0.26**	35	0.05	**0.14**	33	0.04	**0.16**	13	0.01	0.03
Mercury - Soluble						4		<0.0003												
Mercury - Total	0.001 [b]	0.002	39		<0.0005	12	<0.00003	0.0001										4	0.0004	0.0005
Molybdenum - Soluble			6		<0.05	4	<0.0005	0.0005												
Molybdenum - Total	0.05 [b]	0.05	6	0.001	0.004	4	<0.0006	0.0006										4	0.001	0.002
Nickel - Soluble			6		<0.05	4	<0.0005	0.0009												
Nickel – Total	0.02 [b]	2	46	0.002	0.001	12	0.002	0.007										4	0.002	0.002
Selenium - Soluble			6		<0.05	4	<0.003	0.007												
Selenium - Total	0.01 [b]	0.05	5		<0.003	4	<0.003	0.007										4	0.003	0.003
Silver - Soluble						4	<0.0002	0.0006												

	Guidelines		Parafield			Cobbler Creek			Greenfields			Kaurna Park			Paddocks			Unity Park		
	DWG	STV	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile
Silver - Total	0.1 [b]		5		<0.0002	4		<0.0002										1	0.002	0.002
Thallium - Soluble						4		<0.0005												
Thallium - Total			5		<0.0001	4		<0.0005										4	0.005	0.005
Vanadium - Total		0.5	6		0.004	4	0.004	0.006										4	0.003	0.003
Zinc - Soluble			3	0.04	0.05	4	0.004	0.01												
Zinc - Total	3 [a]	5	83	0.085	0.269	12	0.02	0.08	51	0.04	0.20	35	0.06	0.13	34	0.03	0.10	14	0.02	0.04
Sterols (ng/L)																				
24-ethylcholestanol			26	272	1265	10	308	995												
24-ethylcholesterol			26	3310	10775	10	3225	8462												
24-ethylcoprostanol			26	80	152	10	66	485												
24-ethylepicoprostanol			26	55	151	10		<200												
Cholestanol			26	123	491	10	164	3026												
Cholesterol			25	1700	3816	10	1450	2909												
Coprostanol			25	57	426	10	80	400												
Epicholestanol			25	50	139	9	<133	215												
Epicoprostanol			25	50	186	9		<200												
Trihalomethanes Formation Potential (FP) (µg/L)																				
Bromoform FP			4		<1	4	<1	4										4	1	1
Chloroform FP			4	251	319	4	85	91										4	1	1
Dibromochloroform FP			4	3	6	4	19	40												
Dichlorobromoform FP			4	35	52	4	53	75												
Total Trihalomethanes FP			4	277	371	4	162	196										4	4	4
Radiological (Bq/L)																				
Gross Alpha Activity	0.5 [s]		7	<0.005	0.23	1		<0.005												
Gross Beta Activity	0.5 [s]		7	<0.010	0.32	1		<0.010												
Other (mg/L)																				
Biochemical Oxygen Demand			24	5	21													13	2	3

	Guidelines		Parafield			Cobbler Creek			Greenfields			Kaurna Park			Paddocks			Unity Park		
	DWG	STV	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile
Biochemical Oxygen Demand - Soluble			8	3	4															
Chemical Oxygen Demand			8	76	95															
Chemical Oxygen Demand - Soluble			8	55	66															
OP & Triazine Pesticides (μg/L)																				
Atrazine	20 [b]		49	<0.05	0.70	12		<0.05	48	0.6	1.4	31	0.5	0.5	30	0.5	0.6	14	0.5	0.5
Azinphos-methyl	30 [b]		49	<0.1	0.73	12		<0.5	48	0.5	0.6	31	0.5	0.5	30	0.5	0.5	14	0.5	0.5
Diazinon	4 [b]		48		<0.5	12		<0.5	48	0.5	0.5	30	0.5	0.5	30	0.5	0.5	14	0.5	0.5
Fenitrothion	7 [b]		47		<0.5	12		<0.5	48	0.5	0.5	31	0.5	0.5	30	0.5	0.5	14	0.5	0.5
Hexazinone	400 [b]		48		<0.5	12		<0.5	48	0.5	0.5	31	0.5	0.5	30	0.5	0.5	14	0.5	0.5
Malathion	70 [b]		41		<0.5	12		<0.5	48	0.5	0.5	31	0.5	0.5	30	0.5	0.5	14	0.5	0.5
Parathion	20 [b]		48		<0.5	12		<0.5	48	0.5	0.5	31	0.5	0.5	30	0.5	0.5	14	0.5	0.5
Parathion methyl	0.7 [b]		48		<0.3	12		<0.3	48	0.3	0.3	31	0.3	0.3	30	0.3	0.3	14	0.3	0.3
Prometryne			41		<0.5	12		<0.5	48	0.5	0.5	31	0.5	0.5	30	0.5	0.5	14	0.5	0.5
Simazine	20 [b]		50	<0.05	.693	12	<0.05	0.13	48	0.9	**43.4**	31	1.1	11.8	30	0.7	4.4	14	0.5	0.9
Other organic scans with detections (μg/L)																				
Phenanthrene						4	<0.1	0.1										4	0.50	0.50
2,4-D	30 [b]		6	<0.1	0.05													4	0.50	0.50
Chlorpyrifos			7	<0.1					37	0.05	0.05	19	0.05	0.05	14	0.05	0.05	14	0.05	0.05
Dicamba			5	0.15	0.24													4	0.50	0.50
Diuron	20 [b]		5	0.21	0.37															
Heptachlor	0.3 [b]								52	0.05	0.05	35	0.05	0.05	34	0.05	0.05	14	0.05	0.05
Linuron																				
Metolachlor	300 [b]		5		<0.1															
Mecoprop			5		<0.1															
MCPA	40 [b]		5	0.35	1.10													4	0.50	0.50
Triclopyr	20 [b]		5	0.02	0.06													4	0.50	0.50
Dalapon			5	0.03	0.03															

	Guidelines		Parafield			Cobbler Creek			Greenfields			Kaurna Park			Paddocks			Unity Park		
	DWG	STV	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile
Desethyl Atrazine			5	0.05	0.06															
Desisopropyl Atrazine			5	0.02	0.50															
Terbutryn			5	<0.01	0.01															
Dichloromethane			5	<0.1	9.7															
Trichloroethene			5	<0.1	9.7															
1,2-Dichloroethane	3 [b]		5	<0.1	**120**															
3-& 4-Methylphenols			5	<0.1	0.44															
Pharmaceuticals (µg/L)																				
Acesulfame			4	<0.01	0.19															
Caffeine			4	0.53	0.83															
DEET			4	0.06	0.29															
Erythromycin			4	<0.01	0.03															
Paracetamol			4	0.10	0.28															
Salicylic acid			4	<0.01	0.04															
Detergent as MBAS (mg/L)			5	<0.05	0.25															

Parafield data compiled from CSIRO catchment site and in-stream basin inlet site sampling data (sites ISB1-2, PDS, PC1-4, BC1-2); Cobbler Creek data compiled from CSIRO catchment sampling site data only (sites CCk1 and CCk2); Greenfields, Kaurna Park, Paddocks and Unity Park data compiled from City of Salisbury wetland inlet sampling data.

Bold values exceed the Australian Drinking Water Guidelines (ADWG; NHMRC–NRMMC 2011, or Augmentation of Drinking Water Supplies Guidelines (AugDWSG; NRMMC–EPC–NHMRC 2008); underlined values exceed the short term irrigation guideline values (STV) from ANZECC-ARMCANZ (2000); a = aesthetic guidelines from ADWG; b = health guideline from ADWG; c = A value greater to that stated can cause foliar damage in sensitive crops; d = To avoid bioclogging in irrigation equipment; e = For very sensitive crops; sensitive 0.5-1, moderately sensitive 1-2. See ANZECC-ARMCANZ (2000) for a detailed tolerance of different crops to salinity in irrigation water; s = screening level to identify requirement for radionuclide analysis

Appendix 6 Wetland Outlet Water Quality Data

	Guidelines		Parafield			Greenfields			Kaurna Park			Paddocks			Unity Park		
	DWG	STV	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile
Field Readings																	
EC (µS/cm)			49	235	513												
Temperature (°C)			47	14.3	21.6							1	22	22			
pH (pH units)	6.5-8.5 [a]	6.5-8.5	46	6.8	8.1												
DO (mg/L)			45	3.6	7.2												
Eh (mV SHE)			44	338	438												
Physical Characteristics																	
EC (µS/cm)			110	228	377	68	1820	4820	67	207.5	493.5	59	187	890	15	1555	2416
pH (pH units)	6.5-8.5 [a]	6.5-8.5	111	7.0	7.6	69	8	**9.0**	67	7.5	8.3	59	7.4	8.5	15	8.5	**9.8**
Suspended Solids (mg/L)			110	4.0	16	69	5	30	69	8	124	58	10	67	16	10	62
Total Dissolved Solids (mg/L; by EC)	600 [a]		109	125	200	67	**1000**	**2655**	66	110	271	57	100	530	15	**860**	**1330**
Turbidity (NTU)	5 [a]		108	3.6	**13**	34	**5**	**27**	34	**9.1**	**29**	27	**6**	**28**	15	**7**	**31**
True Colour (HU)	15 [a]		66	**26**	**82**												
Particle size - d_{10}			20	5	12												
Particle size - d_{50}			20	23	103												
Particle size - d_{90}			19	84	662												
Major Ions (mg/L)																	
Alkalinity as $CaCO_3$			84	59	118	27	129	202	23	63	94	14	55	92	14	193	300
Bicarbonate			90	72	144	27	153	247	23	75	114	12	67	117	14	236	366
Bromide			56	0.09	0.40												
Sulphate	250 [a] (500 [b])		88	9.6	21.8	27	113	229	28	10	19	18	5.1	21	14	98	245
Chloride	250 [a]		92	28	54	27	**356**	**739**	28	19	50	14	14	22	13	**364**	**504**
Fluoride	1.5 [b]		90	0.15	0.36	27	0.32	0.44	23	0.15	0.26	14	0.10	0.14	14	0.43	0.69
Calcium			91	19	36	27	38	55	29	19	34	14	14	29	14	34	63

	Guidelines		Parafield			Greenfields			Kaurna Park			Paddocks			Unity Park		
	DWG	STV	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile
Magnesium			91	4.4	8.8	27	26	47	28	4	8	14	4	7	14	39	52
Potassium			90	3.1	6.5	27	7	13	23	3	9	14	4	8	14	7	18
Sodium	180 [a]	115 [c]	90	18	45	27	**237**	**527**	23	19	26	14	14	20	14	**239**	**397**
Microbiological (cfu/100 mL)																	
Colony Count (20˚C) Aerobic			37	7,600	160,000												
Coliforms - Presumptive			36	1,700	25,000												
Coliforms			37	2,000	24,000	14	2,850	35,100	18	3,700	37,400	12	4,800	89,500	12	6,400	42,150
E. coli/F Coliforms - Presumptive			80	35	549												
Faecal coliforms	0 [b]		69	**35**	**554**												
E. coli	0 [b]		108	**33**	**588**	64	**33**	**656**	60	**45.5**	**1,898**	55	**120**	**11,300**	13	**29**	**4,280**
Ent/F.Strep - Presumptive			64	16	350												
Enterococci	0 [b]		66	**16**	**340**	23	**48**	**1,608**	18	**36**	**700**	17	**77**	**2,875**	6	**149**	**728**
Faecal Streptococci	0 [b]		53	**15**	**250**	8	**39**	**88**	6	**82**	**3,673**	7	**190**	**3,990**	6	**149**	**728**
Sulphite reducing Clostridia			3	100	320												
Clostridium - presumptive			4	220	590												
Clostridium perfringens			3	10	19												
Campylobacter (cfu/L)	0 [b]		16	**93**	**716**												
Cryptosporidium – confirmed (oocytes/10 L)			14		<2												
Giardia – confirmed (oocytes /10 L)			14		<3												
Bacteriophage (/10 mL)			17	3	181												
Rotovirus (PDU/L)			2		ND												
Adenovirus (gene copies/L)			12	<10	275												
Nutrients (mg/L)																	
Nitrate + Nitrite as N	11.3 [b] (NO_3-N)		101	<0.005	0.03	65	0	0.17	65	0.005	0.32	50	0.01	0.17	15	0.03	0.28

	Guidelines		Parafield			Greenfields			Kaurna Park			Paddocks			Unity Park		
	DWG	STV	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile
Ammonia as N	0.4 [a]		98	0.01	0.09	31	0	**0.54**	29	0.02	0.20	20	0.02	0.27	15	0.03	**2.2**
TKN			103	0.35	0.86	65	1	1.4	64	0.57	5.8	49	0.86	3.5	15	0.89	5.9
Total Nitrogen		25	96	0.36	0.86	30	1	1.1	31	0.45	1.3	19	0.53	1.3	13	0.97	6.5
Filterable Reactive P			69	0.01	0.04	31	0	0.02	28	0.012	0.17	28	0.03	0.11			
Total Phosphorus		0.8 (0.05 LTV [d])	101	0.04	0.10	66	0	0.125	63	0.07	0.59	50	0.10	0.39	15	0.39	<u>1.3</u>
Biodegradable Dissolved Organic Carbon			22	2.1	5.0												
Dissolved Organic Carbon			69	4.7	11												
Total Organic Carbon			107	5.2	13	36	8	15	37	6.5	17	29	9.0	17	15	9.9	24
Silica	80 [a]		24	3	7				5	2	8						
UV_{254} Filtered (cm^{-1})			49	0.19	0.46												
UV_{254} Unfiltered (cm^{-1})			18	0.18	0.26												
Metals and metalloids (mg/L)																	
Aluminium - Soluble	0.2 [a]		48	<0.01	0.07	21	0	0.02	22	0.11	**1.12**	13	0.06	0.08	4	<0.01	**0.21**
Aluminium - Total		20	68	0.08	0.76												
Antimony - Soluble																	
Antimony - Total	0.003 [b]		20	<0.005	0.002	7	0	0.001	3	0.0005	0.001	3	0.001	0.001	4	0.001	0.001
Arsenic - Soluble			59	0.0005	0.003												
Arsenic – Total	0.01 [b]	2	108	<0.001	0.006	65	0.003	**0.011**	65	0.002	0.010	59	0.002	**0.025**	14	0.005	**0.014**
Barium - Soluble			6	0.017	0.020												
Barium - Total	2 [b]		38	0.017	0.024	7	0.034	0.075	3	0.018	0.024	3	0.016	0.022	4	0.059	0.069
Beryllium - Total	0.06 [b]	0.5	5		<0.005	12	0.0005	0.0005	7	0.0005	0.0005	5	0.0005	0.0005	4	0.0005	0.0005
Boron - Soluble	4 [b]	0.5 [e]	56	0.05	0.08												
Cadmium - Total	0.002 [b]	0.05	103		<0.0001	37	0.0005	0.0005	36	0.0005	**0.005**	29	0.0005	0.0008	14	0.0005	0.0008
Chromium (VI) – Soluble	0.05 [b]	1				7	<0.01	0.01	5	<0.01	0.01				2	<0.01	0.01
Chromium - Total	0.05 as Cr(VI) [b]		76	<0.003	0.005	12	<0.003	0.041	9	0.004	0.0116	6	0.015	0.012	4	0.003	0.009
Cobalt - Total		0.1	20	<0.0005	<0.0005	7	0.0006	0.0009	3	0.0005	0.0023	3	0.0009	0.0009	4	0.0008	0.0008

	Guidelines		Parafield			Greenfields			Kaurna Park			Paddocks			Unity Park		
	DWG	STV	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile
Copper - Soluble			6	0.002	0.003												
Copper - Total	1 [a] (2 [b])	5	86	0.002	0.006	68	0.003	0.03	65	0.004	0.05	59	0.003	0.04	14	0.003	0.007
Iron - Soluble			63	0.13	**0.49**												
Iron - Total	0.3 [a]	10	110	**0.45**	**1.3**	68	**0.49**	**1.2**	67	**0.98**	**3.6**	59	**0.70**	**4.7**	14	0.29	**0.59**
Lead - Total	0.01 [b]	5	108	<0.001	0.005	68	0.001	0.004	65	0.003	0.01	60	0.004	**0.02**	14	0.002	0.003
Lithium – Soluble			6	0.002	0.002												
Lithium - Total		2.5	33	0.002	0.002	7	0.001	0.008	3	0.002	0.003	4	0.002	0.01	4	0.02	0.02
Manganese - Soluble			48	0.02	0.15												
Manganese - Total	0.1 [a] (0.5 [b])	10	106	0.04	**0.21**	68	0.061	**0.40**	66	0.028	**0.18**	56	0.040	**0.49**	14	0.015	**0.11**
Mercury - Soluble			6		<0.0003												
Mercury - Total	0.001 [b]	0.002	51		<0.0003	15	0.0003	0.0005	11	0.0004	0.0005	8	<0.0003	0.0005	4	0.0003	0.0003
Molybdenum - Soluble			6	0.001	0.004												
Molybdenum - Total	0.05 [b]	0.05	35	0.001	0.003	12	0.002	0.004	8	0.001	0.002	5	0.001	0.002	4	0.002	0.002
Nickel – Total	0.02 [b]	2	75	0.001	0.003	7	0.002	0.004	3	0.002	0.003	3	0.002	0.003	4	0.003	0.003
Selenium - Total	0.01 [b]	0.05	22	<0.003	<0.003	12	<0.003	0.003	8	0.003	0.003	5	0.003	0.003	4	0.003	0.003
Silver - Total	0.1 [b]					9	0.002	0.002	7	0.002	0.002				2	0.002	0.002
Thallium - Total						7	0.0005	0.0005	3	0.0005	0.0005	3	0.0005	0.0005	4	0.0005	0.0005
Vanadium - Total		0.5				7	0.005	0.03	1	0.004	0.005	3	0.006	0.006	4	0.008	0.012
Zinc - Total	3 [a]	5	108	0.02	0.2	68	0.016	0.11	65	0.030	**0.14**	59	0.038	**0.13**	14	0.015	0.023
Sterols (ng/L)																	
24-ethylcholestanol			20	268	1080												
24-ethylcholesterol			20	1960	6151												
24-ethylcoprostanol			20	151	601												
24-ethylepicoprostanol			20	<40	430												
Cholestanol			19	135	308												
Cholesterol			20	961	1918												
Coprostanol			20	53	236												
Trihalomethanes Formation Potential (FP) (mg/L)																	

	Guidelines		Parafield			Greenfields			Kaurna Park			Paddocks			Unity Park		
	DWG	STV	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile
Bromoform FP			15	<0.5	3	6	1	1	3	1	1	1	1	1	1	1	1
Chloroform FP			15	120	218	6	1	1	3	1	1	1	1	1	1	1	1
Dibromochloroform FP			15	4	36												
Dichlorobromoform FP			15	29	69												
Total Trihalomethanes FP			15	152	295												
Other (mg/L)																	
Biochemical Oxygen Demand			24	<2	4												
Biochemical Oxygen Demand - Soluble			24	<2	2	34	5	13	36	2	7.2	27	2	9	13	3	21
Chemical Oxygen Demand			24	41	111												
Chemical Oxygen Demand - Soluble			24	32	70												
OP & Triazine Pesticides (mg/L)																	
Atrazine	20 [b]		54	<0.05	0.25	63	0.5	0.75	61	0.5	0.74	42	0.5	0.8	12	0.5	0.5
Azinphos-methyl	30 [b]		53		<0.5	63	0.5	0.5	61	0.5	0.5	42	0.5	0.5	12	0.5	0.5
Diazinon	4 [b]		49		<0.5	62	0.5	0.5	61	0.5	0.5	42	0.5	0.5	12	0.5	0.5
Fenitrothion	7 [b]		49		<0.5	63	0.5	0.5	61	0.5	0.5	42	0.5	0.5	12	0.5	0.5
Hexazinone	400 [b]		54		<0.5	63	0.5	0.5	61	0.5	0.5	42	0.5	0.5	12	0.5	0.5
Malathion	70 [b]		50		<0.5	63	0.5	0.5	61	0.5	0.5	42	0.5	0.6	12	0.5	0.5
Parathion	20 [b]		54		<0.5	63	0.5	0.5	61	0.5	0.5	42	0.5	0.5	12	0.5	0.5
Parathion methyl	0.7 [b]		54		<0.3	63	0.3	0.3	61	0.3	0.3	42	0.3	0.3	12	0.3	0.3
Prometryne			52		<0.5	63	0.5	0.5	61	0.5	0.5	41	0.5	0.5	12	0.5	0.5
Simazine	20 [b]		55	<0.05	0.32	63	0.51	4.1	61	1.2	10.2	41	0.5	0.5	12	0.5	0.5
Other organic scans with detections (mg/L)																	
Phenanthrene						4	0.5	0.5	3	0.5	0.5	1	0.5	0.5	1	0.5	0.5
2,4-D	30 [b]					15	0.5	0.5	13	0.5	0.5	6	0.5	0.5	5	0.5	0.5
Chlorpyrifos						52	0.05	0.05	53	0.05	0.05	32	0.1	0.1	12	0.1	0.1

	Guidelines		Parafield			Greenfields			Kaurna Park			Paddocks			Unity Park		
	DWG	STV	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile
Dicamba						15	0.5	0.5	13	0.5	0.5	6	0.5	0.5	5	0.5	0.5
Heptachlor	0.3 [b]					67	0.05	0.05	66	0.05	0.05	45	0.1	0.1	12	0.1	0.1
Metolachlor	300 [b]		25	0.004	0.03												
MCPA	40 [b]					15	0.5	0.5	13	0.5	0.5	5	0.5	0.5	5	0.5	0.5
Triclopyr	20 [b]					15	0.5	0.5	13	0.5	0.5	5	0.5	0.5	5	0.5	0.5
Pharmaceuticals (µg/L)																	
Caffeine			7	0.07	0.25												
DEET			8	0.12	0.14												
Detergent as MBAS (mg/L)			13	<0.05	0.10												

Parafield data compiled from CSIRO wetland outlet sampling data (WE2); Greenfields, Kaurna Park, Paddocks and Unity Park data compiled from City of Salisbury wetland outlet sampling data. **Bold** values exceed the Australian Drinking Water Guidelines (ADWG; NHMRC–NRMMC 2011, or Augmentation of Drinking Water Supplies Guidelines (AugDWSG; NRMMC–EPC–NHMRC 2008); <u>underlined</u> values exceed the short term irrigation guideline values (STV) from ANZECC-ARMCANZ (2000); a = aesthetic guidelines from ADWG; b = health guideline from ADWG; c = A value greater to that stated can cause foliar damage in sensitive crops; d = To avoid bioclogging in irrigation equipment; e = For very sensitive crops; sensitive 0.5-1, moderately sensitive 1-2. See ANZECC-ARMCANZ (2000) for a detailed tolerance of different crops to salinity in irrigation water; s = screening level to identify requirement for radionuclide analysis

Appendix 7 Ambient Groundwater Quality Data and Aquifer Mineralogy

T2 aquifer ambient groundwater quality

	Guidelines		ASTR – RW 1 & 2 & IW3			Parafield ASR (n=1)	Kaurna Park (n=1)	Unity Park (n=1)
	DWG	STV	n	Median	Max	23/04/2003	18/08/1997	6/12/2001
Field Readings								
EC (mS/cm)			4	3640	3650			
Temperature (°C)			4	24.9	25.2			
pH (pH units)	6.5-8.5 [a]	6.5-8.5	4	6.9	7.2			
DO (mg/L)			1	0.03	0.03			
Eh (mV SHE)			4	119	137			
Physical Characteristics (mg/L)								
EC (mS/cm)			3	3630	3650	3640	4490	3080
pH (pH units)			3	7.2	7.2	8.6	7.2	7.3
Suspended Solids			3	3	3	6		72
Total Dissolved Solids (by EC)	600 [a]		3	**2020**	**2030**		**2500**	**1700**
Turbidity (NTU)	5[a]		3	**27**	**27**	**8.6**		**19**
True Colour (HU)	15 [a]		3	**42**	**42**			
Major Ions (mg/L)								
Alkalinity as $CaCO_3$			3	265	266	353	343	397
Bicarbonate			3	323	324	431	419	484
Bromide			3	3.3	3.32			
Sulphate	250 [a] (500 [b])		3	**273**	**281**	**317**	**344**	**337**
Chloride	250 [a]		3	**922**	**926**	**780**	**1120**	**618**
Fluoride	1.5 [b]		3	0.43	0.44	0.60	0.25	0.83
Calcium			3	136	140	82.9	138	78.7
Magnesium			3	82.5	82.9	59.6	101	58.1
Potassium			3	13.2	13.5	15.5	13.4	15.4
Sodium	180 [a]	115 [c]	3	**504**	**504**	**616**	**645**	**512**
Microbiological (cfu/100 mL)								
Colony Count (20°C) Aerobic			3	2700	2700			
Coliforms - presumptive			3	ND	2			
Coliforms			3	ND	14			
E. coli/F Coliforms - presumptive			3		ND			
Faecal coliforms	0 [b]		3		ND			
E. coli	0 [b]		3		ND	ND		
Ent/F.Strep - presumptive			3		ND			
Enterococci	0 [b]		3		ND	ND		
Faecal Streptococci	0 [b]		3		ND			
Nutrients (mg/L)								
Nitrate + Nitrite as N	11.3 [b] (NO_3-N)		3	ND	<0.005	0.014	<0.005	<0.005
Ammonia as N	0.5 [a]		3	0.036	0.037	0.034	0.050	0.015
TKN			3	0.07	0.07	0.060	0.160	0.080
Total Nitrogen		25	3	0.07	0.07	0.070		
Filterable Reactive P			3	0.007	0.007		<0.005	
Total Phosphorus		0.8 (0.05 LTV [d])	3	0.017	0.02	0.03	0.1000	0.030
Dissolved Organic Carbon			3	1.3	1.6			
Total Organic Carbon			3	1.4	1.6	<1.0		0.8
UV_{254} Filtered (cm^{-1})			3	0.065	0.089			

	Guidelines		ASTR – RW 1 & 2 & IW1			Parafield ASR (n=1)	Kaurna Park (n=1)	Unity Park (n=1)
	DWG	STV	n	Median	Max	23/04/2003	18/08/1997	6/12/2001
Metals and metalloids (mg/L)								
Aluminium - Soluble	0.2 [a]					<0.020		0.010
Aluminium - Total		20	3	ND	<0.020			
Antimony - Total	0.003 [b]					<0.0005		
Arsenic - Soluble			3	0.01	**0.011**			
Arsenic – Total	0.01 [b]	2	3	**0.011**	**0.011**	0.01	0.002	**0.018**
Barium - Total	2 [b]					<0.0200		
Beryllium - Total	0.06 [b]	0.5				<0.0005		
Boron - Soluble	4 [b]	0.5 [e]				0.578	0.504	0.736
Cadmium - Total	0.002 [b]	0.05	3	ND	<0.0005	<0.0005	<0.0002	0.001
Chromium (VI) – Soluble	0.05 [b]	1	3	ND	<0.010			
Chromium - Total	0.05 as Cr (VI) [b]		3	ND	<0.003	0.005	<0.005	0.006
Cobalt - Total		0.1				<0.0005		0.024
Copper - Total	1 [a] (2 [b])	5				<0.0001	<0.005	2.060
Iron - Soluble			3	1.59	1.59			
Iron - Total	0.3 [a]	10	3	**1.52**	**1.61**	**0.728**	<0.005	0.002
Lead - Total	0.01 [b]	5	3	0.0005	0.0005	<0.0005	<0.001	
Lithium - Total		2.5				0.024		0.026
Manganese - Soluble			3	0.007	0.007			
Manganese - Total	0.1 [a] (0.5 [b])	10	3	0.007	0.007	0.036	0.074	<0.005
Mercury - Total	0.001 [b]	0.002				<0.0005	<0.0001	
Molybdenum - Total	0.05 [b]	0.05				0.0007		0.004
Nickel – Total	0.02 [b]	2	3	ND	<0.0005	0.0002	0.003	
Selenium - Total	0.01 [b]	0.05				0.004		
Thallium - Total						<0.0005		
Vanadium - Total		0.5				0.014		0.022
Zinc - Total	3 [a]	5	3	0.035	0.046	0.018	0.210	
Radiological (Bq/L)								
Gross Alpha Activity	0.5 [s]							
Gross Beta Activity	0.5 [s]							
OP & Triazine Pesticides (µg/L)								
Atrazine	20 [b]					<0.5	<1.20	<0.5
Azinphos-methyl	30 [b]					<0.8	<0.6	<0.05
Diazinon	4 [b]					<0.5	<0.60	<0.05
Fenitrothion	7 [b]					<0.05	<0.6	<0.05
Hexazinone	400 [b]					<0.5	<1.5	<0.05
Malathion	70 [b]					<0.05	<0.60	<0.05
Parathion	20 [b]					<0.5	<0.6	<0.3
Parathion methyl	0.7 [b]					<0.03	<0.6	<0.5
Prometryne						<0.5	<1.20	<0.5
Simazine	20 [b]					<0.5	<1.20	<0.10

Bold values exceed the Australian Drinking Water Guidelines (ADWG) (NHMRC–NRMMC, 2011) or the Augmentation of Drinking Water Supply Guidelines (NRMMC–EPHC–NHMRC, 2008); underlined values exceed the short term irrigation guideline values (STV) from ANZECC-ARMCANZ (2000); a = aesthetic guidelines from ADWG; b = health guideline from ADWG; c = A value greater to that stated can cause foliar damage in sensitive crops; d = To avoid bioclogging in irrigation equipment; e = For very sensitive crops; sensitive 0.5-1, moderately sensitive 1-2. See ANZECC-ARMCANZ (2000) for a detailed tolerance of different crops to salinity in irrigation water; s = screening level to identify requirement for radionuclide analysis.

Mineralogy of the T2 aquifer core samples (well number 6228-24539, permit number 149449) determined by X-Ray Diffraction

Depth (m bgs)	Sample ID	Quartz (%)	Calcite[1]	Aragonite	Ca-Dolomite/ Ankerite[2]	Hematite	Goethite	Pyrite	Albite	Microcline	Siderite[3]
163.9	1	4.1	91.8	1.5	2.3	0.4					
164.6	2	8.5	86.1	1.6	3.5	0.2					
166.5	4	8.7	82.8	1.7	6.6	0.3					
166.9	5	5.8	88.7	0.8	4.6	0.2					
171.0	11	58.1	35.0	0.4	0.9	0.7	2.2		0.7	1.9	
173.8	14	14.8	83.7	0.2	0.2	0.3				0.8	
176.3	18	49.4	43.6	0.9	0.6	0.5	1.1	0.7	1.1	2.2	
177.9	20	31.3	63.0	1.5	0.4	0.3	0.6	0.5	0.7	1.6	
179.6	22	39.3	55.6	0.6	0.6	0.4	0.8	0.4	0.9	1.6	
182.9	25	19.2	75.7	0.9	1.9	0.6	0.6		0.2	0.9	
185.7	27	63.3	26.3	2.9	0.9	0.3	1.7		1.5	2.1	0.8
189.3	29	51.2	43.0	0.4	0.3	0.4	1.9		1.0	1.9	
Min		4.3	26.3	0.2	0.2	0.2	0.6	0.4	0.2	0.8	0.8
Max		63.3	91.8	2.9	6.6	0.7	2.2	0.7	1.5	2.2	0.8
Mean		29.5	64.6	1.1	1.9	0.4	1.3	0.5	0.9	1.6	0.8

[1] Calcite is magnesium substituted
[2] Siderite is tentatively identified in sample 27 due to a single minor peak
[3] XRD search/match identified ankerite, however, Ca-substituted dolomite also has the same pattern
Note: The quantitative analysis results are normalised to 100% and hence do not include estimates of amorphous or unidentified phases. Samples 1 through 4 also show evidence of clays but confirmation is not possible without separating the clay fractions from the bulk samples.

Major elemental composition of the T2 aquifer core material (well number 6628-24539, permit number 149449) determined by X-Ray Fluorescence

Depth (m bgs)	Sample ID	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	Cl
		(%)	(ppm)										
163.9	1	5.04	0.01	0.48	1.37	0.01	1.74	46.30	0.00	0.23	0.02	0.19	151
164.6	2	10.82	0.03	0.64	2.04	0.01	1.93	43.09	0.00	0.43	0.02	0.19	156
166.5	4	10.46	0.03	0.69	2.19	0.01	2.56	42.00	0.00	0.45	0.02	0.17	150
166.9	5	6.37	0.01	0.34	1.21	0.00	1.89	46.34	0.00	0.18	0.02	0.14	138
171.0	11	53.54	0.06	1.15	3.45	0.00	0.86	19.58	0.07	0.37	0.03	0.06	97
173.8	14	16.68	0.04	0.56	1.06	0.03	1.08	42.04	0.00	0.17	0.01	0.09	135
176.3	18	45.73	0.08	1.15	2.32	0.01	0.99	24.17	0.11	0.40	0.02	1.20	121
177.9	20	27.15	0.08	1.01	1.87	0.01	1.35	34.16	0.09	0.32	0.02	0.97	142
179.6	22	34.39	0.07	0.94	1.86	0.01	1.07	30.52	0.06	0.30	0.01	0.76	120
182.9	25	18.86	0.04	0.70	1.92	0.02	1.49	38.92	0.01	0.32	0.02	0.14	137
185.7	27	58.92	0.16	1.72	3.38	0.01	1.31	15.92	0.18	0.47	0.02	0.31	130
189.3	29	45.58	0.05	1.15	2.70	0.03	0.68	24.81	0.07	0.38	0.02	0.08	88
	Min	5.04	0.01	0.34	1.06	0.00	0.68	15.92	0.00	0.17	0.01	0.06	88
	Max	58.92	0.16	1.72	3.45	0.03	2.56	46.34	0.18	0.47	0.03	1.20	156
	Mean	27.79	0.05	0.88	2.11	0.01	1.41	33.99	0.05	0.34	0.02	0.36	130

Trace elemental composition of the T2 aquifer core material (well number 6628-24539, permit number 149449) determined by X-Ray Fluorescence

Depth (m bgs)	Sample ID	As	Ba	Br	Ce	Co	Cr	Cs	Cu	Ga	I	La	Mo	Nb	Nd	Ni	Rb	Sr	Ta	Th	Tl	U	V	Y	Zn	Zr
		(ppm)																								
163.9	1	6	21	<1	<20	<5	34	<11	<1	<1	<8	<18	<1	2	<11	<2	16	702	<7	6	4	5	17	2	4	19
164.6	2	13	21	2	<20	5	63	13	11	<1	10	<18	<1	2	<11	<2	20	651	<7	6	4	7	35	3	6	40
166.5	4	10	20	2	21	<5	51	<11	11	<1	<8	<18	<1	3	<11	<2	21	669	7	7	4	4	28	3	4	39
166.9	5	8	18	<1	23	<5	41	15	<1	<1	<8	<18	<1	1	<11	<2	11	542	8	5	4	6	10	2	<2	23
171.0	11	144	28	<1	<20	<5	87	<11	<1	<1	<8	<18	<1	4	<11	5	13	189	<7	7	3	<2	160	4	5	63
173.8	14	18	22	<1	23	<5	51	<11	<1	2	<8	<18	<1	2	<11	<2	9	227	<7	5	5	3	84	3	3	62
176.3	18	142	21	5	21	<5	78	<11	<1	<1	<8	<18	2	4	16	15	13	315	<7	5	3	3	142	6	4	81
177.9	20	86	20	3	<20	<5	72	<11	<1	<1	12	<18	<1	3	<11	<2	12	473	<7	5	5	4	104	5	3	73
179.6	22	60	<13	4	<20	5	119	12	<1	<1	<8	<18	<1	3	<11	5	12	256	8	7	8	<2	119	4	6	57
182.9	25	19	24	<1	<20	7	128	<11	<1	<1	<8	<18	<1	3	<11	<2	15	413	<7	7	8	5	63	3	4	44
185.7	27	52	42	2	<20	<5	101	<11	<1	<1	<8	18	<1	5	<11	11	19	498	<7	7	5	6	189	5	13	109
189.3	29	58	30	<1	<20	<5	104	<11	<1	<1	<8	<18	<1	2	<11	6	12	123	<7	<4	6	3	165	2	7	30

Additional trace elements that were below that X-Ray Fluorescence detection limit

Depth (m bgs)	Sample ID	Ag (ppm)	Bi	Cd	Ge	Hf	Hg	Pb	Sb	Sc	Se	Sm	Sn	Te	Yb
163.9	1	<4	<3	<4	<1	<8	<13	<3	<8	<7	<2	<12	<3	<7	<10
164.6	2	<4	<3	<4	<1	<8	<13	<3	<8	<7	<2	<12	<3	<7	<10
166.5	4	<4	<3	<4	<1	<8	<13	<3	<8	<7	<2	<12	<3	<7	<10
166.9	5	<4	<3	<4	<1	<8	<13	<3	<8	<7	<2	<12	<3	<7	<10
171.0	11	<4	<3	<4	<1	<8	<13	<3	<8	<7	<2	<12	<3	<7	<10
173.8	14	<4	<3	<4	<1	<8	<13	<3	<8	<7	<2	<12	<3	<7	<10
176.3	18	<4	<3	<4	<1	<8	<13	<3	<8	<7	<2	<12	<3	<7	<10
177.9	20	<4	<3	<4	<1	<8	<13	<3	<8	<7	<2	<12	<3	<7	<10
179.6	22	<4	<3	<4	<1	<8	<13	<3	<8	<7	<2	<12	<3	<7	<10
182.9	25	<4	<3	<4	<1	<8	<13	<3	<8	<7	<2	<12	<3	<7	<10
185.7	27	<4	<3	<4	<1	<8	<13	<3	<8	<7	<2	<12	<3	<7	<10
189.3	29	<4	<3	<4	<1	<8	<13	<3	<8	<7	<2	<12	<3	<7	<10

Physio-chemical characteristics of the T2 aquifer core material (well number 6628-24539, permit number 149449)

Depth (m bgs)	Sample ID	EC	Cl	pH	pH	TC	Org C	TN	NH_4	NO_3	CO_3 as $CaCO_3$	Exchangeable cations					CEC
		1:5 soil:water			0.01 M $CaCl_2$				KCl extracts			Ca	Mg	N	K	Total	
		dS/m	mg/kg			(%)	(%)	(%)	mg/kg	mg/kg	(%)						
163.9	1	0.18	24	9.0	7.9	10.9	<0.5	<0.01	<0.5	<0.5	92	1.4	0.87	0.18	0.09	2.5	2.3
164.6	2	0.29	37	8.8	7.9	10.2	<0.5	<0.01	<0.5	<0.5	85	2.3	1.3	0.25	0.18	4.0	2.9
166.5	4	0.20	30	9.0	7.9	10.0	<0.5	<0.01	<0.5	<0.5	86	2.0	1.4	0.23	0.19	3.9	3.6
166.9	5	0.19	14	9.0	7.9	10.8	<0.5	<0.01	<0.5	<0.5	92	1.3	0.70	0.15	0.09	2.3	1.6
171.0	11	0.10	18	9.0	7.9	4.4	<0.5	<0.01	<0.5	<0.5	37	1.2	0.25	0.13	0.20	1.8	1.5
173.8	14	0.09	14	9.3	8.0	8.8	<0.5	<0.01	<0.5	0.5	74	0.88	0.21	0.13	0.03	1.3	0.8
176.3	18	0.77	165	8.4	7.8	5.5	<0.5	<0.01	<0.5	<0.5	46	1.8	0.46	0.08	0.04	2.4	1.3
177.9	20	0.54	79	8.5	7.9	8.0	<0.5	<0.01	<0.5	0.5	63	1.7	0.47	0.10	0.01	2.3	1.3
179.6	22	0.62	104	8.4	7.9	7.2	<0.5	<0.01	<0.5	0.6	58	3.0	0.53	0.07	0.01	3.6	0.9
182.9	25	0.20	24	9.0	8.0	9.3	<0.5	<0.01	<0.5	<0.5	78	1.2	0.63	0.16	0.06	2.1	2.0
185.7	27	0.26	27	8.7	7.9	3.9	<0.5	<0.01	0.6	<0.5	31	1.6	0.52	0.11	0.02	2.2	2.4
189.3	29	0.10	15	9.1	8.0	5.7	<0.5	<0.01	<0.5	0.6	47	1.1	0.16	0.10	0.01	1.3	0.9

Elemental composition of the T2 aquifer core material (well number 6628-24539, permit number 149449) determined by ICP-OES or ICP-MS following reverse aqua regia digestion

Depth (m bgs)	Sample ID	Al	As	B	Ba	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Mo	Ni	P	Pb	S	Zn
		(ppm)																	
163.9	1	1942	3.68	21.1	6.6	0.02	4.29	20.0	1.6	8636	1787	9581	183	0.08	2.6	74.5	1.48	2217	3.6
164.6	2	2750	11.1	49.6	6.8	0.04	4.25	44.8	1.6	14548	3700	11599	144	0.10	7.4	82.4	1.92	2116	10.3
166.5	4	2972	4.96	49.3	7.4	0.02	2.49	43.9	1.6	15321	3794	15517	127	0.10	4.4	92.0	1.76	2006	4.8
166.9	5	1565	4.80	15.0	5.2	0.06	1.41	17.9	2.4	8485	1381	11384	113	0.10	5.7	73.8	1.12	2042	4.2
171.0	11	2953	102	11.5	5.0	0.06	2.28	44.7	1.2	24403	654	5119	109	0.90	9.5	141	1.92	832	11.3
173.8	14	1728	17.2	4.41	4.4	0.02	3.99	28.2	1.6	8785	<20	5883	282	0.42	4.1	48.2	1.32	1567	6.0
176.3	18	2227	108	8.07	5.2	0.06	3.09	43.3	1.2	15706	450	5904	165	2.30	16.0	77.0	1.64	5445	4.8
177.9	20	2363	80.7	10.0	7.4	0.04	1.85	40.5	1.6	12615	396	7554	177	1.86	9.2	52.7	1.60	4818	5.4
179.6	22	2040	44.1	7.03	5.4	0.02	4.16	38.5	1.6	12023	<20	6159	163	0.86	10.8	52.4	1.24	3684	14.8
182.9	25	2241	14.8	33.3	6.2	0.04	6.45	37.0	3.2	13039	2147	9425	202	0.22	31.3	69.3	1.48	1817	6.6
185.7	27	4328	42.4	20.4	8.4	0.04	2.47	64.4	2.4	22395	627	7299	170	0.76	14.2	82.9	2.72	1561	18.8
189.3	29	2672	53.2	8.82	3.6	0.02	3.74	49.4	2.0	19504	<20	4108	347	0.76	10.5	91.1	1.44	1146	11.3

T1 Aquifer Groundwater Quality

	Guidelines		Parafield Well# 20742	Paddocks (n=1)	Greenfields[2] (n=2)	
	DWG	STV	(n=2)	22/08/1994	Well 16624	Well 16625
Physical Characteristics						
EC (mS/cm)			4000 - 4050	340	3650	4100
pH (pH units)			7.4 - 8.5	7.3	7.7	7
Suspended Solids (mg/L)			8	5		7
Total Dissolved Solids (mg/L; by EC)	600 [a]		**2200***		**2029**	**2284**
Turbidity (NTU)	5			**13**		**27**
True Colour (HU)	15 [a]					
Major Ions (mg/L)						
Alkalinity as $CaCO_3$			233 - 256			
Bicarbonate			285 - 312	525		
Bromide						
Sulphate	250 [a] (500 [b])		237 - 254	230	**445**	**480**
Chloride	250 [a]		1070 - 1080		**715**	**840**
Fluoride	1.5 [b]		0.3			0.30
Calcium			173 - 189	86	110	180
Magnesium			112 - 125	68	62	71
Potassium			11.2 - 11.7	19	7.2	9.3
Sodium	180 [a]	115 [c]	489 - 513	**610**	**545**	**500**
Microbiological (cfu/100 mL)						
Coliforms						
E. coli/F Coliforms - presumptive						
Faecal coliforms	0 [b]					
E. coli	0 [b]		ND			
Ent/F.Strep - presumptive						
Enterococci	0 [b]		ND			
Nutrients (mg/L)						
Nitrate + Nitrite as N	11.3 [b] (NO_3-N)		<0.005 - 0.011	<0.2		0.11
Ammonia as N	0.5 [a]		0.022	<0.5		
TKN			0.06	0.05		0.10
Total Nitrogen		25	0.07			
Filterable Reactive P				<0.01		
Total Phosphorus		0.8 (0.05 LTV [d])	0.027	0.05		0.04
Total Organic Carbon			<1.0			
Silica	80 [a]		22			
Metals and metalloids (mg/L)						
Aluminium - Soluble	0.2 [a]		<0.020			
Antimony - Total	0.003 [b]		<0.0005			
Arsenic – Total	0.01 [b]	2	0.013	0.02	0.01	0.003
Barium - Total	2 [b]		0.052			
Beryllium - Total	0.06 [b]	0.5	<0.0005			
Boron - Soluble	4 [b]	0.5 [e]	0.125	<u>1.10</u>	<u>1.30</u>	0.220
Cadmium - Total	0.002 [b]	0.05	<0.0005	<0.05	0.005	0.010
Chromium - Total	0.05 as Cr (VI) [b]		0.004	<0.05	0.010	0.010
Cobalt - Total		0.1	<0.0005			
Copper - Total	1 [a] (2 [b])	5	<0.001	0.030	0.010	0.070
Iron - Total	0.3 [a]	10	1.9 - 2.5	0.5	**1.27**	0.220
Lead - Total	0.01 [b]	5	0.0007	<0.05	**0.160**	0.010
Lithium - Total		2.5	0.01			

	Guidelines DWG	STV	Parafield ASR[1] (n=2) well 20742	Paddocks (n=1) 22/08/1994	Greenfields[2] (n=2) Well 16624	Well 16625
Manganese - Total	0.1 [a] (0.5 [b])	10	0.0186	0.030	0.100	0.030
Mercury - Total	0.001 [b]	0.002	<0.0005			
Molybdenum - Total	0.05 [b]	0.05	0.0018			
Nickel – Total	0.02 [b]	2	0.002	<0.05	0.010	0.010
Selenium - Total	0.01 [b]	0.05	0.006			
Thallium - Total			<0.0005			
Vanadium - Total		0.5	0.011			
Zinc - Total	3	5	0.014	0.010	0.020	0.180
Radiological (Bq/L)						
Gross Alpha Activity	0.5 [s]					
Gross Beta Activity	0.5 [s]					
OP & Triazine Pesticides (mg/L)						
Atrazine	20 [b]		<0.5			
Azinphos-methyl	30 [b]		<0.5			
Diazinon	4 [b]		<0.5			
Fenitrothion	7 [b]		<0.5			
Hexazinone	400 [b]		<0.5			
Malathion	70 [b]		<0.01			
Parathion	20 [b]		<0.5			
Parathion methyl	0.7 [b]		<0.3			
Prometryne			<0.5			
Simazine	20 [b]		<0.5			

Bold values exceed the Australian Drinking Water Guidelines (ADWG) (NHMRC–NRMMC, 2011) or the Augmentation of Drinking Water Supply Guidelines (NRMMC–EPHC–NHMRC, 2008); underlined values exceed the short term irrigation guideline values (STV) from ANZECC-ARMCANZ (2000); a = aesthetic guidelines from ADWG; b = health guideline from ADWG; c = A value greater to that stated can cause foliar damage in sensitive crops; d = To avoid bioclogging in irrigation equipment; e = For very sensitive crops; sensitive 0.5-1, moderately sensitive 1-2. See ANZECC-ARMCANZ (2000) for a detailed tolerance of different crops to salinity in irrigation water; s = screening level to identify requirement for radionuclide analysis.

[1]23/4/03 & 24/10/03; [2] not date specified, estimate 1997.

Appendix 8 Parafield ASR and ASTR Groundwater Quality Data

	Guidelines		ASR 1 & 2			ASTR – RW 1 & 2		
	DWG	STV	n	Median	95th %ile	n	Median	95th %ile
Field Readings								
EC (mS/cm)			5	646	801	18	546	616
Temperature (°C)			5	18	19	17	19	20
pH (pH units)	6.5-8.5 [a]	6.5-8.5	5	7.4	7.6	17	7.5	8.2
DO (mg/L)			4	0.1	3.9	15	0.1	1.4
Eh (mV SHE)			4	-129	-42	16	5	207
Physical Characteristics								
EC (mS/cm)			35	446	1290	17	539	631
pH (pH units)			35	7.8	8.0	19	7.8	7.9
Suspended Solids (mg/L)			34	5	103	17	<1	8
Total Dissolved Solids (mg/L; by EC)	600 [a]		29	240	**710**	17	300	344
Turbidity (NTU)	5 [a]		35	1.1	**16**	17	0.7	**5.9**
True Colour (HU)	15 [a]		35	1.1	**15.9**	19	**21**	**36**
Particle size - d_{10}			23	13	31	20	0.1	16
Particle size - d_{50}			4	3	7	20	0.2	178
Particle size - d_{90}			4	17	23	20	4.2	298
Major Ions (mg/L)								
Alkalinity as $CaCO_3$			15	145	201	19	157	213
Bicarbonate			22	165	228	19	192	260
Bromide			4	0.1	0.3	19	0.2	0.3
Sulphate	250 [a] (500 [b])		22	24	62	19	24	42
Chloride	250 [a]		22	35	146	19	63	84
Fluoride	1.5 [b]		22	0.28	0.41	19	0.3	0.6
Calcium			26	39	47	19	45	69

	Guidelines		ASR 1 & 2			ASTR – RW 1 & 2		
	DWG	STV	n	Median	95^{th} %ile	n	Median	95^{th} %ile
Magnesium			24	8.3	15.2	19	10	18
Potassium			23	3.6	6.5	19	4.2	5.2
Sodium	180 [a]	115 [c]	23	42	120	19	42	61
Microbiological (cfu/100 mL)								
Colony Count (20°C) Aerobic			1		210			
Coliforms			1		ND			
Faecal coliforms	0 [b]		5	ND	**96**	15		ND
E. coli	0 [b]		32	ND	**220**	15		ND
Enterococci	0 [b]		16		ND	7		ND
Faecal Streptococci	0 [b]		1		ND	7		ND
Sulphite reducing Clostridia					ND	5	35	378
Clostridium perfringens						5	ND	2
Campylobacter (cfu/L)	0 [b]		4	<4	**938**	10		ND
Cryptosporidium - confirmed (oocytes/10 L)			1	ND	<5	10	ND	21
Giardia - confirmed (cysts/10 L)					ND	10	ND	17
Bacteriophage (/10 mL)			4	ND	11	12	ND	11
Rotavirus (PDU/L)			1		ND	5		ND
Adenovirus (gene copies/L)			4		<4.5	4	<10	7046
Nutrients (mg/L)								
Nitrate + Nitrite as N	11.3 [b] (NO_3-N)		27	<0.005	0.052	18	<0.005	0.023
Ammonia as N	0.5 [a]		28	0.094	0.32	18	0.14	**5.75**
TKN			28	0.17	0.77	17	0.32	5.69
Total Nitrogen		25	23	0.18	.77	18	0.32	5.69
Filterable Reactive P			5	0.02	0.03	18	0.02	0.03
Total Phosphorus		0.8 (0.05 LTV [d])	28	0.029	0.11	18	0.03	0.23
Biodegradable Dissolved Organic Carbon			4	1	1.3	7	0.40	1.77
Dissolved Organic Carbon			5	2.3	3.3	18	3.90	6.43
Total Organic Carbon			34	2.7	5.4	18	4.20	9.29

	Guidelines		ASR 1 & 2			ASTR – RW 1 & 2		
	DWG	STV	n	Median	95th %ile	n	Median	95th %ile
Silica	80 [a]		4	5.5	7.9	15	8	10
UV_{254} Filtered (cm^{-1})						3	0.17	0.21
UV_{254} Unfiltered (cm^{-1})			1			5	0.21	0.59
Metals and metalloids (mg/L)								
Aluminium - Soluble	0.2 [a]		23		<0.01	13	<0.001	0.002
Aluminium - Total		20	4	0.04	0.13	**16**	**<0.01**	**0.034**
Antimony - Total	0.003 [b]		1		<0.0005	5	<0.0005	0.001
Arsenic - Soluble			4	0.002	0.003	17	0.002	0.002
Arsenic – Total	0.01 [b]	2	36	0.003	0.006	19	0.002	0.003
Barium - Total	2 [b]		2		0.023	5	0.020	0.036
Beryllium - Total	0.06 [b]	0.5	3		<0.0003	5		<0.0005
Boron - Soluble	4 [b]	0.5 [e]	8	0.062	0.17	15	0.08	0.09
Cadmium - Total	0.002 [b]	0.05	36		<0.0001	15		<0.0001
Chromium (VI) – Soluble	0.05 [b]	1	2		<0.0001			
Chromium - Total	0.05 as Cr (VI) [b]		8		<0.003	15	<0.0001	0.005
Cobalt - Total		0.1	1		<0.0005	5	<0.0005	0.0005
Copper - Total	1 [a] (2 [b])	5	36	<0.0010	0.054	15	<0.0001	0.008
Iron - Soluble			4	**1.31**	**2.8**	18	0.3	**5.7**
Iron - Total	0.3 [a]	10	36	**0.38**	**3.7**	19	**0.36**	**5.5**
Lead - Total	0.01 [b]	5	35	<0.0005	0.004	15	<0.0001	0.003
Lithium - Total		2.5	2		0.003	5	0.003	0.004
Manganese - Soluble			4	0.08	0.14	17	0.06	0.27
Manganese - Total	0.1 [a] (0.5 [b])	10	34	0.041	**0.15** [†]	19	0.06	**0.31**
Mercury - Total	0.001 [b]	0.002	4		<0.0003	15	<0.00003	0.0007
Molybdenum - Total	0.05 [b]	0.05	4	0.001	0.001	5	<0.0005	0.0007
Nickel – Total	0.02 [b]	2	6	0.002	0.006	15	0.0003	0.002
Selenium - Total	0.01 [b]	0.05	3	<0.0001	0.0001	5		<0.003
Silver - Total	0.1 [b]		2		<0.0003	5		<0.0002

	Guidelines		ASR 1 & 2			ASTR – RW 1 & 2		
	DWG	STV	n	Median	95^{th} %ile	n	Median	95^{th} %ile
Thallium - Total			1		<0.0005	5		<0.0005
Uranium – Total	0.017 [b]					1		<0.0005
Vanadium - Total		0.5	2		0.008	5	<0.003	0.006
Zinc - Total	3 [a]	5	35	0.008	0.090	15	<0.003	0.017
Sterols (ng/L)								
24-ethylcholestanol						5	40	405
24-ethylcholesterol						5	88	567
24-ethylcoprostanol						5		<100
24-ethylepicoprostanol						5		<100
Cholestanol						5	36	252
Cholesterol						5	26	312
Coprostanol						5		<100
Epicholestanol						5		<100
Epicoprostanol						5		<100
Trihalomethanes Formation Potential (FP) (mg/L)								
Bromoform FP								
Chloroform FP						73		128
Dibromochloroform FP						21		22
Dichlorobromoform FP						45		55
Total Trihalomethanes FP						141		205
Radiological (Bq/L)								
Gross Alpha Activity	0.5 [s]					4	<0.005	0.034
Gross Beta Activity	0.5 [s]					4	<0.010	0.018
OP & Triazine Pesticides (mg/L)								
Atrazine	20 [b]		12		<0.05 *	15		<0.05 *
Azinphos-methyl	30 [b]		12		<0.5	12		<0.5
Diazinon	4 [b]		12		<0.5	12		<0.5
Fenitrothion	7 [b]		12		<0.5	12		<0.5
Hexazinone	400 [b]		10		<0.5	15		<0.5

	Guidelines		ASR 1 & 2			ASTR – RW 1 & 2		
	DWG	STV	n	Median	95^{th} %ile	n	Median	95^{th} %ile
Malathion	70 [b]		10		<0.5	12		<0.5
Parathion	20 [b]		12		<0.5	12		<0.5
Parathion methyl	0.7 [b]		12		<0.5	12		<0.5
Prometryne			12		<0.5	13		<0.5
Simazine	20 [b]		12		<0.05 *	15		<0.05 *
Other organic scans with detections (mg/L)								
2,4-D	30 [b]		6		ND	3		ND
Chlorpyrifos			8		ND	0		
Dicamba			6		ND	8	<0.01	0.05
Diuron	20 [b]					8	0.17	0.22
Metolachlor	300 [b]					2		ND
Mecoprop						8	<0.01	0.06
MCPA	40 [b]		6		ND	8	<0.01	0.03
Triclopyr	20 [b]		6		ND	8	<0.01	0.02
Dalapon						4		ND
Desethyl Atrazine						4		ND
Desisopropyl Atrazine						4		ND
Pharmaceuticals (mg/L)								
Caffeine						5	0.05	0.10
DEET						5	0.06	0.07
Erythromycin						5	<0.01	0.02
Paracetamol						5	<0.01	0.01
Salicylic acid						5	0.05	0.16
Detergent as MBAS (mg/L)						9	0.11	0.20

Bold values exceed the Australian Drinking Water Guidelines (ADWG; NHMRC–NRMMC 2011, or Augmentation of Drinking Water Supplies Guidelines (AugDWSG; NRMMC–EPC–NHMRC 2008); STV = short term irrigation guideline values (ANZECC-ARMCANZ 2000); a = aesthetic guidelines from ADWG; b = health guideline from ADWG; c = A value greater to that stated can cause foliar damage in sensitive crops; d = To avoid bioclogging in irrigation equipment; e = For very sensitive crops; sensitive 0.5-1, moderately sensitive 1-2. See ANZECC-ARMCANZ (2000) for a detailed tolerance of different crops to salinity in irrigation water; s = screening level to identify requirement for radionuclide analysis; † outlier excluded from statistics (Mn 11.1 mg/L); ND= not detected. Well unit numbers are: ASR1 6628-20743; ASR2 6628-20943; RW1 6628-22533; RW2 6628-22532.

Appendix 9 ASR Groundwater Quality Data

	Guideline		Kaurna Park			Paddocks			Unity Park		
	DWG	STV	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile
Physical Characteristics											
EC (µS/cm)			34	289	703	23	449	1122	4	1260	1269
pH (pH units)	6.5-8.5 [a]	6.5-8.5	34	8.0	8.2	23	7.7	**8.7**	4	7.8	7.8
Suspended Solids (mg/L)			32	3	290	21	15	490	7	6	250
Total Dissolved Solids (mg/L; by EC)	600 [a]		34	155	384	23	250	**617**	4	**690**	**699**
Turbidity (NTU)	5 [a]		17	0.7	**78**	14	2	**27**	4	3	4
True Colour (HU)	15 [a]		2	7	8						
Major Ions (mg/L)											
Alkalinity as $CaCO_3$			17	98	142	13	122	203	4	204	229
Bicarbonate			17	120	173	11	149	253	4	249	280
Sulphate	250 [a] (500 [b])		21	11	37	14	25	107	4	84	91
Chloride	250 [a]		22	20	117	13	59	215	3	226	228
Fluoride	1.5 [b]		17	0.20	**25**	12	0.21	0.27	3	0.39	0.40
Calcium			22	28	45	13	36	59	4	55	59
Magnesium			22	7	12	12	9	25	3	31	33
Potassium			17	3	5	13	5	8	4	7	7
Sodium	180 [a]	115 [c]	17	19	76	13	25	**180**	4	153	158
Microbiological (cfu/100 mL)											
Colony Count (20°C) Aerobic			4	<1	8500						
Coliforms			8	80	19040	7	<1	2450			
E. coli	0 [b]		17	<1	**45**	19	<1	**232**			
Enterococci	0 [b]		4	<1	**3**	5	<1	<1			
Faecal Streptococci	0 [b]		5	<1	**6**	5	<1	<1			
Nutrients (mg/L)											
Nitrate + Nitrite as N	11.3 [b] (NO_3-N)		32	0.01	0.21	18	0.01	0.05	2	0.03	0.03
Ammonia as N	0.4 [a]		18	0.20	**0.53**	13	0.20	**4.5**	3	0.39	**0.72**
TKN			32	0.36	3.8	24	0.52	7.3	3	0.52	0.70
Total Nitrogen		25	9	0.42	1.2	11	0.35	7.48	1	0.77	0.77
Filterable Reactive P			15	0.02	0.05	10	0.01	0.06			
Total Phosphorus		0.8 (0.05 LTV [d])	30	0.05	0.27	24	0.06	0.42	3	0.05	0.05
Silica	80 [a]		12	2.5	4.5						
Metals and metalloids (mg/L)											
Aluminium - Soluble	0.2 [a]					1	0.02	0.02			
Aluminium - Total		20	6	0.13	2.62						
Antimony - Total	0.003 [b]		1	0.001	0.001	2	0.010	0.001			
Arsenic – Total [l]	0.01 [b]	2	32	0.006	**0.013**	23	0.004	**0.023**	4	0.009	0.01
Barium - Total	2 [b]		2	0.011	0.014	2	0.024	0.031			
Beryllium - Total	0.06 [b]	0.5	1	0.001	0.001	1	0.001	0.001			
Cadmium - Total	0.002 [b]	0.05	12	0.001	0.001	7	0.001	0.001			

	Guideline		Kaurna Park			Paddocks			Unity Park		
	DWG	STV	n	Median	95th %ile	n	Median	95th %ile	n	Median	95th %ile
Chromium (VI) – Soluble	0.05 [b]	1				1	0.003	0.003			
Chromium - Total	0.05 as Cr (VI) [b]		2	0.02	0.04	3	0.001	0.01			
Cobalt - Total		0.1	1	0.001	0.001	1	0.001	0.001			
Copper - Total	1 [a] (2 [b])	5	30	0.001	0.025	20	0.002	0.010			
Iron - Total	0.3 [a]	10	35	**0.57**	**9.6**	23	**1.0**	**<u>11</u>**	4	**0.45**	**0.85**
Lead - Total	0.01 [b]	5	27	0.001	0.006	16	0.001	0.004			
Lithium - Total		2.5	2	0.001	0.002	2	0.004	0.006			
Manganese - Total	0.1 [a] (0.5 [b])	10	34	0.03	**0.42**	23	0.04	**1.2**	4	0.02	0.05
Mercury - Total	0.001 [b]	0.002	2	0.00	0.00	2	0.00	0.00			
Molybdenum - Total	0.05 [b]	0.05	2	0.002	0.002	2	0.003	0.004			
Nickel – Total	0.02 [b]	2	3	0.007	0.014	3	0.001	0.002			
Selenium - Total	0.01 [b]	0.05	1	0.003	0.003	1	0.003	0.003			
Silver - Total	0.1 [b]					1	0.002	0.002			
Thallium - Total			1	0.001	0.001	1	0.001	0.001			
Vanadium - Total		0.5	1	0.003	0.003	2	0.016	0.024			
Zinc - Total	3 [a]	5	29	0.02	0.75	19	0.03	0.33			
Trihalomethanes Formation Potential (FP) (mg/L)											
Bromoform FP			1	1	1	2	1	1			
Chloroform FP			1	1	1	1	1	1			
Total Trihalomethanes FP			1	4	4	2	4	4			
Other (mg/L)											
Biochemical Oxygen Demand			14	2	2	6	2	200	1	8	8
OP & Triazine Pesticides (mg/L)											
Atrazine	20 [b]		29	0.50	0.50	15	0.05	0.05			
Azinphos-methyl	30 [b]		29	0.50	0.50	15	0.05	0.05			
Diazinon	4 [b]		25	0.50	0.50	15	0.05	0.05			
Fenitrothion	7 [b]		29	0.50	0.50	15	0.05	0.05			
Hexazinone	400 [b]		29	0.50	0.50	15	0.05	0.05			
Malathion	70 [b]		29	0.50	0.50	15	0.05	0.05			
Parathion	20 [b]		29	0.50	0.50	15	0.05	0.05			
Parathion methyl	0.7 [b]		29	0.30	0.30	15	0.05	0.05			
Prometryne			29	0.50	0.50	15	0.05	0.05			
Simazine	20 [b]		29	0.50	1.60	15	0.05	0.05			
Other organic scans with detections (mg/L)											
Phenanthrene			1	0.50	0.50	1	0.50	0.50			

Bold values exceed the Australian Drinking Water Guidelines (ADWG; NHMRC–NRMMC 2011, or Augmentation of Drinking Water Supplies Guidelines (AugDWSG; NRMMC–EPC–NHMRC 2008); <u>underlined</u> values exceed the short term irrigation guideline values (STV) from ANZECC-ARMCANZ (2000); a = aesthetic guidelines from ADWG; b = health guideline from ADWG; c = A value greater to that stated can cause foliar damage in sensitive crops; d = To avoid bioclogging in irrigation equipment; e = For very sensitive crops; sensitive 0.5-1, moderately sensitive 1-2. See ANZECC-ARMCANZ (2000) for a detailed tolerance of different crops to salinity in irrigation water; s = screening level to identify requirement for radionuclide analysis

Appendix 10 Salisbury Ring Main Distribution Water Quality Data

	Guideline			Ring Main Distribution		
	ADWG	STV	ANZECC*	n	Median	95th %ile
Field Readings						
EC (µS/cm)				23	425	592
Temperature (°C)				23	19.8	23.0
pH (pH units)	6.5-8.5 [a]	6.5-8.5		22	7.3	7.5
Dissolved oxygen (mg/L)	>85% [a]			21	0.4	2.4
Eh (mV SHE)				22	88	401
Physical characteristics						
EC (µS/cm)				22	447	636
pH (pH units)	6.5-8.5 [a]			22	7.6	7.8
Suspended Solids (mg/L)				22	<1	7
Total Dissolved Solids (mg/L; by EC)	600 [a]			22	245	350
Turbidity (NTU)	5 [a]			22	1.8	4.0
True Colour (HU)	15 [a]			22	14	**59**
Particle size - d_{10}				23	2.5	6.4
Particle size - d_{50}				23	7.9	201
Particle size - d_{90}				23	29	478
Major Ions (mg/L)						
Alkalinity as $CaCO_3$				22	142	154
Bicarbonate				22	174	188
Bromide				22	0.13	0.26
Sulphate	250 [a] (500 [b])			22	27	36
Chloride	250 [a]			22	51	84
Fluoride	1.5 [b]			22	0.37	0.63
Calcium				22	36	42
Magnesium				22	10	19
Potassium				22	4.1	5.7
Sodium	180 [a]	115 [c]		22	36	63
Microbiological						
Thermotolerant coliforms	0 [b]			22	**24**	**286**
E. coli (cfu/100 mL)	0			22	**35**	**313**
Campylobacter (cfu/L)	0			22	<4	**2200**
Cryptosporidium - Confirmed oocysts/10 L)				22	<4	9
Giardia - Confirmed (oocysts/10 L)				22		<2
Bacteriophage (n/10mL)				22	<1	9
Adenovirus (gene copies/L)				21	<6.8	407
Nutrients (mg/L)						
Nitrate + Nitrite as N	11.3 [b] (NO_3-N)		17	22	0.01	0.06
Ammonia as N	0.4 [a]		2.3	22	0.08	0.19
Total Kjeldahl Nitrogen				22	0.25	1.1
Total Nitrogen		25		22	0.28	1.1
Filterable Reactive Phosphorus				22	0.02	0.08
Total Phosphorus		0.8 (0.05 LTV[d])		22	0.03	0.15
Biodegradable Dissolved Organic Carbon				21	1.1	5.4
Dissolved Organic Carbon				22	2.8	10

	Guideline			Ring Main Distribution		
	ADWG	STV	ANZECC*	n	Median	95th %ile
Total Organic Carbon				22	3.0	12
Silica	80 [a]			22	7	10
Metals and metalloids (mg/L)						
Aluminium - Soluble	0.2 [a]			22	0.004	0.037
Aluminium - Total		20	0.15	22	0.009	0.108
Arsenic - Soluble				22	0.002	0.002
Arsenic - Total	0.01 [b]	2	0.14	22	0.002	0.003
Boron - Soluble	4 [b]	0.5 [e]	1.3	22	0.07	0.11
Cadmium - Total	0.002 [b]	0.05	0.0008	22	<0.0001	0.0002
Chromium - Total	0.05 [b] as Cr(VI)	1	0.004	22	<0.0001	0.0006
Copper - Total	1 [a] (2 [b])	5	0.0025	22	0.001	**0.008**
Iron – Soluble				22	0.22	**0.87**
Iron – Total	0.3 [a]	10		22	**0.38**	**1.31**
Lead – Total	0.01 [b]	5	0.0094	22	<0.0001	0.0008
Manganese - Soluble				22	0.025	0.137
Manganese - Total	0.1 a (0.5 [b])	10	3.6	22	0.026	0.140
Mercury - Total	0.001 [b]	0.002	0.0054	22		<0.00003
Nickel - Total	0.02 [b]	2	0.0017	22	0.0005	0.0011
Zinc - Total	3 [a]	5	0.031	22	0.004	0.041
Sterols (ng/L)						
24-ethylcholestanol				6	778	2018
24-ethylcholesterol				6	2228	6145
24-ethylcoprostanol				6	338	1558
24-ethylepicoprostanol				6	<25	273
Cholestanol				6	331	788
Cholesterol				6	1599	3893
Coprostanol				6	<25	354
Epicholestanol				6	<40	86
Epicoprostanol				6	<25	80
Radiological (Bq/L)						
Gross alpha activity	0.5 [s]			6	<0.005	0.02
Gross beta activity (K-40 corrected)	0.5 [s]			6	<0.01	0.04
Organic chemicals (µg/L)						
Atrazine	20 [b]			22		<0.05
Azinphos-methyl	30 [b]			22		<0.5
Diazinon	4 [b]			22		<0.5
Fenitrothion	7 [b]			22		<0.5
Hexazinone	400 [b]			22		<0.5
Malathion	70 [b]			22		<0.5
Parathion	20 [b]			22		<0.5
Parathion methyl	0.7 [b]			22		<0.3
Prometryne				22		<0.5
Simazine	20 [b]		35	22	<0.05	0.14

Bold values exceed the Australian Drinking Water Guidelines (ADWG; NHMRC–NRMMC 2011, or Augmentation of Drinking Water Supplies Guidelines (AugDWSG; NRMMC–EPC–NHMRC 2008); STV = short term irrigation guideline values (ANZECC-ARMCANZ 2000); exceed the ANZECC = freshwater ecosystems Avalues for lowland South central Australian rivers *80% of species protected (highly modified system) (ANZECC-ARMCANZ 2000); a = aesthetic guidelines from ADWG; b = health guideline from ADWG; c = A value greater to that stated can cause foliar damage in sensitive crops; e = for very sensitive crops; s = screening level to identify requirement for radionuclide analysis

Appendix 11 Mawson Lakes Distribution Water Quality Data

	Guideline	Mawson Lakes Distribution			
	STV	n	Median	Mean	95th %ile
Temperature (°C)		390	22	22	29
EC (µS/cm)	650	390	1320	1131	1680
Total Dissolved Solids (mg/L; by EC)	*600	390	720	606	930
Free chlorine (mg/L)	1	390	0.2	0.6	2.2
True Colour (HU)	*15	77	3	4	7
E. coli (cfu/100 mL)	†<10	393	<1	<1	<1
Iron – Soluble		97	0.01	0.02	0.07
Iron - Total	10	96	0.10	0.14	0.37
Manganese – Soluble		96	0.01	0.01	0.04
Manganese – Total	10	96	0.01	0.02	0.06

Data source from SA Water. Pooled data from 5 sites within the Mawson Lakes third pipe distribution system (14023, 14024, 14025, 14032, 14037) from Jan 1st 2010 to Oct 6th 2011. STV = Short term irrigation guideline values from ANZECC-ARMCANZ (2000); *ADWG aesthetic value from ADWG; NHMRC–NRMMC (2011); † trigger value for thermotolerant coliforms for raw human food crops in direct contact with irrigation water (e.g. via sprays, irrigation of salad vegetables) from ANZECC-ARMCANZ (2000); values exceeding guideline values are underlined.

Appendix 12 Little Para Catchment and Reservoir Water Quality Data

		Guideline*		Snake Gully (catchment)				Loc 9 (reservoir)			
	Detection Limit	DWG	STV	n	# detects	Median	95th %ile	n	# detects	Median	95th %ile
Physical Characteristics											
EC (µS/cm)								127	127	620	743.7
Dissolved Oxygen (mg/L)								435	435	9.6	12.3
pH (pH units)		6.5-8.5 [a]	6.5-8.5	59	59	8	8				
Total Dissolved Solids by EC (mg/L)		600 [a]						127	127	340	407
Temperature (°C)				119	119	16	24	557	557	19	23
Turbidity (NTU)		5 [a]						521	521	**6**	**16**
True Colour 456nm (HU)		15 [a]						521	521	14	**52**
Microbiological (cfu/100 mL)											
Algae (cells/mL)	ND			105	105	118	1424	763	761	429	10106
Coliforms	ND							126	123	320	3775
E. coli	ND	0 [b]						126	108	**3**	**24**
Cryptosporidium - presumptive (oocytes /10 L)				126	64	1	25				
Cryptosporidium - confirmed (oocytes/10 L)				64	41	2	27				
Giardia - Presumptive (cysts/10 L)				126	53	0	124				
Giardia - Confirmed (cysts/10 L)				53	32	0	74				
Nutrients (mg/L)											
Nitrate + Nitrite as N	<0.005	11.3 [b]						126	118	0.15	0.33
TKN	<0.005							428	127	0.60	0.97
Total Phosphorus			0.8 (0.05 LTV [d])					127	127	0.032	0.075

	Detection Limit	Guideline* DWG	STV	Snake Gully (catchment) n	# detects	Median	95th %ile	Loc 9 (reservoir) n	# detects	Median	95th %ile
Dissolved Organic Carbon								127	127	6.1	9.0
Metals and metalloids (mg/L)											
Iron - Soluble	<0.005 - 0.03							208	109	0.002	0.15
Iron - Total		0.3 [a]	10					208	208	**0.40**	**0.84**
Manganese - Soluble	<0.005							208	69	<0.005	0.024
Manganese - Total	<0.005	0.1 [a] (0.5 [b])	10					208	202	0.018	0.056
Trace Organics (µg/L)											
Aldrin	<0.05 - 0.01	0.3 [b]		130	0			56	0		
Atrazine	<0.5	20 [b]		130	0			56	0		
Azinphos-methyl	<0.5	30 [b]		130	0			56	0		
Chlordane-a	<0.05 - 0.01	2 [b]		130	0			56	0		
Chlordane-g	<0.05 - 0.01			130	0			56	0		
Chlorpyrifos	<0.05 - 0.01			130	0			56	0		
Chlorthal-Dimethyl	<0.05 - 0.1			130	2			56	0		
DDD	<0.05 - 0.1			130	0			56	0		
DDE	<0.05 - 0.1			130	0			56	0		
DDT	<0.05 - 0.1			130	0			56	0		
Diazinon	<0.5			130	0			56	0		
Dieldrin	<0.01 - 0.05			130	0			56	0		
Endosulfan 1	<0.05 - 0.1	20 [b]		130	0			56	0		
Endosulfan 2	<0.05 - 0.1			130	0			56	0		
Endosulfan Sulphate	<0.05 - 0.1			130	0			56	0		
Endrin	<0.05 - 0.1			130	0			56	0		
Fenitrothion	<0.5			130	0			56	0		
Heptachlor	<0.05 - 0.1	0.3 [b]		130	0			56	0		

		Guideline*		Snake Gully (catchment)				Loc 9 (reservoir)			
	Detection Limit	DWG	STV	n	# detects	Median	95th %ile	n	# detects	Median	95th %ile
Heptachlor Epoxide	<0.05 - 0.1			130	0			56	0		
Hexachlorobenzene	<0.05			19	0			18	0		
Hexazinone	<0.5	400 [b]		130	0			56	0		
Lindane	<0.05 - 0.1			130	0			56	0		
Malathion	<0.5	70 [b]		130	0			56	0		
Methoxychlor	<0.05 - 0.1			130	0			56	0		
Parathion	<0.5	20 [b]		130	0			56	0		
Parathion methyl	<0.3	0.7 [b]		130	0			56	0		
Prometryne	<0.5			130	0			56	0		
Simazine	<0.5	20 [b]		130	0			56	0		
Trifluralin	<0.05 - 0.1	90 [b]		130	0			56	0		
Vinclozolin	<0.05 - 0.1			130	0			56	0		

*** Bold** values exceed the Australian Drinking Water Guidelines (ADWG; NHMRC–NRMMC 2011, or Augmentation of Drinking Water Supplies Guidelines (AugDWSG; NRMMC–EPC–NHMRC 2008) and are used for comparison only; STV = short term irrigation guideline values (ANZECC-ARMCANZ 2000); a = aesthetic guidelines from ADWG; b = health guideline from ADWG; c = A value greater to that stated can cause foliar damage in sensitive crops; d = To avoid bioclogging in irrigation equipment; e = For very sensitive crops; sensitive 0.5-1, moderately sensitive 1-2. See ANZECC-ARMCANZ (2000) for a detailed tolerance of different crops to salinity in irrigation water; s = screening level to identify requirement for radionuclide analysis; ND= not detected

Appendix 13 Little Para Treated Drinking Water Quality

	Guideline		Little Para			
	DWG	STV	n	minimum	maximum	average
Field/Physical characteristics						
Temperature (°C)			1788	10.0	32.0	20.0
pH (pH units)	6.5-8.5 [a]		265	7.0	7.9	7.4
Total Dissolved Solids (mg/L; by EC)	600 [a]		60	290	420	356
Turbidity (NTU)	5 [a]		265	0.10	1.4	0.16
True Colour (HU)	15 [a]		265	<1	10	1
Total Hardness as $CaCO_3$	200 [a]		60	104	160	129
Langelier Index			60	-1.4	-0.5	-0.9
Major Ions (mg/L)						
Alkalinity as $CaCO_3$			60	52	91	69
Bicarbonate			60	63	111	84
Sulphate	250 [a] (500 [b])		60	38	55	47
Chloride	250 [a]		60	103	151	127
Fluoride	1.5 [b]		60	0.18	1.0	0.84
Calcium			60	20	33	25
Magnesium			60	13	20	16
Potassium			60	3.3	6.2	4.1
Sodium	180 [a]	115 [c]	60	64	90	75
Nutrients (mg/L)						
Nitrate as N	11.3 [b]		60	<0.005	0.283	0.140
Nitrite as N	0.9		60	<0.005	0.008	0.005
Ammonia as N	0.4		60	<0.005	0.06	0.008
Total Kjeldahl Nitrogen			60	0.05	0.38	0.23
Filterable Reactive Phosphorus			60	<0.005	0.012	0.005
Total Phosphorus		0.8 (0.05 LTV [d])	59	<0.005	0.012	0.005
Silica	80 [a]		60	<1	7	3
Metals and metalloids (mg/L)						
Aluminium - Soluble	0.2 [a]	20	60	0.018	0.084	0.040
Antimony - Total	0.003 [b]		60	<0.0005	0.0007	<0.0005
Arsenic - Total	0.01 [b]	2	60	<0.0003	0.0020	0.0009
Boron - Soluble	4 [b]		60	<0.04	0.093	0.046
Cadmium - Total	0.002 [b]	0.05	59	<0.0001	0.0006	0.0004
Chromium - Total	0.05 [b] as Cr(VI)	1	59	<0.0001	<0.003	0.0025
Copper - Total	1 [a] (2 [b])	5	59	0.0045	0.065	0.0167
Iron - Total	0.3 [a]	10	134	0.0038	0.028	0.0083
Lead - Total	0.01 [b]	5	59	0.0002	<0.01	0.0006
Manganese - Total	0.1 [a] (0.5 [b])	10	134	<0.0005	0.0050	0.00027
Molybdenum – Total	0.05 [b]	0.05	59	0.0001	0.0008	0.0005
Nickel - Total	0.02 [b]	2	60	0.0004	*0.0050*	0.0007
Silver – Total	0.1 [b]		60	<0.00003	<0.002	0.00086
Zinc - Total	3 [a]	5	59	0.0028	0.0217	0.0056

Treated drinking water quality from Little Para treatment plant (1/7/2005 – 30/6/2010), data supplied by United Water. DWG **=** Australian Drinking Water Guidelines (ADWG; NHMRC–NRMMC 2011, or Augmentation of Drinking Water Supplies Guidelines (AugDWSG; NRMMC–EPC–NHMRC 2008); STV =short term irrigation value (ANZECC-ARMCANZ 2000); a = aesthetic guidelines from ADWG; b = health guideline from ADWG; c = A value greater to that stated can cause foliar damage in sensitive crops; d = To avoid bioclogging in irrigation equipment; e = For very sensitive crops; sensitive 0.5-1, moderately sensitive 1-2. See ANZECC-ARMCANZ (2000) for a detailed tolerance of different crops to salinity in irrigation water.

Note: A conservative approach has been used to calculate the average values tabulated above. Where the lower limit of detection for any parameter is preceded by a"<" sign, the absolute number has been used to calculate the average rather than using a zero.

Appendix 14 Technical Committee Workshop: Risk Assessment Results

Following the first hazard identification workshop in March of 2011, the risk assessment methods and hazard identification workshop with around 20 representatives from existing project partner satellite sites in Singapore, Melbourne, Geelong, Orange and Brisbane joining MARSUO project team members helped define the system to be used. The resulting hazard identification and risk analysis table (Table A.9) was produced using the agreed method and applied to spatial models to generate the risk hot spot maps and map statistics.

LAND_USE	HAZARD	CODE	EVENT	MAR_WQ	COMMENTS	LIKELI.	SEVER.	RISK
Building materials supply yard	Sand, rubble, cement, metals in storage	2031	Material handling/deposition+runoff	inorg chem	visible sediment on adjacent roads; compounds of Ni, Co, Zn, Cr, Cd, Cu	3	4	Extreme
Cement Factory	cement production	3690	runoff	inorg chem	visible sediment on adjacent roads; gypsum, calcium sulphate, limestone, aluminium compounds	4	4	Extreme
Metal Industry	metal/machinery/transport/other manufacturing	3800	spill/leak+runoff	inorg chem	metals & compounds of Al, Ag, Co, Ba, As, Hg, Se, Cr, Ni, Pb, Mg, Cd etc., inorganic acids (hydrochloric, sulphuric)	3	4	Extreme
Quarry	cutting/landfill	8250	runoff	inorg chem	large open cut mines and backfill areas; compounds of metals (e.g. Fe, Co, Ni, Al), colloids, Al/Fe always high in CCk/PDS samples	5	4	Extreme
Roads	High vol traffic (>30000 AADT))	NA	Runoff, accidents	inorg chem	>>traffic areas, >>bulk transport, >> chance of accidents	3	3	High
Construction/Land Development	construction, earth moving	4200	runoff	inorg chem	Temporary so requires regular review, mobilisation of metals in soils through land disturbance; visible sediment on adjacent roads	4	3	High
Scrap metal/waste recycling	Outdoor bulk storage of metals, hazardous chemicals	6300	runoff	inorg chem	Leaking drums, outdoor exposure, piles of scrap, visible sediment on adjacent roads; metals in sediments	5	3	High
Chemical Industry	chemical manufacturing incl. fertilisers, petroleum, plastic, rubber, paints	3500	spill/leak+/-runoff	inorg chem	Potential contamination with wide range of inorganic metallic compounds	2	4	High
Horticulture (crops, market gardens)	Fertilisers, pesticides	9700	Application+runoff	inorg chem	several small gardens in Salisbury, some areas in TTG	4	3	High
Infrastructure	mains water pipes	NA	burst/repair	inorg chem	bursts and repairs are hazardous events, Cl shock treatments, land disturbance	3	3	High

LAND_USE	HAZARD	CODE	EVENT	MAR_WQ	COMMENTS	LIKELI.	SEVER.	RISK
Dairy Processing	Cleaning and production chemicals	3112	spill/leak+runoff	inorg chem	high vol storage/use; cleaning solutions (bases e.g. sodium hydroxide), sodium hypochlorite, nitric/phosphoric acid, chlorine dioxide, peroxide, sulfur dioxide	3	2	Moderate
Forestry	Fertilisers, pesticides	9400	Application+runoff	inorg chem	fertilisers containing compounds of S, Ca, Mg, Cu, B, Cl, Fe, Mn, Mo, Zn, Cd, Hg, Pb	3	1	Moderate
Printing Industry	Chemicals used in print production	3420	spill/leak+runoff	inorg chem	high volume storage	2	3	Moderate
Textile Industry	Chemicals used in wool, textiles, leather processing	3200	spill/leak+runoff	inorg chem	e.g. Michel Wools (wool scouring), RM Williams (leather processing)	2	3	Moderate
Horticultural Supply	Storage of fertilisers, pesticides, herbicides	2650	spill+/-runoff	inorg chem	Various metal and other inorg chem compounds	2	3	Moderate
Pharmaceutical Industry	pharmaceuticals manufacturing	3120	spill/leak+runoff	inorg chem	Various inorg chems used in production processes, very high security, probably very good compliance and very clean industry	2	2	Low
NA	Mobile contractors		illegal drainage	inorg chem	not adhere/aware of waste disposal contractual obligations; low vols	2	2	Low
NA	mobile businesses		illegal drainage	inorg chem	dog-washers, mobile mechanics, cleaners etc; low vols; regulatory structures	2	1	Low
Infrastructure	paint on concrete drains		runoff	inorg chem	very fresh/very old paint, direct contact	2	1	Low
Quarry	dewatering ponds/detention basins		leak	inorg chem	baseflow from storage ponds into SW/GW, only in Cobbler Creek, effect << cuttings	2	2	Low
Other	dust		dust storm	inorg chem	increase first flush effect but mainly turbidity problem	2	1	Low
Railway	rail cars		leak+runoff	inorg chem	rail line near Parafield drain, construction (rail upgrade)	2	1	Low
Urban Residential	building materials (roofs, gutters, drain pipes)	1100	runoff	inorg chem	Zn from galvanised iron; effect probably insig	5	1	Low
Urban Residential	fire	1100	fire+/-runoff	inorg chem	Major incidents would require notification and possibly some action	2	2	Low
Urban Residential	grey water	1100	Cross-connection	inorg chem	washing machines not piped into sewer (into stormwater drain instead)	2	1	Low
Urban Residential	paint	1100	runoff	inorg chem	very fresh/very old paint, lead paint on old buildings, mainly new housing, probably low amounts of toxic materials	3	1	Low
Urban Residential	swimming pools		leakage/emptying	inorg chem	illegal emptying into SW system, SA EPA enforces fines if not drained to sewage, most pools permanently connected to sewage	1	2	Low
Minor Roads	traffic	NA	runoff	inorg chem	<traffic, little-no bulk transport, <accidents	2	1	Low

LAND_USE	HAZARD	CODE	EVENT	MAR_WQ	COMMENTS	LIKELI.	SEVER.	RISK
Commercial	storage areas		spill+runoff	inorg chem	captured in specific commercial land uses	na	na	na
Commercial	driveways/thoroughfares		runoff	inorg chem	captured in specific commercial land uses	na	na	na
Tyre Factory	tyre manufacturing	3600	spill/leak+runoff	inorg chem	Shut down in April 2011	na	na	na
Industrial	driveways/thoroughfares		runoff	inorg chem	captured in specific industrial land uses	na	na	na
Industrial	laboratories		leak/spill+runoff	inorg chem	captured in specific industrial land uses	na	na	na
Industrial	storage areas		spill+runoff	inorg chem	captured in specific industrial land uses	na	na	na
Other	volcano		eruption	inorg chem	unlikely to affect water quality in Parafield, >>>>distance from volcanic activity	na	na	na
Urban Residential	driveways/thoroughfares	1100	runoff	inorg chem	Cumulative impact in built up areas, captured in roads class	na	na	na
Horticulture (crops, market gardens)	Fertilisers	9700	Application+runoff	nutrients	fertilisers (N, P, K compounds)	5	4	Extreme
Livestock Pastures	Manure, fertilisers	9800	runoff	nutrients	fertilisers on grazing land, nutrients e.g. ammonia from animal faeces	4	4	Extreme
Infrastructure	sewer mains	NA	overflow/leak	nutrients	High nutrients in raw sewage	3	3	High
Rural Residential	septic tanks; domestic livestock (e.g. chickens, horses)	1912	leak/runoff	nutrients	nutrients from animal faeces/feed, septic tank leaks	3	3	High
Aquaculture	Aquaculture waste stream	9290	spill/leak/runoff	nutrients	land based farm in Little Para, unknown product; wastewater discharge in particular nutrients from uneaten feed, abalone faeces, spat settlement plate tanks	3	3	High
Forestry	fertilisers	9400	runoff	nutrients	fertilisers (N, P, K compounds)	3	3	High
Agric. Chem. Manuf.	Fertilisers, pesticides	3512	spill/leak+/-runoff	nutrients	N and P compounds used in process and in final product, potentially large stores, on-site controls e.g. bunding	2	3	Moderate
Food Manuf. Industy	Dairy, meat, poultry, beverage etc.	3110	spill/leak+runoff	nutrients	Large vols of N and P compounds used in processes, high vols emitted and transferred, on-site controls e.g. bunding	2	3	Moderate
Infrastructure	sewer pumping station	NA	breakdown+overflow	nutrients	High nutrients in raw sewage; risk higher near streams	2	3	Moderate
Infrastructure	stormwater GPTs	NA	overflow/blockage	nutrients	floods out and over GPT rendering ineffective & picks up additional rubbish on side of SW drain	3	2	Moderate
Other	meteorological	NA	extreme weather event	nutrients	general increase of all potential pollutants e.g. major storm event; org matter washed down in large storm event	2	3	Moderate
Other	deciduous plants	NA	deciduous leaf drop	nutrients	autumn and winter periods; large amounts of organic matter (high org C)	3	2	Moderate

LAND_USE	HAZARD	CODE	EVENT	MAR_WQ	COMMENTS	LIKELI.	SEVER.	RISK
Recreational Facility	Fertilisers on sports fields	7260	application+runoff	nutrients	sports grounds, school ovals, golf courses; compounds of N, P, K	3	2	Moderate
Plant Nurseries	fertilisers	9930	application+runoff	nutrients	compounds of N, P, K; impact probably << horticulture (cropping)	3	2	Moderate
Horticultural Supplies	horticultural supplies/stores	2650	spill+/-runoff	nutrients	compounds of N, P, K; impact probably << horticulture (cropping)	2	3	Moderate
Metal Industry	metal/machinery/transport/other manufacturing	3800	spill/leak+runoff	nutrients	N compounds e.g. ammonia, P compounds used in processes, impact likely < org/inorg chems, on site controls e.g bunding	3	2	Moderate
Quarry	blasting	8250	blasting/storage leak+runoff	nutrients	Possible leaks from storage; impact probably insig	2	2	Low
Construction/Land Development	Earth moving	4200	runoff	nutrients	Temporary so requires regular review, mobilisation of nutrients in soils through land disturbance; impact >> metals, turbidity	2	1	Low
Infrastructure	sewer mains	NA	Earthquake	nutrients	Rupture of sewer pipes; historically only very low magnitude events in area	1	2	Low
Other	dust		dust storm	nutrients	increase first flush effect but mainly turbidity problem	2	1	Low
Urban Residential	fire	1100	fire+/-runoff	nutrients	fire without runoff may still pollute, proximity and rain will increase risk	1	2	Low
Urban Residential	grey/recycled water	1100	runoff	nutrients	irrigation runoff from existing ASR/water recycling schemes	3	1	Low
Urban Residential	pets (eg dogs, cats)	1100	rain/runoff	nutrients	low vols; effect probably negligible	2	1	Low
Tyre Factory	tyre manufacturing	3600	spill/leak+runoff	nutrients	Bridgestone (Parafield) closed April 2011	na	na	na
Other	population/land use density	NA	runoff	nutrients	scale of risk i.e. higher densities present higher & more numerous risks; difficult to assess; impact < rural areas with livestock/crops	na	na	na
Horticulture (crops, market gardens)	Pesticides, herbicides	9700	Application+runoff	org chem	pesticide compounds e.g. organophosphates, carbamates, organochlorides, pyrethroids, herbicide compounds e.g. chloropenoxy, mecoprop	3	4	Extreme
Rail Infrastructure	Herbicide use on railways	6400	spraying+runoff	org chem	Weed control; herbicide compounds e.g. chloropenoxy, mecoprop	3	4	Extreme
Rail Infrastructure	Rail engines/cars	6400	leak+/-runoff	org chem	Oil deposition by rail cars, well documented in impact studies	3	4	Extreme
Roads	High traffic vol (>30000 AADT)	NA	runoff	org chem	>>traffic areas, >>bulk transport, >>accidents; >> hydrocarbon load	3	3	High

LAND_USE	HAZARD	CODE	EVENT	MAR_WQ	COMMENTS	LIKELI.	SEVER.	RISK
Service Stations	Fuel, oil and related compounds	2181	major spill+/-runoff	org chem	persistent/low soluble diesel; paraffins, olefins, alkylbenzenes, indenes, napthalenes, bisphenyls, phenanthrenes etc., petrol, diesel	1	5	High
Service Stations	Fuel, oil and related compounds	2181	fuel handling/spill /leak+runoff	org chem	persistent/low soluble diesel; paraffins, olefins, alkylbenzenes, indenes, napthalenes, bisphenyls, phenanthrenes etc., petrol, diesel	3	3	High
Recreation	Pesticides and herbicides used on sports fields	7260	applicaiton+runoff	org chem	Various pesticides/herbicides applied to sports grounds, school ovals, golf courses	3	3	High
Roads	road resurfacing	NA	works+runoff	org chem	org chem assoc with bitumen products	3	3	High
Median Strips/Road Verges	herbicides	4530	spraying+runoff	org chem	Weed control; spraying of verges; various herbicide compounds	3	3	High
Beverage Production	Production and cleaning chemicals	3134	spill/leak+runoff	org chem	high volumes, large storage tanks, sodium benzoate, benzene, organic acids (e.g. ascobic, nitric)	3	2	Moderate
Motor Vehicle Services	Use of solvents, oils, fuel by auto repairers	2910	spill/leak+runoff	org chem	Oils, solvents, fuels etc., med vol storage, possibly less EPA compliance for small businesses	3	2	Moderate
Metal Industry	metal/machinery/transport/other manufacturing	3800	spill/leak+runoff	org chem	high number of businesses in Salisbury catchment	3	2	Moderate
Chemical Industry	chemical manufacturing incl. fertiliser, petroleum, plastic, rubber, paints	3500	spill/leak+/-runoff	org chem	Potential contamination with wide range of organic compounds	3	2	Moderate
Printing Industry	Chemicals used in print production	3420	spill/leak+runoff	org chem	potentially high volume storage; tolulene, glycol ethers, xylenes, nitric acid, acetone, methanol, chlorinated ethyls/methanes, ethylenes, isopropyl, benzenes	3	2	Moderate
Dairy Processing	dairy processing	3112	spill/leak+runoff	org chem	high volumes, large storage tanks	2	3	Moderate
Forestry	Herbicides	9400	Application+runoff	org chem	Herbicides used mainly in early plantation, pre-emergent weed control	3	2	Moderate
Auto Parts Store	automotive parts store	2184	spill/leak+runoff	org chem	med volumes, several businesses within catchment	2	3	Moderate
Wood Cork Furniture Manufacturing	wood, timber, cork, furniture manufacturing	3300	leak/spill/runoff	org chem	a handful in catchment	3	2	Moderate
Textile Industry	wool, textiles, leather processing	3200	spill/leak+runoff	org chem	eg Michel Wools, leather factory	2	3	Moderate
Infrastructure	electrical susbstations (incl booster stations)	6170	leak+/-runoff	org chem	large stores of oils and chems on sites, none appear to be in catchment	2	3	Moderate

LAND_USE	HAZARD	CODE	EVENT	MAR_WQ	COMMENTS	LIKELI.	SEVER.	RISK
Infrastructure	sewer mains	NA	earthquake	org chem	likely not monitored, known in other areas, this catchment?	1	3	Moderate
Infrastructure	stormwater GPTs	NA	overflow/blockage	org chem	floods out and over GPT rendering ineffective & picks up additional rubbish on side of SW drain	3	2	Moderate
Horticultural Supplies	horticultural supplies/stores	2650	spill+/-runoff	org chem	several small gardens in Salisbury, some areas in TTG	2	3	Moderate
Medical/Vet Clinics	Org chems use in medical/vet clinics	5890	Spill/leak	org chem	Low vols, probably excellent compliance and very clean premises and practices	1	3	Low
Pharmaceutical Factory	Chemical used in pharmaceuticals manufacturing	3120	spill/leak+runoff	org chem	one large factory in Parafield, probably excellent compliance and very clean	2	2	Low
Other	contractors	NA	illegal drainage	org chem	may not adhere/be aware of contractual obligations regarding waste disposal	2	2	Low
Drycleaners	chemicals used in dry cleaning	2340	spill/leak+runoff	org chem	low vols	2	2	Low
Commercial	grease traps, waste disposal in commercial food industry	various	spill/leak+runoff	org chem	probably low vols compared to other organic rubbish sources	2	1	Low
Commercial	mobile businesses	NA	drainage to SW	org chem	dog-washers, mobile mechanics, cleaners etc; low vols; regulatory structures	2	1	Low
Plant Nurseries	pesticides	9930	spill/runoff	org chem	low vols compared to crops, market gardens	2	1	Low
Forestry	Pesticides, herbicides	9400	runoff	org chem	low vols compared to crops, market gardens; mainly fertiliser use for planting	3	1	Low
Airport	crop dusting planes	NA	leak/spill	org chem	flight paths over catchment, 2-3 operations exist from Parafield, planes often taxi near ponds	2	2	Low
Council Depot	washdown areas	2601	drainage to SW/runoff	org chem	probably low vols org chems e.g. fuel, oils, from vehicle wash areas	2	1	Low
Other	dust	NA	dust storm	org chem	increase first flush effect but mainly turbidity problem	2	2	Low
Urban Residential	junk mail	NA	runoff	org chem	low vols compared to leaf litter	3	1	Low
Other	litter	NA	runoff	org chem	litter from range of sources that passes through GPTs	3	1	Low
Urban Residential	backyard mechanics	1100	runoff	org chem	private/unlicensed automotive work in driveways; relatively very low vols	2	1	Low
Urban Residential	fire	1100	fire+/-runoff	org chem	fire without runoff may still pollute, proximity and rain will increase risk	1	2	Low
Urban Residential	garden	1100	runoff	org chem	probably low vols applied compared to market gardening/horticulture but many properties	3	1	Low

LAND_USE	HAZARD	CODE	EVENT	MAR_WQ	COMMENTS	LIKELI.	SEVER.	RISK
Urban Residential	grey/recycled water	1100	runoff	org chem	irrigation runoff, washing machines not piped into sewer	3	1	Low
Urban Residential	rubbish bins	1100	spill/leak/runoff	org chem	low vols compared to market gardening/horticulture but many properties	3	1	Low
Transport	aircraft	NA	crash+/- runoff	org chem	flight school, trainee pilots > chance of incidents, small aircraft	2	2	Low
Minor Roads	traffic	NA	runoff	org chem	< traffic, little-no bulk transport, < accidents	2	1	Low
Aquaculture	cleaning chemicals, fuels, oils	9290	spill/leak+/-runoff	org chem	chemicals used to treat disease, cleaning equipment/chemicals, fuels/oils; probably very low vols	2	2	Low
Commercial	storage areas	NA	spill	org chem	high volumes (point), captured in specific land uses	na	na	na
Commercial	subsurface tanks	NA	spill/leak	org chem	assoc with service stations	na	na	na
Commercial	driveways/thoroughfares	NA	runoff	org chem	captured in separate commercial land uses	na	na	na
Commercial	fuel storage	NA	vandalism/leak/spill	org chem	after water fuel is stored in highest volumes, captured in specific land uses	na	na	na
Commercial	hazardous material	NA	vandalism/leak/spill	org chem	assoc with other specific land uses already documented	na	na	na
Commercial	rubbish bins	NA	spill/leak/runoff	org chem	assoc with other specific land uses already documented	na	na	na
Industrial	airport refuelling station	NA	leakage/spillage/runoff	org chem	not in catchment	na	na	na
Industrial	fuel storage	NA	vandalism/leak/spill	org chem	after water fuel is stored in highest volumes, captured in specific land uses	na	na	na
Tyre Factory	tyre manufacturing	3600	spill/leak+runoff	org chem	Bridgestone (Parafield) closed April 2011	na	na	na
Industrial	hazardous material	NA	vandalism/leakage/spillage	org chem	assoc with other specific land uses already documented	na	na	na
Industrial	laboratories	NA	leakage/spillage	org chem	probably very few, captured in other land uses	na	na	na
Industrial	rubbish bins	NA	spill/leak/runoff	org chem	assoc with other specific land uses already documented	na	na	na
Industrial	storage areas	NA	spillage/runoff	org chem	high volumes (point), captured in specific land uses	na	na	na
Industrial	subsurface tanks	NA	spill/leak	org chem	vents around Parafield? assoc with service stations/specific industrial land uses	na	na	na
Institution	driveways/thoroughfares	NA	runoff	org chem	captured in separate land uses	na	na	na
Institution	storage areas	NA	spillage	org chem	high volumes (point), captured in specific land uses	na	na	na

LAND_USE	HAZARD	CODE	EVENT	MAR_WQ	COMMENTS	LIKELI.	SEVER.	RISK
Mining	storage areas	NA	spillage	org chem	high volumes (point), captured in specific land uses	na	na	na
Mining	waste transfer stations	NA	leakage/runoff	org chem	none known in mines in study area	na	na	na
Mining	waste transfer stations	NA	leakage/runoff	org chem	none known in mines in study area	na	na	na
Other	population/land use density	NA	runoff	org chem	scale of risk i.e. higher densities present higher & more numerous risks; difficult to compare with mining/agriculture however	na	na	na
Urban Residential	driveways/thoroughfares	1100	rain/runoff	org chem	captured in separate land uses	na	na	na
Infrastructure	sewer mains	NA	overflow/leak	pathogens	tree root growth in dry months chokes usually after first rainfalls, sediment traps in sewer network; specific human pathogens	4	4	Extreme
Infrastructure	sewage pumping station	NA	breakdown+overflow+/-runoff	pathogens	particularly high risk near streams e.g. Cobbler Creek	3	4	Extreme
Livestock Pastures	livestock (e.g. sheep, cows)	9800	faecal deposition+runoff	pathogens	mainly sheep grazing; close proximity to water courses and on steep slopes; animal pathogens less infectious to humans	3	3	High
Infrastructure	sewer mains	NA	major earthquake	pathogens	known in other areas, less likely near Salisbury	1	5	High
Rural Residential	septic tanks; livestock (eg chickens, horses)	1912	leak/runoff	pathogens	high risk human pathogens from septic tank failures (rate high in area)	2	4	High
Other	plumbing	NA	cross/illegal connections	pathogens	assumed 1:1000 frequency in dual retic suburbs; audits conducted; plumbing codes	2	4	High
Commercial	mobile businesses	NA	drainage to SW	pathogens	dog-washers; very low vols; regulatory structures	2	1	Low
Development	portable toilets	4200	leak+runoff	pathogens	chem toilets on construction sites, low vols	1	2	Low
Reserve	bushland	4500	fire+runoff	pathogens	impact << turbidity, org C in event of fire	2	1	Low
Reserve	dead animals	4500	runoff	pathogens	only risk if carcass is in stream, impact probably insig	2	1	Low
Urban Residential	pets (e.g. dogs, cats)	1100	runoff	pathogens	low volumes compared to livestock production and sewer failures	2	1	Low
Roads	dead animals	NA	runoff	pathogens	impact probably insig	4	1	Low
Roads	livestock transport	NA	runoff	pathogens	dung falling off trucks onto road, low risk compared to septic/sewer/grazing etc	4	1	Low
Abattoirs	waste disposal	3111	waste disposal/spillage+runoff	pathogens	only meat processing in study area	na	na	na
Other	population/land use density	NA	runoff	pathogens	scale of risk ie higher densities present higher & more numerous risks; difficult to compare with mining/agriculture however	na	na	na

LAND_USE	HAZARD	CODE	EVENT	MAR_WQ	COMMENTS	LIKELI.	SEVER.	RISK
Industrial	salt plains	8220	runoff/infiltration	salinity	Former salt marshes/salt flats adjacent to Greenfields wetlands	4	4	Extreme
Other	saline groundwater	NA	intrusion	salinity	possible ingress to Parafield instream basin from saline upper aquifer	2	3	Moderate
Other	Soil salinity	NA	Soil salinity+runoff	salinity	Occasional high salinity in Unity Park from Dry Creek source, maybe soil salinity potential in catchment but little data	2	3	Moderate
Quarry	cuttings	8250	cutting+runoff	salinity	large open cut mines and backfill areas exposing saline groundwater; issue not seen in Parafield sampling (sampling point PC1), probably diluted	2	1	Low
Streams	occurrence of saline tails	NA	runoff	salinity	thought to occur in some systems; data from Parafield sampling point (PDS) does not support	2	1	Low
Construction/Land Development	construction	4200	runoff	turbidity	Temporary so requires regular review, land disturbance; visible sediment on adjacent roads	4	4	Extreme
Building materials supply yard	storage areas, traffic	2031	material handling+/-runoff	turbidity	Uncovered storage, visibly dirty adjacent roads, high bulk transit traffic	5	4	Extreme
Cement Factory	cement production	3690	Runoff	Turbidity	visibly dirty adjacent roads, high bulk transit traffic	5	4	Extreme
Quarry	cutting/landfill	8250	Runoff	Turbidity	large open cut mines and backfill areas	5	4	Extreme
Scrap metal recycling	Storage areas, traffic	6300	material handling+/-runoff	Turbidity	Uncovered storage, visibly dirty adjacent roads	4	4	Extreme
Roads	High traffic vol (>30000 AADT)	NA	runoff	turbidity	>>traffic areas, >>bulk transport, >>accidents	5	3	High
Infrastructure	mains water pipes	NA	burst/repair+/-runoff	turbidity	bursts and repairs are hazardous events; usually involve land disturbance	3	3	High
Horticulture (crops, market gardens)	tillage	9700	tillage+runoff	turbidity	main assoc pollutant is suspended sediment; conventional tillage	4	3	High
Other	carp in wetlands	NA	illegal stocking,	turbidity	carp feeding behaviour (muddling), known turbidity problems in wetlands	2	4	High
Reserve	bushland	4500	fire/runoff	turbidity	Rare but potentially catastrophic event	1	5	High
Livestock	livestock (eg sheep)	9800	overgrazing+runoff	turbidity	overgrazing -> erosion, proximity to water courses	5	2	Moderate
Other	meteorological	NA	extreme weather events, rain/dust storms	turbidity	general increase of all potential pollutants e.g. large storm event	2	3	Moderate
Infrastructure	stormwater GPTs	NA	overflow/blockage+runoff	turbidity	regular cleaning and maintenance programs	2	2	Low
Wood, Cork, Furniture Manufacturing	wood, timber, cork, furniture manufacturing	3300	leak/spill/runoff	turbidity	impact probably insignificant	3	1	Low

LAND_USE	HAZARD	CODE	EVENT	MAR_WQ	COMMENTS	LIKELI.	SEVER.	RISK
Mining	dewatering ponds/detention basins	NA	leak	turbidity	baseflow from storage ponds into SW/GW, only in Cobbler Creek, effect << cuttings	2	2	Low
Other	litter	NA	runoff	turbidity	litter from range of sources that passes through GPTs	3	1	Low
Other	litter	NA	runoff	turbidity	litter from range of sources that passes through GPTs	3	1	Low
Residential	fire	1100	fire+/-runoff	turbidity	fire without runoff may still pollute, proximity and rain will increase risk	2	2	Low
Minor Roads	low vol traffic	NA	runoff	turbidity	<traffic, little-no bulk transport, <accidents	2	1	Low
Other	volcano	NA	erruption	turbidity	unlikely to affect water quality in study area >>>> distance from volcanic activity	na	na	na

Appendix 15 Aquifer treatment of microbial pathogens

A15.1 Introduction

Pathogen transport calculations incorporate available data on aquifer parameters, virus *in-situ* inactivation studies described in the previous section, and literature data concerning interaction of pathogens (viruses in particular) with aquifer material. The predictions of pathogen removal in the ASTR schemes using selected models of transport are reviewed in this section. Note that although the NRMMC-EPHC-NHMRC (2009b) MAR guidelines do not account for pathogen attachment and detachment, it was considered useful to explore the extent to which this might influence potential future reliance on aquifers for pathogen removal.

Pathogen removal in ASR is not considered in this section as the water quality monitoring data for the Parafield ASR bores indicates that it cannot be relied upon for sustainable treatment.

A15.2 Calculation of removal at the ASTR system

The residence time of water in the ASTR scheme has been previously described using numerical modelling. The average pore water velocity (n) based on the minimum travel time between the injection and recovery well can also be calculated by dividing the travel distance (L) by the modelled minimum transit time (t_{min}) (eqn. 6):

$$v = \frac{L}{t_{\min}} \qquad \textbf{(6)}$$

The removal of viruses in an ASTR scheme is calculated as follows (Schijven and Hassanizadeh, 2000) (eqn. 7):

$$\log_{10}\left(\frac{C}{C_0}\right) = \frac{-(\mu_1 + k_{att})L}{2.3v} \qquad \textbf{(7)}$$

where C is the concentration of virus at time t , C_0 the initial concentration of viruses, μ_1.the decay rate, k_{att} the attachment rate, L the distance travelled and v the pore water velocity. Dispersion was neglected as the Peclet number is expected to be much larger than one. This formula combines the components for inactivation and net attachment, that is, attachment is assumed to be irreversible.

Previously in the ASTR system inactivation was considered to be the only process responsible for the virus removal at early recovery times when residence time is at a minimum (Page *et al*., 2010). Hence the storage time and decay rates were the controlling parameters for the virus removal in the scheme. Figure A15.1 shows removal of Adenovirus and Coxsackievirus versus time where the *in-situ* decay experiment results for inactivation rate coefficient were considered to be 0.007 /d for Adenovirus and 0.012 /d for Coxsackievirus.

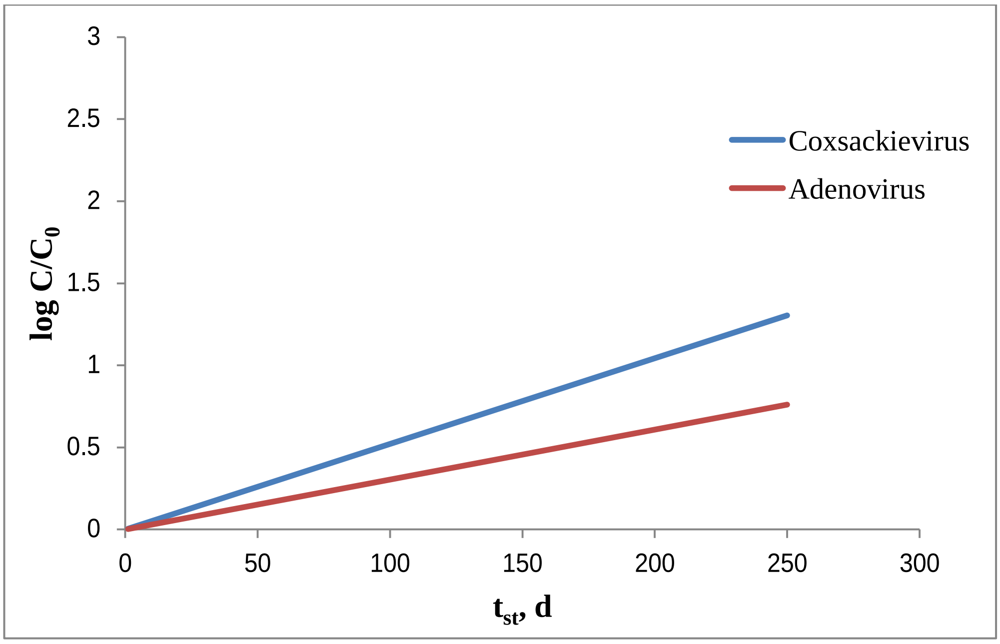


Figure A15.1 Removal of Adenovirus and Coxsackievirus over time through the inactivation process only.

If in the ASTR system both inactivation and the attachment to the aquifer material are considered the potential for virus removal between the injection and recovery wells can be explored (Figure A15.2). The attachment rate coefficient was determined from filtration theory (Yao *et al*., 1971) for a range of α (sticking efficiency) varying from 10^{-5} to 10^{-4}. The other parameter values used in the calculation were: Inactivation rate μ_l of 0.007 /d (the lowest value for Adenovirus and shown in Figure A15.1), pore water velocity (n) of 0.83 m/d, distance (L) of 50 m, porosity (n) of 0.35, virus size of 65 nm, soil grain size of 250 µm (conservatively based on size distribution analysis), diffusion of 6.60×10^{-12} m^2/s (Schijven *et al*., 2006), temperature 20 ^{0}C. Figure 30 shows the removal of adenovirus as a function of attachment factor in the ASTR system.

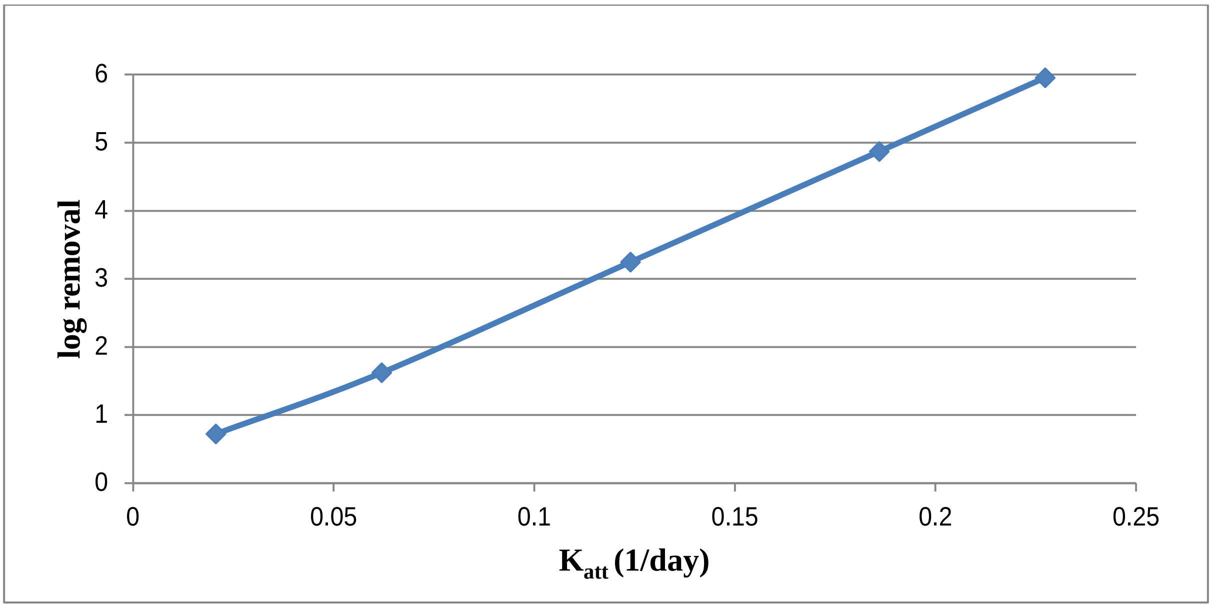


Figure A15.2 Removal of Adenovirus as a function of attachment factor.

Greater $\log_{10}$ removals are likely to be relevant to the ASTR system when attachment to the aquifer is considered. A conservative attachment rate (as the actual value is currently unknown for this aquifer) of

0.023 /d based on α = 10^{-5} would result in 0.8 $\log_{10}$ removal. Further work is needed to evaluate the attachment factor at the ASTR site, to improve the estimate of pathogen removal potential.

Normally the collision efficiency (α) is thought to vary from 10^{-5} to 10^{0} (Schijven, 2001), depending on aquifer mineralogy and cation exchange capacity, which would increase the attachment and removal of viruses as shown in Figure 30. It appears that if K_{att}=0.094 /d corresponding to α = 10^{-4} , a likely conservative value for a limestone aquifer containing iron, a capacity for 6.0 $\log_{10}$ removal of viruses may be available.

According to conventions in the Australian Drinking Water Guidelines however, a maximum of 4.0 $\log_{10}$ can be attributed to any unit treatment process to encourage multiple barrier approaches. Therefore this maximum value is used for the quantitative microbial risk assessment in the following section for viruses. Even though protozoa and bacteria are much larger and also attenuate much more rapidly a similar conservative approach of 4.0 $\log_{10}$ is used for them.

In addition dilution with ambient groundwater is neglected. The injected water is never fully recoverable, which means that dilution with ambient groundwater always occurs. However in brackish aquifers such as the ASTR scheme, dilution is very small. The colloid filtration theory (CFT) used for prediction of virus attachment during ASTR assumes that viruses are attached to solid media through Brownian diffusion and the effects of interception and sedimentation is neglected (Schijven and Hassanizadeh, 2000).

A15.3 Implications of the studies

In a single well ASR system the minimum attenuation of pathogens and viruses is assumed to be controlled by the process of inactivation only. However as the recovery period progresses transport processes could potentially also play a role in reducing pathogen concentrations in recovered water.

In a multiple well ASTR system the fate of pathogens and viruses is assumed to be controlled by the processes of inactivation and attachment to the aquifer material. Time available for inactivation is the time for pathogens to travel from the injection to the recovery wells. This can take into account retardation due to net attachment.

The low rates of inactivation of viruses and *Cryptosporidium* as measured by PCR in this anoxic aquifer are consistent with previously measured values, which were lower than anticipated at the time of construction of the ASTR project. Using conservative values for attachment factor, in the absence of transport data from this site, suggests that log removals for attachment are small and similar in magnitude to those achieved by inactivation after six months of residence time. However prospective rates of attachment, if validated, could produce a six log reduction in viruses and *Cryptosporidium* for ASTR wells with the current 50 m separation distance. The resulting risk assessment accounting for such a reduction, even if only 4.0 $\log_{10}$ are used could result in a significantly cheaper disinfection system and this is likely to justify future effort in validating removal due to net attachment in the aquifer.

Appendix 16 Pathogen inactivation studies

A16.1 Methodology

Two of the Parafield ASTR observation piezometers P1 and P3 (Figure 5) were selected for performing *in situ* pathogen decay studies with diffusion chambers. These monitoring boreholes were found to intercept the injected water in an earlier study (Kremer *et al*., 2010).

A16.1.1 Groundwater Collection

At the ASTR site piezometer (P1) was purged by pumping until the measured parameters (pH, EC and DO) had stabilised prior to the collection of groundwater samples. Then groundwater was collected into sterile, nitrogen-flushed 1 L borosilicate glass bottles and shipped to the laboratory on ice and stored at 4°C prior to use. Prior to assembling the diffusion chambers, the collected water sample was split into two equal volumes and one volume was seeded with the selected bacteria and the other with enteric viruses. An additional portion of the water sample was twice filtered, sterilised (0.22 mm) and used to set up a control experiment.

A16.1.2 *In situ* pathogen decay studies in diffusion chambers

The *in situ* pathogen decay studies were performed using diffusion chambers as described previously (Sidhu *et al*., 2010). Briefly, Teflon chambers with 25 mm diameter and an internal water holding capacity of 7 mL were constructed (Figure A16.1). The chambers were fitted with 0.025 µm pore size (250K) and 25 mm diameter membranes (Millipore mixed cellulose esters). The membranes allowed gradual water flow through the chambers via diffusion, but retained the seeded microorganisms within the chambers.

Figure A16.1 Diffusion chambers used in the pathogen decay study.

Each chamber was assembled by adding ~7 mL of groundwater seeded with either the bacteria or viruses and then sealing the ends with the membranes. The assembled chambers were then connected to a stainless steel cable and suspended in the open interval of the P1 and P3 piezometers at a depth of 170 m. Basic water quality parameters pH, temperature, redox potential, dissolved oxygen (DO), electrical conductivity (EC), dissolved organic carbon (DOC) in the groundwater were recorded on a fortnightly intervals.

The pathogen decay experiment was performed for 105 days from 31st August to 1st December 2011. Triplicate chambers were collected at regular intervals and processed to determine the numbers of seeded pathogens and indicator bacteria remaining. The water sample was then recovered from each of the collected chambers using sterile 21 gauge needles and syringe through the membrane chamber. The collected groundwater was then tested for the presence of the number of seeded microorganisms (as described below). Apart from the enteric virus, all of the microorganisms were quantified within 24 hours of sample collection. Samples for quantification of enteric virus numbers were frozen at -80^{o}C and processed in one single batch at the end of the experiment.

A16.1.3 Microorganisms used in this study

The representative pathogens and indicators tested in this study were: *Escherichia coli* (ACM 1803), and *Enterococcus faecalis* (ACM 2517). *E. coli* and *E. faecalis* was cultured in Nutrient Broth (Oxoid), and Brain Heart Infusion broth, at 37 ^{o}C overnight in a shaking incubator. All the microorganisms were washed twice in sterile phosphate buffer (P-buffer) to remove culture media and then re-suspended in P-buffer prior to use in the pathogen decay experiments (Sidhu *et al*., 2010). This suspension was used to seed groundwater to achieve a final number of ~10^5 cfu mL^{-1} of each microorganism.

The enteric viruses, coxsackievirus B3 and adenovirus strain 41 were cultured in cell lines (African Green Monkey Kidney cells) by PathWest, Western Australia. The viruses were then harvested from and frozen at -80^{o}C until required. The infective viral particles in the viral suspensions were determined using the MPN method in fresh cell culture lawns. The titre for was determined to be 10^9 pfu mL^{-1} for coxsackievirus and 10^7 pfu mL^{-1} for adenovirus.

A16.1.4 Quantification of microorganisms

All seeded bacteria were quantified by spread-plating 100 µL of appropriate serial dilutions with five replicates on the selective agar plates as outlined in Sidhu *et al*. (2008). Briefly, *E. coli* was detected by spread plating 100 µL on Chromocult^{TM} coliform agar (Merck) and *E. faecalis* on Chromocult^{TM} enterococci agar (Merck). Inoculated plates were incubated at 37 ^{o}C overnight and typical colonies were counted averaged between replicates and then multiplied by the dilution factor to determine the average number of colony forming units per mL.

A16.1.5 Viral nucleic acid extraction and quantification

Viral RNA/DNA was extracted from the samples using a BD biosciences Clontech NucleoSpin® kit as per manufacturer instructions. Final elution (50 ml) was collected in sterile RNase free tubes and stored at -80 °C prior to analysis. All analysis for virus quantification was performed in triplicate. Virus numbers in the samples were quantified via real-time PCR. Quantitative RT-PCR and PCR reactions were run on a BioRad iCycler, using iScript one step RT-PCR kit and PCR Supermix (Bio-Rad) kits. Adenovirus was detected using primer set used by Heim *et al*. (2003) and coxsackievirus was quantified by using primer sets previously used by Abbaszadegan and Delong (1997).

The thermal cycling conditions for coxsackievirus was as follows: 30 min at 50 ^{o}C, initial removal of reverse transcriptase at 95 ^{o}C for 5 min, then 45 cycles at 95 ^{o}C for 30 sec, 60 ^{o}C for 30 sec and 72 ^{o}C for 30 sec. Thermal cycling conditions for adenovirus were: Initial incubation at 95 ^{o}C for 8 min and 30 sec, then 55 cycles at 95 ^{o}C for 30 sec, 55 ^{o}C for 20 sec. 72 ^{o}C for 20 sec. as outlined in Sidhu *et al*. (2010).

A16.1.6 Pathogen decay chamber data analysis

All numbers of all microorganisms at each sample interval were $\log_{10}$ transformed and plotted as a function of time. Pathogen and indicator numbers were averaged from three replicates (chambers) and used to estimate the first order removal rate (μ_1):

$$\frac{\partial C}{\partial t} = -\mu_l C \qquad \textbf{(8)}$$

where C is the concentration, t is time, μ_l is the inactivation rate coefficient (slope of the line of best fit). Thus one $\log_{10}$ reduction time is calculated as:

$$T_{90} = \frac{1}{\mu_l} \qquad \textbf{(9)}$$

A Student's *t-test* was performed to compare the inactivation times (T_{90}) of different pathogens under different conditions. The critical *P*-value for the test was set at 0.05.

Based on this approach a length of the storage period must be long enough to facilitate inactivation of a contaminant. Hence the removal of viruses in an ASR scheme is calculated as follows:

$$\log_{10}\left(\frac{C}{C_0}\right) = \frac{(-\mu_l t_{st})}{2.3} \qquad \textbf{(10)}$$

where C is the concentration in recovered water, C_0 is the concentration in injected water, and t_{st} is the length of the storage period.

A16.2 Results

A16.2.1 Groundwater characteristics

During the pathogen decay studies water samples were collected from both P1 and P3 boreholes and water quality analysed. Both boreholes had very similar groundwater characteristics with 18-19 °C temperature, very low DO of 0.8 mg/L, redox potential of ~80 mV SHE with low DOC of <2 mg/L (Table A16.1). The value of electrical conductivity (357-592 µS/cm) indicates that groundwater was fresh during the duration of the experiment (Table A16.1).

Table A16.1 Groundwater characteristics (n=3) of two boreholes used in this study; mean (±stdev)

Parameters	P1	P3
pH	7.9 (±0.1)	8.0 (±0.1)
Temp (°C)	18.3 (±1.5)	19.8 (±1.4)
DO (mg/L)	0.8 (±1.2)	0.8 (±1.2)
EC (µS/cm)	592 (±44)	357 (±18)
Eh (mV SHE)	85 (±70)	82 (±55)
Turbidity (NTU)	19 ±(3)	3 ±(4)
NO_3^- (mg/L)	<0.05	<0.05
SO_4^{2-} (mg/L)	27 (±2)	12 (±7)
DOC (mg/L)	1.9 (±0.9)	1.6 (±0.7)
TOC (mg/L)	1.8 (±0.9)	1.6 (±0.4)

A16.2.2 Decay of pathogens and indicators in groundwater

The rate of microbial indicator and pathogen decay in boreholes P1 and P3 are presented in Figure A16.2-Figure A16.4 and summarised in Table A16.2. The total duration of *in-situ* pathogen decay studies was 105 days in P1 and 78 days in P3. Slower decay was observed for both enteric viruses in this study, for a comparison with other reported studies an extrapolation of T_{90} values (Table A16.2) based on the observed inactivation rate was made.

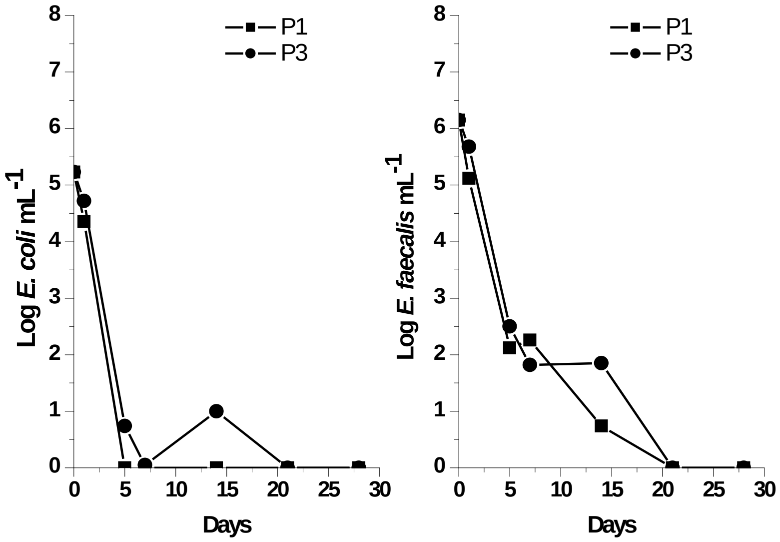


Figure A16.2 *E. coli* and *E. faecalis* decay in boreholes P1 and P3 at ASTR site

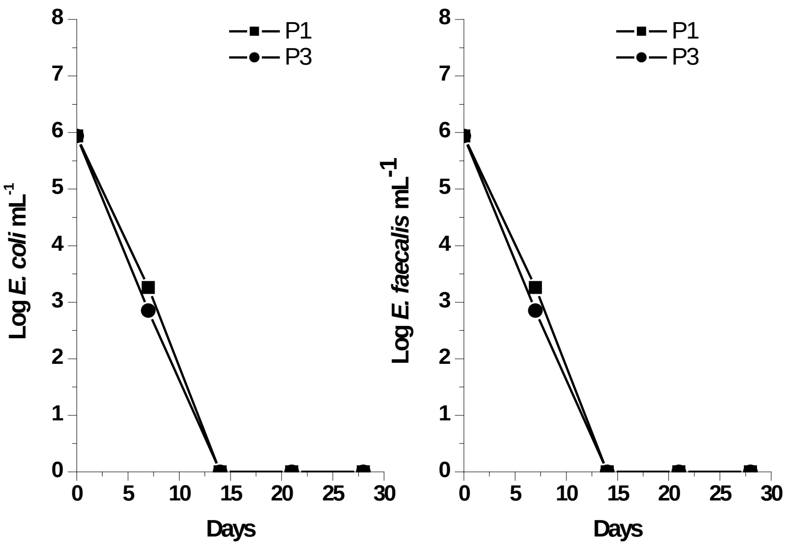


Figure A16.3 *E. coli* and *Enterococcus faecalis* decay in sterile groundwater (control) in boreholes P1 and P3 at ASTR site

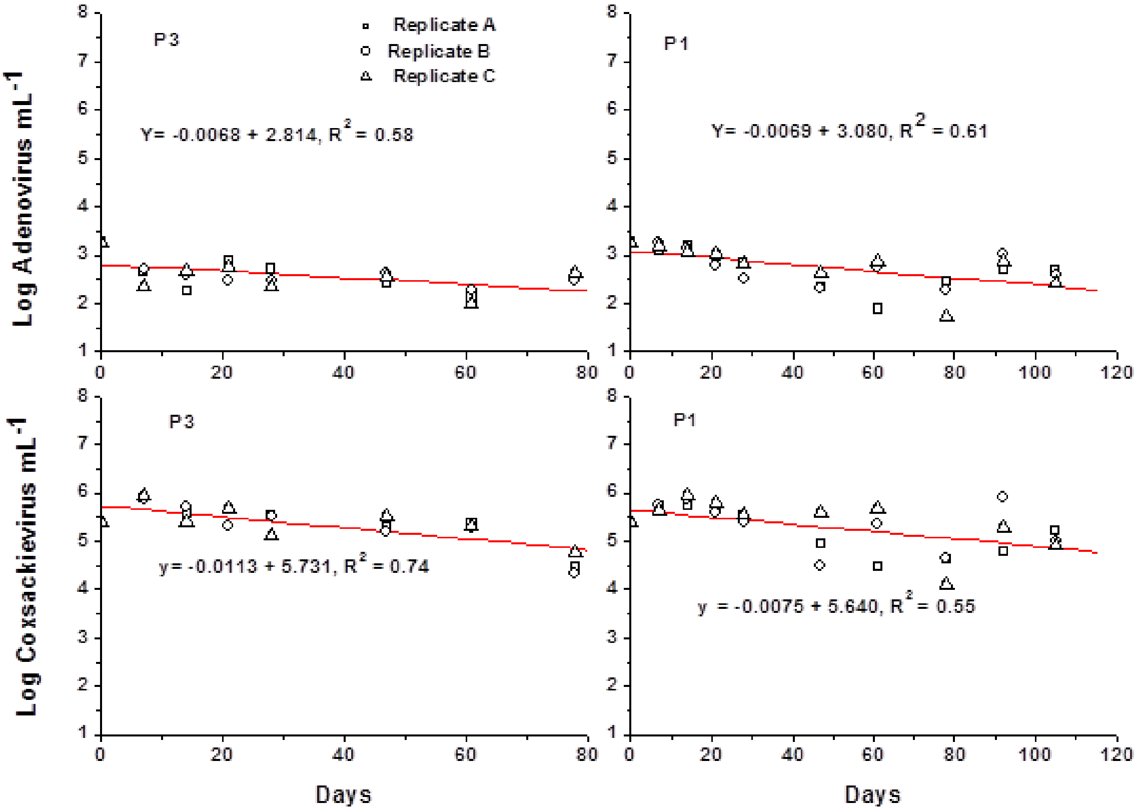


Figure A16.4 Adenovirus and Coxsackievirus reduction decay in boreholes P3 and P1 at ASTR site.

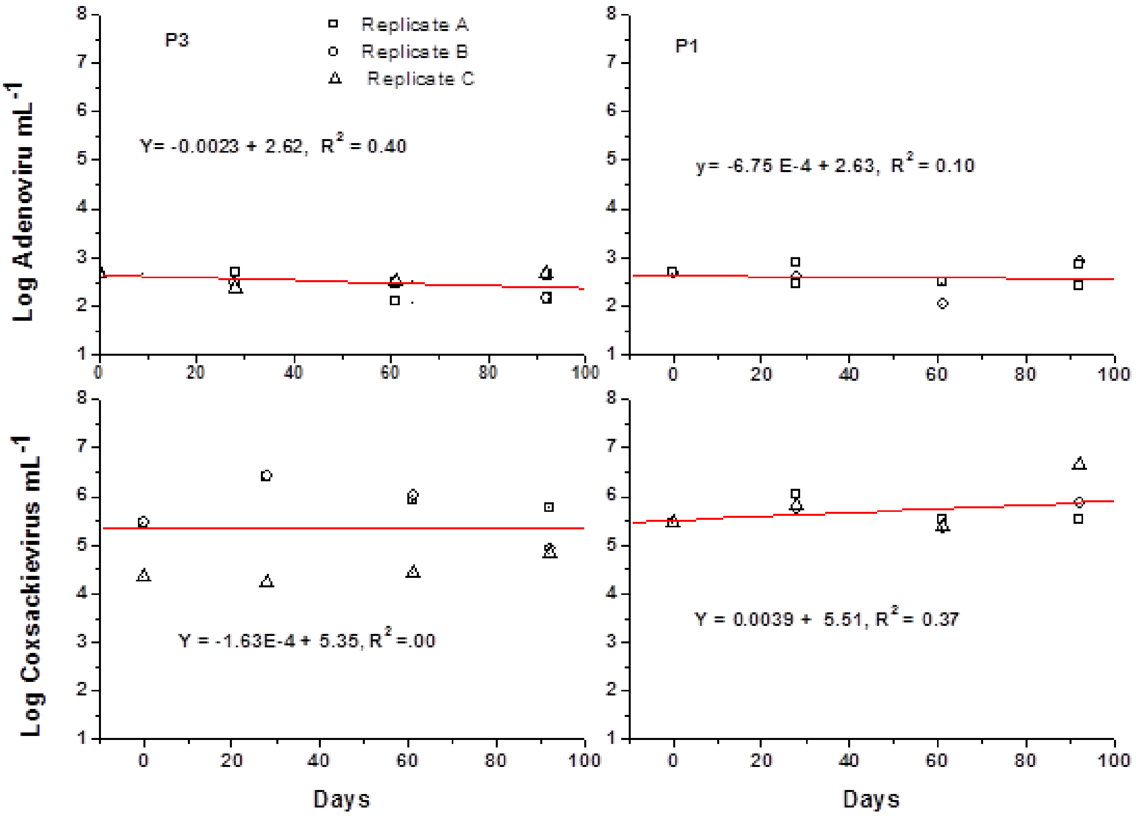


Figure A16.5 Adenovirus and Coxsackievirus decay in sterile water (control) in piezometers P3 and P1 at ASTR site.

Table A16.2 Average T_{90} values for pathogens and indicator microorganisms in groundwater.

Pathogen/Indicator	Parafield ASTR P1		Parafield ASTR P3		Parafield ASR (Sidhu *et al.*, 2010)	
	Non-sterile	Sterile #	Non-sterile	Sterile #	Non-sterile	Sterile #
E. coli	7	7	6	7	0.1	0.2
Enterococcus faecalis	5	5	5	5	2.5	0.6
Coxsackievirus	122	>200	118	>200	>200	>200
Adenovirus	145	>200	146	>200	>200	>200

#Sterile is control with sterile groundwater

Limited inactivation (T_{90} > 200 days) of seeded adenovirus and coxsackievirus was observed in the control experiments conducted with filter sterilised water from both P1 and P3 (Table A16.2). In contrast, rapid inactivation (T_{90} < 7 days) of both *E. coli* and *E. faecalis* was observed in both P1 and P3 in sterile and non-sterile groundwater. Adenovirus appeared to be marginally more resistant to inactivation than coxsackievirus with T_{90} time of 146-174 days as compared to 118-122 days. For the T_{90} values exceeding the duration of the experiment of 105 days the low rate of decay lead to higher variance in the estimates of pathogen inactivation times.

A16.3 Discussion and implication of the pathogen inactivation studies

Bacteria: E. coli and *E. faecalis* decay times (T_{90} values) observed in this study (5-7 days) were slightly higher than < 2.5 days observed in the nearby ASR well in the previous study conducted during November December 2008 (Sidhu *et al*., 2010). This is potentially due to the higher salinity (3,600 µS/cm) at the ASR site during the 2008 study. Whereas, during the current study, aquifer recharge with fresh stormwater with low EC (357-592 µS/cm) contributed to the lower salinity. Adverse effect of salinity on pathogen survival has been previously reported in the literature (Sinton *et al*., 2002).

Viruses: Adenovirus and coxsackievirus decay times (T_{90} values) were >100 days. Coxsackievirus decay time of 118-122 days is comparable to the previous study at ASR site, where coxsackievirus decay time of 109 days was observed at a groundwater temperature of 20°C (±0.5°C). Similarly, adenovirus T_{90} decay times of 146 to 176 days are comparable to >200 days observed in brackish water of the same study. In comparison, T_{90} times of 7 to 10 days at 28 °C was observed for coxsackievirus in the groundwater in earlier laboratory based studies (Toze and Hanna, 2002; Gordon and Toze, 2003). Factors such as higher temperature and the presence of oxygen have been shown to increase the inactivation rate of coxsackievirus and poliovirus in the groundwater (Gordon and Toze, 2003). The lower water temperature (18-19 °C) observed in this study may have enhanced survival of enteric viruses compared to the earlier studies where incubation was performed at a higher temperature. In a published microcosm-based study, adenovirus was reported to survive and remain infectious for up to 364 days in groundwater stored at 12 °C (Charles *et al*., 2009).

PCR-based techniques are very sensitive and specific in detection of virus genomes. However, there could be a difference between the loss of infectivity and complete degradation of viral genomes. It is possible that a virus detected with PCR might not be infectious. Schijven (2001) reported 2.0 to 3.0 $\log_{10}$ less culturable viruses than detectable with PCR. However, currently there is no comparable data available from this study.

Appendix 17 Microbial ecology and biofilm development in aquifer water in ASTR wells

Recognising the likely dependence of pathogen inactivation and biodegradation of trace organic organics on autochthonous microbial communities, it was considered valuable to perform some assessment of the groundwater microbial ecology and determine the extent of changes as a result of MAR operations. This could provide direct ecological indicators of the potential for changes in pathogen inactivation and trace organic chemical biodegradation rates over the longer time at the MAR site.

A17.1 Methods

A17.1 Bio-film incubation chambers

Teflon chambers used for the *in situ* pathogen decay studies were modified to support for biofilm development (Figure A17.1). Briefly, internal space of the chambers was filled with silica (quartz) fine wool (SC0006 - Sercon, Crewe, UK) to provide a substrate for aquifer water microbes. The open sides of the chambers were fitted with metal mesh discs (2-3 mm pores), which allow free flow of water and movement of micro and meso-fauna. All parts the chambers were sterilized by autoclaving (20 min) and assembled in a laminar-flow cabinet to reduce outside contamination. The chambers were added to the cables used to suspend pathogen decay chambers and incubated in the P1 and P3 piezometers. Triplicate chambers from each piezometer were removed after 1, 2 and 3 months of incubation, transported at 4 °C for laboratory processing. In the lab, silica fibre wool from each chamber was removed aseptically, weights recorded and transferred to sterile tubes and stored at -80 °C until further analyses.

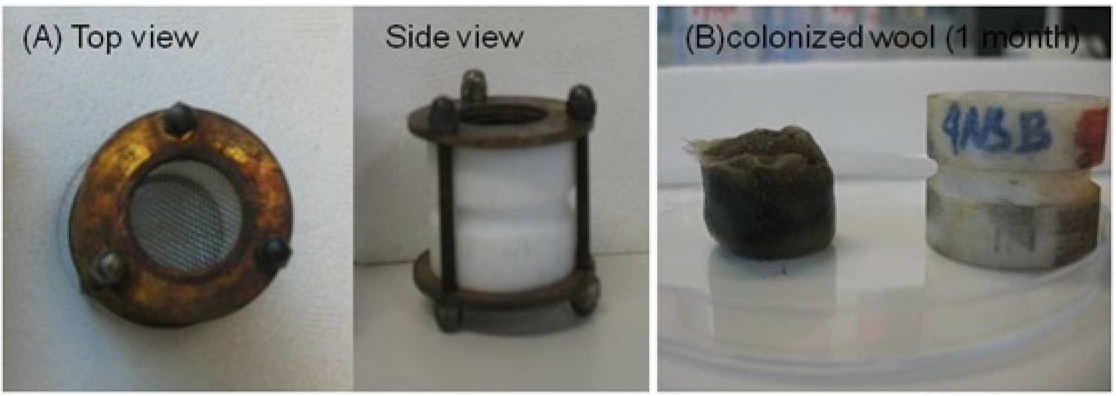


Figure A17.1 Teflon bio-film chambers (A) and the silica wool matrix (B) colonized by aquifer water microbial communities.

A17.1.2 DNA extraction and quantification

DNA was extracted from the biofilm samples using PowerMax® Soil DNA isolation kit (Catalogue no. 12988-S, MoBio Laboratories, Inc.) from ~4.5 g of the quartz wool containing the biofilm using the protocol from the supplier. The concentration of extracted DNA was quantified using the Quant-iT™ PicoGreen ® dsDNA reagent according to the manufacturer's instructions and the total DNA from each biofilm chamber was calculated on per unit weight of biofilm matrix. Aliquots of DNA were stored at -20 °C.

A17.1.3 Quantification of the DNA of specific microbial groups

Quantities of total bacteria, fungi and specific group DNA were measured using qPCR method with primers specific for each group i.e. bacteria (16S; Smalla, 1997), total fungi (18S; Vainio and Hantula, 2000), actinomycetes (group specific 16S; Stach, 2003) and *Pseudomonas* species (group specific 16S, Widmer 1998). PCR was conducted on a MxPro3000 real time machine (Stratagene, Australia) and the amount of specific DNA was estimated using standard curves generated with known concentrations of DNA for each group. All the data analysis was performed using the software supplied by the manufacturers. Statistical significance (ANOVA) of the effect of well type and time of sampling was estimated using Genstat 12.1 (VSN International Ltd).

A17.1.4 Diversity of microbial communities

Microbial community profiling techniques such as specific amplicon PCR-TRFLP and PCR-DGGE were used to determine the genetic composition of total bacteria (16S rRNA, Edwards 1989; Weisburg, 1991), total fungi (ITS rRNA; White 1990; Gardes, 1993), actinomycetes (16S rRNA; Stach, 2003) and *Pseudomonas* species (16S rRNA; Widmer, 1998) communities. Group or genus specific primers were used to amplify various communities in PCR reactions; all the primers used were obtained from the literature but the specific PCR conditions were modified as required for these aquifer DNA samples. Following PCR amplification the products were checked for size and specificity by electrophoresis on 2% w/v agarose gels and stained with 3, 8-diamino-5-ethyl-6-phenylphenanthridium bromide (ethidium bromide). For TRFLP analysis, a known quantity of purified DNA was then digested with restriction enzymes specific to each group and analysed for sizes by the Australian Genome Research Facility (Adelaide, Australia) using capillary separation on an ABI 3730 DNA analyser with a LIZ500 size standard.

Analysis of size and intensity data was performed using the GeneMarker analysis software (SoftGenetics Inc.), using default settings for tRFLP analysis, with a minimum cut off of 100 intensity units used to distinguish terminal restriction fragments from background noise. Using the data on band intensities (heights) were the relative abundance of a TRF (phylotypes) in a TRFLP profile was calculated by dividing the peak height of the TRF by the total peak height of all TRFs in the profile. All peaks with heights that were < 0.5% of the total peak height were not included in further analyses. tRFLP fragment data are analysed using the Primer6 software package (Primer 6 *ver* 6.1.12 and PERMANOVA+ *ver* 1.0.2; Primer-E Ltd., Plymouth, U.K.).

For DGGE analyses, forward primers in PCR reaction were tagged with a GC clamp and the products of the PCR mix were subjected to DGGE analysis using an INGENYphorU DGGE electrophoresis system (Ingeny, The Netherlands). Following the electrophoresis, images of stained gels were captured using an Olympus E500 SLR digital camera. DNA fragment position and intensity was determined using the GelQuant software. For each sample, relative abundance of different fragments was calculated and the data analysed using the Primer6 software package.

Abundance data for microbial diversity was transformed and similarity matrices constructed using the Bray Curtis algorithm. Cluster analysis, followed by similarity profile testing was used to identify significant groupings of communities in response to well type and time of sampling. Relationships between samples were mapped in ordination plots using non-metric multidimensional scaling (MDS). Diversity indices were estimated using the 'DIVRSE' function in Primer6 software and the statistical significance (ANOVA) of diversity measures was calculated using Genstat 12.1 (VSN International Ltd).

Glossary

Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES)	Australian Bureau of Agricultural and Resource Economics and Sciences is a research bureau within the Department of Agriculture, Fisheries and Forestry.
Australian Drinking Water Guidelines (ADWG)	The Australian Drinking Water Guidelines undergoes rolling revision to ensure it represents the latest scientific evidence on good quality drinking water.
Australian Land Use and Management (ALUM)	The Australian Land Use and Management classification (ALUM) is based on a classification developed for the Murray-Darling Basin Commission and emphasises the level of intervention in the landscape.
anaerobic	Conditions where oxygen is lacking; organisms not requiring oxygen for respiration.
aquifer	A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water. Aquifer types include confined, unconfined and artesian.
aquifer storage and recovery (ASR)	The recharge of an aquifer via a well for subsequent recovery from the same well.
aquifer storage transfer and recovery (ASTR)	The recharge of an aquifer via a well for subsequent recovery from another well, to allow a minimum residence time in the aquifer before recovery.
aquitard	A geological layer that has low permeability and confines or separates aquifers.
beneficial use	The value of water in sustaining ecological systems, as well as the economic uses of water (e.g. drinking water, irrigation, industrial and mining water supplies). Water-quality requirements are determined by the class of beneficial use.
Campylobacter	A genus of bacteria that is a major cause of diarrhoeal illness.
catchment	Area of land that collects rainfall and contributes to surface water (eg streams, rivers, wetlands) or to groundwater.
conductivity or electrical conductivity (EC)	A measure of the conduction of electricity through water; can be used to determine the total dissolved soluble salts content. EC is measured in µS/cm.
critical control point	A step or procedure at which controls can be applied and a hazard can be prevented, eliminated or reduced to acceptable (critical) levels.
critical limit	A prescribed tolerance that must be met to ensure that a critical control point effectively controls a potential health hazard; a criterion that separates acceptability from unacceptability.
Cryptosporidium	Microorganism that is highly resistant to disinfection; commonly found in lakes and rivers. Cryptosporidium has caused several large outbreaks of gastrointestinal illness with symptoms such as diarrhoea, nausea and stomach cramps. People with severely weakened immune systems are likely to have more severe and more persistent symptoms than healthy individuals (adapted

	from United States Environmental Protection Agency).
Defence, Science and Technology Organisation (DSTO)	The Defence Science and Technology Organisation (DSTO) is part of Australia's Department of Defence. DSTO is the Australian Government's lead agency charged with applying science and technology to protect and defend Australia and its national interests.
Disability adjusted life years (DALY)	DALYs are used to set health-based targets and assess risks for human health in relation to pathogens. DALYs are used to convert the likelihood of infection or illness into burdens of disease; one DALY represents the loss of one year of equivalent full health.
Digital Elevation Model (DEM)	A digital elevation model is a digital model or 3-D representation of a terrain's surface created from terrain elevation data.
Dissolved Air Floatation Filtration (DAFF)	Dissolved air flotation filtration (DAFF) is a water treatment process that clarifies wastewaters by the removal of suspended matter. The removal is achieved by dissolving air in the wastewater under pressure and then releasing the air at atmospheric pressure in a flotation tank or basin. The released air forms tiny bubbles which adhere to the suspended matter causing the suspended matter to float to the surface of the water where it may then be removed by a skimming device.
disinfection	The process designed to kill most microorganisms, including essentially all pathogenic bacteria. There are several ways to disinfect; chlorine is most frequently used in water treatment.
Distribution system	A network of pipes leading from a treatment plant to customers' plumbing systems.
Department of Planning and Local Government (DPLG)	The Department of Planning and Local Government (DPLG) plays a lead role in the creation and maintenance of sustainable communities and in guiding South Australia's growth and development.
E. coli	*Escherichia coli*; bacterium found in the gut. Used as an indicator of faecal contamination of water.
effluent	The outflow water or wastewater from any water processing system or device.
Geographical Information System (GIS)	A geographic information system is a system designed to capture, store, manipulate, analyse, manage, and present all types of geographical data.
guideline value	guideline value The concentration or measure of a water quality characteristic that, based on present knowledge, either does not result in any significant risk to the health of the consumer (health-related guideline value), or is associated with good-quality water (aesthetic-guideline value).
hazard	A biological, chemical, physical or radiological agent that has the potential to cause harm.
hazard control	The application or implementation of preventive measures that can be used to control identified hazards.
Hazard identification	The process of recognising that a hazard exists and defining its characteristics.
hazardous event	An incident or situation that can lead to the presence of a hazard (what can happen, and how it can happen).
indicator	Measurement parameter or combination of parameters that can be used to assess the quality of water; a specific contaminant, group of contaminants or

	constituent that signals the presence of something else.
injectant	The water injected (pumped or fed by gravity) into an ASR or ASTR injection well.
irrigation	Provision of sufficient water for the growth of crops, lawns, parks and gardens; can be by flood, furrow, drip, sprinkler or subsurface water application to soil.
Langelier Index	The Langelier Saturation Index (LSI) is an indicator of the degree of saturation of water with respect to calcium carbonate. It depends on temperature, pH, alkalinity and calcium hardness. Positive values indicate potential for calcite precipitation and negative values can indicate corrosion potential.
log reduction or removal	Logarithmic (base 10) concentration reductions, effectively reduction by a factor of 10. Used in reference to the physical–chemical treatment of water to remove, kill, or inactivate microorganisms such as bacteria, protozoa and viruses.
managed aquifer recharge (MAR)	The intentional recharge of water to aquifers for subsequent recovery or environmental benefit.
inherent risk	The level of risk in the absence of preventive measures; also referred to as inherent or unmitigated risk.
monitoring	Systematically keeping track of something, including sampling or collecting and documenting information.
multiple barriers	Use of more than one preventive measure as a barrier against hazards.
Native groundwater	Groundwater that was present before recharge operations.
Nephelometric turbidity unit (NTU)	A measure of turbidity.
observation well	A narrow bore, well or piezometer; its sole function is to permit measurement of water level and water quality.
pathogen	A disease-causing organism (e.g. bacteria, viruses, protozoa).
pre-treatment	Any treatment (e.g. detention, filtration) that improves the quality of water before injection.
Preventive measure	Any planned action, activity or process that is used to prevent hazards from occurring, or reduce them to acceptable levels of risk.
quality	The totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs; the term ‘quality’ should not be used to express a degree of excellence.
quality assurance	All the planned and systematic activities implemented within the quality system, and demonstrated as needed, to provide adequate confidence that an entity will fulfil requirements for quality.
quality control	Operational techniques and activities that are used to fulfil requirements for quality.
Quantitative Microbial risk Assessment (QMRA)	A method for assessing risks from microbial agents in a framework that defines the statistical probability of an infection from the environmental.
recycled water	Water generated from sewage, grey water or stormwater systems and treated

	to a standard that is appropriate for its intended use.
residual risk	The risk remaining after consideration of existing preventive measures.
reuse	Using water that would otherwise be discharged to wastewater or stormwater systems, for domestic, commercial, agricultural or industrial purposes.
risk	The likelihood of a hazard causing harm to exposed populations in a specified timeframe; includes the magnitude of that harm.
risk assessment	The overall process of using available information to predict how often (likelihood) hazards or specified events may occur and the magnitude of their consequences.
risk management	The systematic evaluation of the water supply system, the identification of hazards and hazardous events, the assessment of risks, and the development and implementation of preventive strategies to manage the risks.
runoff	Surface overland flow of water resulting from rainfall or irrigation that exceeds the soil's infiltration capacity.
salinity	The presence of soluble salts in soil or water. Electrical conductivity and total dissolved salts are measures of salinity.
sewage or wastewater	Material collected from internal household and other building drains; includes faecal waste and urine from toilets, shower and bath water, laundry water and kitchen water.
sodicity	A condition in which positively charged sodium ions cause the soil particles to repel each other, resulting in soil swelling, dispersion and reduced soil permeability.
source water	Water as harvested, before any treatment and before recharge.
stakeholder	A person or group (e.g. an industry, a government jurisdiction, a community group, the public) that has an interest or concern in something.
stormwater	Rainwater that runs off all urban surfaces such as roofs, pavements, car parks, roads, gardens and vegetated open space.
surrogate	Surrogate analytes are used to improve monitoring cost efficiency or reliability for classes of hazards for which representative surrogates are easier to measure or have lower detection levels.
target criteria	Quantitative or qualitative parameters established for preventive measures to indicate performance; performance goals.
Thermotolerant coliforms	Coliform bacteria that originate from the gut of warm-blooded animals and whose presence in drinking water can be used as an indicator for operational monitoring.
Total dissolved solids (TDS)	Total Dissolved Solids (TDS) is a measure of the combined content of all inorganic and organic substances contained in a liquid in: molecular, ionized or micro-granular (colloidal sol) suspended form.
turbidity	The cloudiness of water caused by the presence of fine suspended matter.
virus	Protein-coated molecules of nucleic acid (genetic material) unable to grow or reproduce outside a host cell.
water recycling	A generic term for water reclamation and reuse. Can also describe a specific type of reuse where water is recycled and used again for the same purpose (eg recirculating systems for washing and cooling), with or without treatment in between.

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