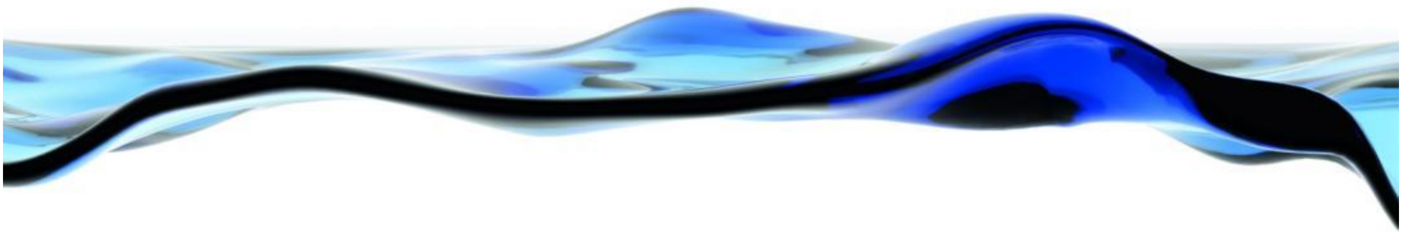
Managed Aquifer Recharge and Stormwater Use Options: Satellite Sites Stormwater Quality Monitoring and Treatment Requirements for Potable Supplies

Vanderzalm, J., Page, D, Gonzalez, D, Barry, K, Toze, S, Bartak, R, Shisong, Q., Weiping, W., Dillon, P. and Lim, M. H.



Goyder Institute for Water Research

Technical Report Series No. 14/10

www.goyderinstitute.org

Goyder Institute for Water Research Technical Report Series ISSN: 1839-2725

The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department of Environment, Water and Natural Resources, CSIRO, Flinders University, the University of Adelaide and the University of South Australia. The Institute will enhance the South Australian Government's capacity to develop and deliver science-based policy solutions in water management. It brings together the best scientists and researchers across Australia to provide expert and independent scientific advice to inform good government water policy and identify future threats and opportunities to water security.

Partner organisations for the MARSUO project are:

Enquires should be addressed to: Goyder Institute for Water Research
Level 1, Torrens Building
220 Victoria Square, Adelaide, SA, 5000
tel: 08-8303 8952
e-mail: enquiries@goyderinstitute.org

Citation

Vanderzalm, J., Page, D, Gonzalez, D, Barry, K, Toze, S, Bartak, R, Shisong, Q., Weiping, W., Dillon, P. and Lim, M. H. 2014, *Managed Aquifer Recharge and Stormwater Use Options: Satellite Sites Stormwater Quality Monitoring and Treatment Requirements Report,* Goyder Institute for Water Research Technical Report 14/10.

Contents

List of Figures

List of Tables

Acknowledgements

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, City of Orange, City of Mount Gambier, Public Utilities Board, Singapore, the University of Jinan, China and the Dresden University of Applied Sciences, Germany. The Dresden University of Applied Sciences supplied data on Haridwar as part of the Saph Pani project (Grant agreement number: 282911) of the European Commission. Data was also sourced from the Water Environment Research Foundation International Stormwater Best Practice Management Database. The authors gratefully acknowledge the review comments of John Radcliffe (CSIRO Fellow) and Steve Gatti (Natural Resources Adelaide and Mt Lofty Ranges) and thank Greg Rinder (CSIRO) for assistance with production of figures.

Executive Summary

This report :

- summarises all available stormwater quality data from sites where harvested stormwater is used, or evaluated for potential use, for drinking water supplies
- relates the water quality data to climatic and catchment characteristics, to existing data on stormwater quality related to non-potable use and to Australian Drinking Water Guidelines
- determines the extent to which the information acquired at Parafield, South Australia, is relevant and representative of stormwater quality and water treatment requirements elsewhere
- illustrates the issues associated with sampling of urban stormwater and the implications for risk assessment and risk management measures, using Parafield as an example
- infers that concepts and methods used in the Managed Aquifer Recharge and Stormwater Use Options (MARSUO) project study site in Parafield, are transferable to assessment of stormwater harvesting for drinking water supplies in Australia and internationally.

This report draws Australian urban stormwater quality data from:

- Parafield stormwater harvesting system, in Salisbury, SA (Page *et al*., 2013a)
- City of Mount Gambier, SA
- City of Orange, NSW,
- Fitzgibbon research site of the Urban Water Security Research Alliance, Qld, and
- Australian Guidelines for Water Recycling (Phase 2): Stormwater Harvesting and Reuse (NRMMC-EPHC-NHMRC, 2009b).

International sources of stormwater quality data were provided for this report from:

- City of Jinan, China
- City of Haridwar, India,
- City of Singapore, Singapore, and
- International Stormwater Best Management Practices (BMP) Database (2010) (version 3.2) accessed at www.bmpdatabase.org, including data from various locations within the USA, New Zealand and Taiwan.

Considering the variety of climates and catchments embraced in the study and the temporal variations in stormwater quality at each site, there was a remarkable similarity in the 95th percentile concentrations for all hazards evaluated across all sites. Hazards for which 95th percentile values exceeded the Australian Drinking Water Guideline (ADWG) values (iron, turbidity, colour and faecal indicators) did so at all sites. Likewise hazards for which 95th percentile values were lower than the ADWG values (other metals (e.g. zinc), salinity (electrical conductivity) and nutrients including nitrate) were so at all sites. This is important in consideration of maximal risk assessments and determining treatment requirements for potable use. Importantly, the Parafield site data were found to be not atypical of stormwater quality for the parameters assessed at multiple sites. This has general implications for stormwater treatment for potable use.

A generalised set of default treatment requirements for stormwater for potable use was determined using the Parafield data set. From this dataset the following $\log_{10}$ removals were derived, namely 5.8 for viruses, 4.8 for protozoa, and 5.3 for bacteria. This is comparable to the Australian Guidelines for Recycled Water that recommend $\log_{10}$ removals of 5.5 for viruses, 4.9 for protozoa and 5.5 for bacteria (NRMMC, EPHC, NHMRC 2009a). Stormwater treatment for potable use would include UV and chlorine disinfection. In addition, if aquifer storage is not used to reduce turbidity, either membrane or media filtration would be required to meet guideline values. Iron removal may also be addressed by chlorine oxidation during disinfection and filtration.

The Parafield assessment highlighted the very high cost of sampling intermittent, brief flows of stormwater for pathogen analyses to support maximal risk assessment for human health. Monitoring throughout the treatment train showed a decrease in the median and the range of *E. coli* numbers at each sampling site in sequence downstream. This decrease is the result of mixing, dispersion and removal processes that occur within the harvesting system and aquifer. It is recommended that guidelines be modified to account for intermittency and practicality of the sampling points for maximal risk assessment as significantly fewer resources are required to undertake a maximal risk assessment at a sampling site where flow is reliable. In MAR systems, sampling of injectant is recommended in lieu of catchment stormwater sampling, for pathogens and other water quality hazards. It is desirable that stormwater be monitored at critical control points of the stormwater harvesting system to allow the diversion of stormwater of unacceptable quality. However, real time monitoring systems are currently unavailable for the majority of relevant hazards..

Aquifer treatment validation will require sampling of both the injected and recovered stormwater. An approved validation methodology, such as a challenge test based on injection and recovery of virus and protozoan surrogates remains to be developed. This is recommended as a high priority for future research.

1 Stormwater harvesting and managed aquifer recharge risk assessment and management

An objective of this report is to demonstrate the transferability of methods, data and concepts concerning water quality risk assessment from the Managed Aquifer Recharge and Stormwater Use Options (MARSUO) project study site in Parafield, South Australia with other sites. This was done through comparisons with several stormwater harvesting schemes in Australia and overseas, including sites where either aquifers (identified (A)) or surface water impoundments were used to store the water. Water quality data was sourced from the following sources

- Mount Gambier, South Australia (A)
- Orange, New South Wales.
- Fitzgibbon, Queensland
- Jinan, China (A)
- Haridwar, India (A)
- Singapore City, Singapore
- various locations within the USA, New Zealand and Taiwan, from the International Stormwater Best Management Practices (BMP) Database (2010) (version 3.2) accessed at www.bmpdatabase.org.

The MARSUO risk assessment and management reports (Page *et al*., 2013a, b; Stevens 2014; Vanderzalm *et al.,* 2014) followed the framework for risk management of managed aquifer recharge (MAR) systems as given in the Australian Guidelines for Water Recycling (AGWR) for MAR (NRMMC–EPHC–NHMRC, 2009a). The generic key steps in the risk assessment and management process include 12 elements as shown in Figure 1. The risk assessment component is captured in Element 2 'assessment of the managed aquifer recharge system'.

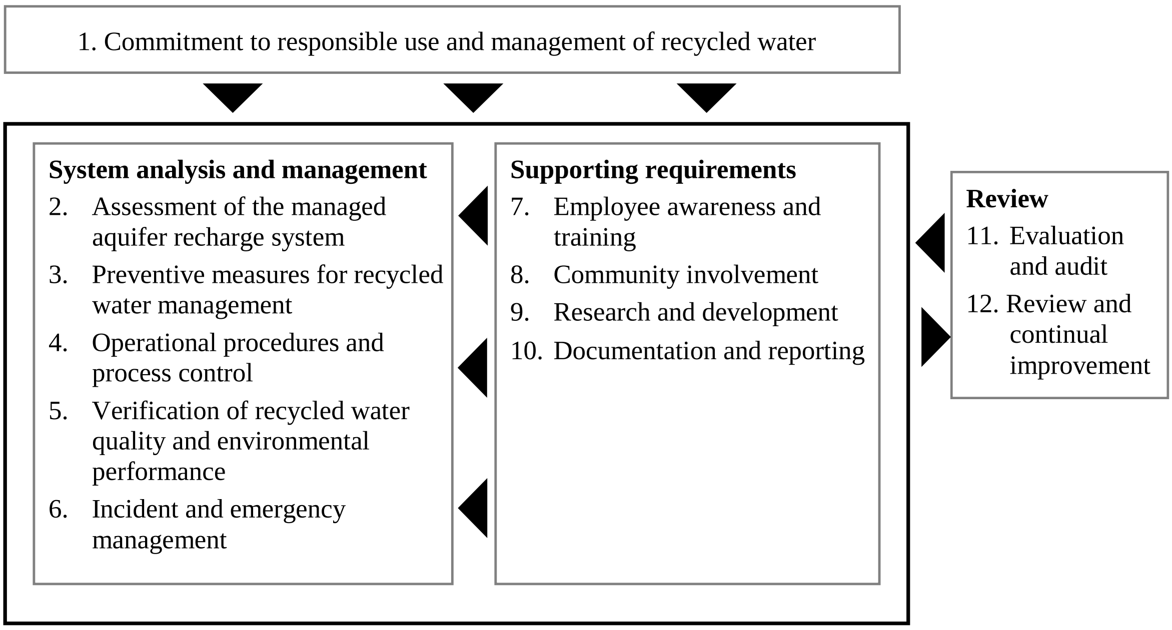


Figure 1 Key elements of the framework for management of managed aquifer recharge systems (after NRMMC–EPHC–NHRMRC 2009a).

For the operator or assessor, Element 2 is designed to *"identify and manage all health and environmental hazards and associated risks in a managed aquifer recharge system. Proponents need* *a thorough documented knowledge of the entire managed aquifer recharge system, from sources of recharged water to uses of recovered water and the fate of recharged water in the aquifer"* (NRMMC–EPHC–NHMRC 2009a). Element 3 covers measures required for hazard exclusion (barriers), reduction (through treatment), and reduction of exposure (usage restrictions) (NRMMC–EPHC–NHMRC, 2009a).

Element 2 requires an understanding of the hazards and hazardous events that lead to risks to human and environmental health through defined exposure pathways. Risks to operational infrastructure (system performance) and aesthetic quality of the product water (i.e. appearance, odour and taste) should also be considered for potable supplies. Assessment of these risks relies on a detailed knowledge of:

- hazards in the catchment and transport pathways of these hazards e.g.land uses, soils, hydrology
- system configuration and operation
- historical water quality data (if available)
- proposed water uses, health and environmental end points and potential exposure pathways, e.g. human contact with irrigation spray drift, receiving environment (aquifer, irrigated land).

This report describes for each satellite site the monitoring methods and results of analyses for a number of water quality parameters. Several parameters common to multiple sites are used to determine the relative difference or similarity between Parafield and the other sites. Comparisons are made between stormwater quality statistics from Parafield, the satellite sites and summary data from an international compilation in the International Stormwater Best Management Practices (BMP) Database (2010) (version 3.2), accessed at www.bmpdatabase.org. This database is a compilation of water quality data from over 500 studies of stormwater best management practices.

Based on the entire water quality data set across all sites, generalised default water treatment recommendations for potable reuse of stormwater are determined along with recommendations for monitoring MAR systems to assess risks to human health and the environment.

2 Assessment of a stormwater managed aquifer recharge system

A critical component for system analysis and management of a stormwater harvesting scheme, as with conventional water supply systems, is an understanding of the nature of the water source. Risk assessment requires knowledge of the characteristics of the stormwater system from "catchment to tap", what hazards may exist, what events may occur to create risks and the processes that may affect stormwater quality. These principles are an essential component of the AGWR (Phase 1) framework for managing water quality (NRMMC-EPHC-AHMC, 2006).

For the larger urban MAR stormwater harvesting systems, flow diagrams may be useful to identify preventative measures for water quality protection, and to understand the level of complexity of the stormwater catchment system. The assessment of stormwater quality may be facilitated by considering sub-catchments with homogeneous land use and careful location of water quality sampling points to assist in determining cause and effect relationships. However, assessment needs to account for the infrequency of many hazardous events e.g. industrial chemical spills.

Effective stormwater quality risk management requires the identification of potential stormwater quality hazards as related to MAR, their sources and any potential hazardous events that may occur. Identifying stormwater hazards can be achieved by:

- recognising land uses and activities in the stormwater catchment that may constitute specific risks to water quality; and
- reviewing stormwater quality data from within the stormwater catchment (if available) for specific trends or issues.

This was undertaken in detail for the Parafield study site and reported in the MARSUO risk assessment and management reports (Page *et al.*, 2013a, b).

Furthermore, stormwater quality can be evaluated as either concentration-based (e.g. management of drinking water quality) or load-based hazard effects (e.g. assessment of marine discharges). Characterisation of load-based hazards is especially important where stormwater discharges to the environment (e.g. stormwater outflows to the marine environment). When reviewing water quality data for specific stormwater catchments, water quality hazards can be identified through:

- exceedances of a guideline value, e.g. public health or environmental trigger level, depending upon specific exposure pathways
- temporal trends in a data series
- anecdotal information, e.g. observation of ecosystem impacts.

The following chapter (Chapter 3) addresses rainfall and land use characteristics for each catchment, while Chapters 4 to 6 address stormwater quality. Chapter 4 provides an overview of stormwater monitoring programs, Chapter 5 summarises the stormwater quality data and Chapter 6 compares stormwater quality hazards across the range of catchments considered.

3 Stormwater catchment characteristics

This report includes a comparison of four Australian and three international study sites. Not all sites include MAR. The sites are briefly summarised as follows:

- Parafield, South Australia – functioning stormwater MAR site for non-potable supply options.
- Mount Gambier, South Australia – functioning stormwater recharge site for indirect potable supply.
- Orange, New South Wales – stormwater harvesting for indirect potable supply via a dam; operational from 2002 – 2010 during drought.
- Fitzgibbon, Queensland – stormwater quality study site for determining health risks for potential use; no harvesting, MAR or use of stormwater.
- Jinan, China – pilot study site roof rain water harvesting for indirect potable supply.
- Haridwar, India – functioning river bank filtration (RBF) site using rural and urban runoff in the River Ganga as water source for potable supply from community wells after aquifer passage.
- City of Singapore, Singapore – full scale stormwater harvesting for indirect potable supply via a water supply reservoir; part of the city's regular water supply.

An overview of each of the characteristics of each catchment (e.g. climate, topography, soils, land use etc.) and system configuration are given in Sections 3.1 – 3.7. Table 1 compares the general attributes of the stormwater catchments. The International Stormwater Best Management Practices (BMP) Database (2010) (version 3.2), accessed at www.bmpdatabase.org, represents numerous catchments that are not described separately in this section.

3.1 Parafield, SA

The Parafield system is a fully operational stormwater harvesting and non-potable reuse system. Parafield, South Australia, is located approximately 20 km north of the capital city, Adelaide.. The region has a temperate climate with a long term average annual rainfall of 453 mm concentrated in the wetter months of winter (BOM, 2013). The Parafield system comprises 2 urban stormwater sub-catchments; the Parafield catchment (15.9 km^2) and the Cobbler Creek catchment (10.2 km^2). Water collected at the Cobbler Creek dam is periodically released and a proportion of this flow is used to augment harvest volumes via transfer to the Parafield system. The headwaters of the Cobbler Creek catchment are at 316 metres above sea level (masl) and flow westwards to the harvest point at 12 masl, giving the combined catchments a mean slope of 3% (Page *et al.*, 2013a).

Total impervious area is estimated at 40% and Parafield catchment yield has been estimated using the WaterCress model at a mean of 1.2 GL/year (Richard Clark, pers. comm.). Parafield catchment land use is primarily urban residential with a light industrial and commercial precinct and some horticulture (market gardens). Cobbler Creek catchment has a more rural character and features agricultural and extractive industries (sand and clay quarries), urban and rural residential zones, some commercial areas and very little industrial land use (Page *et al*., 2013a). Soils in the upper horizon across the area are sandy to silty loams and clays (ASRIS, 2013). A weir diverts water from the Parafield drain into the in-stream basin (50 ML), which is the first of three stages of the stormwater harvesting system. The in-stream basin serves as an initial settling basin for sediments and gross pollutants. Water flows into the in-stream basin during a storm event and is pumped at ~3 ML/hour to the holding storage until capacity (50 ML) is reached or the in-stream basin is drained. Water flows by gravity from the holding storage into the constructed wetland (25 ML). The wetland is diamond shaped with the inlet and outlet at the apexes and has been vegetated with seven different species of reeds, planted in parallel rows that are perpendicular to flow and is designed to achieve a minimum holding time of 7 days. Harvested stormwater is currently used to recharge a deep, confined limestone aquifer for non-potable uses in public open space irrigation, industrial process water and supply to a dual reticulation supply system (Mawson Lakes Recycled Water Scheme). Aquifer residence time varies according to operation of the recharge and recovery cycles but operations target a minimum of 10 days residence in the subsurface (Page *et al.*, 2013b).

3.2 Mount Gambier, SA

The City of Mount Gambier's drinking water supply, the Blue Lake, is a volcanic crater that penetrates the extensive Gambier Limestone aquifer that receives input from stormwater runoff (Telfer and Emmett, 1994; Wolf *et al.,* 2006) via drainage wells. This system is an example of a stormwater harvesting system for potable use that has been operating since the 1880s (Vanderzalm *et al*., 2011). Mount Gambier is located in the south-east part of South Australia, 375 km south-east of Adelaide. The regional climate is temperate with distinctly dry summers and wet winters and the long term average annual rainfall is 713 mm (BOM, 2013). The urban stormwater catchment has an area of 27 km^2 and contains drainage wells that replenish the aquifer directly and therefore the Blue Lake under gravity. Catchment mean slope is 4.8%. Aquifer residence time varies and is estimated to range from 1 to 20 years and Blue Lake residence time is calculated to be 8 ±2 years. Total impervious surface is estimated at 41% and catchment yield is an estimated 2.9-4.2 GL/year (Wolf *et al.,* 2006). Soils in the upper horizon within the catchment are sandy, silty or clay loam (ASRIS, 2013). Land use is primarily residential and public open space but also contains a variety of commercial businesses. There are two main industrial precincts and timber processing is the main heavy industry operating in the catchment (Wolf *et al.,* 2006).

3.3 Orange, NSW

The town of Orange is located 200 km west north west of Sydney in the state of New South Wales, Australia. The region has a temperate climate with hot summers. The long term average annual rainfall is 929 mm with an annual average of 87 days of rain (BOM, 2013). The region recently experienced several years of drought conditions where potable water storages for Orange reached a low of 27% capacity in August 2008 (City of Orange, 2013). Stormwater harvesting for augmentation of potable supplies was identified as a viable option forming part of a strategy to address water security. Two schemes were implemented, harvesting stormwater runoff from the Blackmans Swamp Creek and Ploughmans Creek catchments. Stormwater was captured and pre-treated in detention basins prior to transfer to the Suma Park drinking water reservoir. Stormwater harvesting for indirect potable water supply operated during drought, between 2009 and 2010 (City of Orange, 2013). The combined stormwater catchment area is 34 km^2 with a mean slope of 2.3%. Soils in the catchment are a mixture of red earths, brown cracking clays and alluvial soils. Estimated impervious areas total 33% and the combined average annual yield is an estimated 27 GL/year (City of Orange, 2008). Catchments comprise a range of land uses including cropping, horticulture and pasture, urban residential, commercial and light industry.

3.4 Fitzgibbon, Qld

The Fitzgibbon catchment was analysed as part of a review of urban stormwater contamination and human health risk assessment for potable and non-potable use for the Urban Water Security Research Alliance (Sidhu *et al.,* 2012). The Fitzgibbon site is not currently harvesting any stormwater. Fitzgibbon is located 14 km north of Brisbane in Queensland, Australia. The regional area has a subtropical climate and a long term average annual rainfall of 1017 mm evenly distributed throughout the year. The stormwater catchment relating to the sampling point and collected water quality data covers an area of 3.3 km^2 with an estimated total impervious area of 30% (Chong *et al.,* 2013) and has a mean slope of 2%. Soils in the upper horizon within the catchment are light clay to light medium clay (ASRIS, 2013). Land use is a mixture of urban residential, commercial precincts, education facilities and semi-rural land (Chong *et al.*, 2013).

3.5 Jinan, China

The city of Jinan is located within the Shandong Province in the eastern part of China, 370 km south of Beijing. The regional climate is temperate and Jinan receives an annual average rainfall of 670 mm mainly falling from June to September. Jinan is famous for its karstic springs that support landscape water features as well as being the original town water supply. Over-exploitation of groundwater, combined with reduction in recharge due to urbanisation has led to depletion of groundwater levels resulting in intermittent flow and cessation of the springs. A pilot MAR scheme to replenish the aquifer with urban roof runoff was initiated in 2008 (Weiping *et al.*, in press). This small scale scheme applied Australian MAR guidelines to perform Stage 1, 2 and 3 assessments with two MAR trials run in 2011.The urban roof area catchment is 200 m^2 yielding an annual average of 120 m^3. Water quality is generally better than nearby road runoff and the heavily polluted Yellow River, but is impacted by regional air pollution (mainly through accumulated dust) from fossil-fired power plants, cement factories, an oil refinery and construction sites.

3.6 Haridwar, India

Haridwar is located 200 km northeast of New Delhi in the state of Uttarakhand, India. Haridwar's drinking water supplies have been augmented since the 1980s, by extracting water from the Ganga River via riverbank filtration (RBF) (Sandhu *et al.,* 2012; Bartak *et al.,* in press). The Ganga catchment, above the point of RBF, has an area of over 290,000 km^2 flowing down from the headwaters near Gomukh in the Himalayan Ranges at an elevation of 3892 masl to Haridwar at 314 masl (NRCDMEF, 2009). The climate in Haridwar is subtropical, receiving annual monsoonal rainfall averaging 1,256 mm per year and flow in the Ganga is driven by rainfall, groundwater discharge and glacial melt water (CGWB, 2009). The average annual yield of the Ganga at Haridwar is estimated at 23,900 GL (Kumar unpub. report). Catchment soils range from sandy and silty loams and clays to coarse clastic sediments (CGWB, 2009). The submontane, red earth and alluvial soils in the catchment are easily eroded so the catchment above Haridwar can generally be considered highly erodible (NRCDMEF, 2009). Catchment land use above Haridwar is characteristically rural, containing mainly forestry and cropping (CGWB, 2009) and the city itself contains urban industrial, commercial and residential areas as well as agriculture and forestry. The Ganga River is considered highly sacred in the Hindi religion and up to 550,000 people will bathe in the river every day. Additionally, up to 8.2 million people visit during specific days, such as Kumbh, to bathe at Haridwar (Gangwar and Joshi, 2004). Approximately 80% of Haridwar is sewered. Key issues for stormwater management include dumping of garbage into drains, direct discharge of untreated sewage to stormwater drains from the 15-20% of unsewered homes in Haridwar, and silt accumulation and flow reversal in densely populated areas (UDDU, 2007).

3.7 Singapore

Singapore is a small island state with an area of 710 km^2 located on the southern tip of the Malayan Peninsula. Singapore has a tropical climate with two monsoons per year, no dry season and receives an annual average rainfall of 2,400 mm. Despite high rainfall, Singapore also has relied on importing water (from Malaysia) for drinking and has sought alternatives such as indirect potable reuse of highly treated waste water and urban stormwater harvesting to reduce this reliance on imported water (Po *et al*., 2003). Under the Sungei Seletar and Bedok stormwater harvesting schemes, there are two reservoirs that predominantly capture runoff from urban areas. The Lower Seletar Reservoir drains a largely urban catchment area and the Bedok Reservoir receives stormwater pumped from drains in various urban catchments. The combined area of these catchments is 62 km^2 containing an estimated 60% total impervious surfaces and yielding a combined annual average of 50 GL (Dillon *et al,*. 2011). Soil types within the catchment areas are generally weathered granites and alluvial sedimentary deposits (Rahardjo *et al*., 2004). Singapore has separate sewer and stormwater systems and stormwater harvesting catchments are completely sewered. A major deep sewer system was established and this reduces opportunity for sewer overflows. The government has implemented stringent land use planning regulations for the types of industries and activities that can occur in catchments. This included removing and or relocating some industries e.g. petroleum refining, chemical manufacture and abattoirs and working with other industries to reduce point and diffuse pollution sources (Dillon *et al.,* 2011).

Table 1 Stormwater catchment general attributes.

	Parafield, SA	Mount Gambier, SA	Orange, NSW	Fitzgibbon, Qld	Jinan, China	Haridwar, India	Singapore
Average Annual Rainfall (mm)	453	713	929	1017	670	1256[5]	2,400[7]
Average Annual Days Rain (>1mm)	61	119	87	84	na	na	182
Climate	temperate	temperate	temperate	subtropical	temperate	subtropical[6]	tropical
Seasonality	wet winter, dry summer	wet winter, dry summer	relatively uniform rainfall	relatively uniform rainfall	wet summer, dry winter	annual monsoon rainfall[5]	two monsoons per year, no dry season[8]
Catchment area (km^2)	26	27[2]	58[3]	3.3	0.0002	294364[6]	62[7]
Highest Elevation (masl)	316	168	1030[3]	52	na	3892[6]	57
Lowest Elevation (masl)	12	0	740[3]	10	na	314[6]	0
Mean Slope (%)	3.0	4.8	2.3[3]	1.9%	na	2.6	2.2
Soils	sandy loam, loam, silty loam, sandy clay loam	clay loam, sandy or silty clay loam	red earth, brown cracking clays, alluvial soils[4]	light clay, light medium clay	na	sandy and silty loam, clay, coarse clastic sediments[7]	weathered granite, alluvial sedimentary deposits[8]
Stormwater Pipes/Channels (km)	183	na	na	42	na	na	na
Natural Drainage Paths (km)	33	na	na	na	na	na	na
Land use (basic description)	mainly medium density urban residential, light industrial & commercial precinct	mainly medium density urban, residential, some industrial & commercial precincts	mainly low density urban residential, some industrial & commercial precincts	mainly low density urban residential, some commercial precincts	airshed affects rain water quality, coal burning power stations, traffic air pollution	mainly rural, some high density residential, commercial& industrial areas	mainly high density urban residential & commercial, limited industrial land use
Total Impervious Area (%)	40[1]	41[2]	33[3]	30[4]	100	na	60[7]
Average Annual Yield (GL)	1.2[1]	2.9-4.2[2]	27[3]	0.7	0.00012	23900	50[7]

[1]Richard Clark pers. comm.; [2]Wolf *et al.,* (2006); [3]City of Orange (2008); [4]Chong *et al*. (2013);); [5]CGWB (2009); [6]NRCDMEF (2009); [7]Dillon *et al*., (2011); [8]Rahardjo *et al.* (2004); na=not available.

4 Stormwater quality monitoring programs

Stormwater quality from the Australian urban stormwater catchments was compared to summary statistics for urban stormwater catchments reported in the Australian Guidelines for Water Recycling (Phase 2): Stormwater Harvesting and Reuse (NRMMC-EPHC-NHMRC 2009b), international case study sites and summary data compiled in the International Stormwater Best Management Practices (BMP) Database (2010) (version 3.2) accessed at www.bmpdatabase.org.

A summary of urban stormwater quality data for several Australian and international satellite sites is presented in Appendix 1 and 2. The stormwater quality monitoring program, comprising continuous sensor-based measurements, grab sampling, composite sampling or integrated measurements using passive samplers, undertaken for these catchments is briefly discussed separately in Sections 4.1 - 4.8. For sites where more than one monitoring method was used (Table 2), data for different methods were compiled for the summary statistics in Appendix 1 and 2. The total number of analyses undertaken at each site within the various water quality hazard groups is presented in Appendix 3.

Table 2 Overview of stormwater quality monitoring programs.

	Sampling Method				
	Continuous Monitoring	Grab Sampling	Automated Composite	Manual Composite	Integrated/ Passive Sampling
Parafield	X	X	X		X
Mount Gambier		X	X	X	X
Orange	X		X	X	
Fitzgibbon			X		
Jinan		X			
Haridwar		X			
Singapore	X	X			
BMP database		X	X		

4.1 Parafield, SA

Stormwater quality monitoring in the Parafield catchment was conducted between 2003 and 2012. Sampling methods consisted of event-based grab sampling and event-based automatic composite sampling. Integrated (passive) samplers were deployed in the Parafield wetland. Results are presented in Page *et al*. (2013a).

Event-based grab samples were taken during runoff flow events at 9 catchment sites, and the in-stream basin (ISB1) and analysed according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2005) for collection, storage, transport and analysis by a National Association of Testing Authorities (NATA) accredited laboratory. Grab sampling suites included pathogen analyses (protozoans and viruses) necessitating large sample volumes. Results are reported by Page *et al*. (2013a).

Automatic composite samples were taken at the end of the catchment at the Parafield Drain, 450 m upstream of the harvest point (inlet weir). Composite sampling used an ISCO 6700 automatic sampler, triggered by a Campbell data logger set to begin sampling once the water level in the drain had exceed 1000 mm and after the first 5 minutes of flow. Samples were then collected at 500 kL intervals, with up to 24 samples being collected per flow event and pumped into a single refrigerated tank kept at 4°C. Composite samples were aggregated as one 98 L bulk sample to allow pathogen analyses including viruses. Samples were transported to a NATA accredited laboratory for analyses within 24 hours of collection of the final subsample according to procedures and storage times recommended in the Standard Methods for the Examination of Water and Wastewater (APHA, 2005).

Grab and composite sampling results were pooled for calculation of summary statistics in this report and are presented graphically and discussed in Section 5 and tabulated in Appendix 1. Analytes included physiochemical parameters, major ions, faecal indicators (including bacteria, faecal sterols, viruses and protozoa), nutrients and organic carbon, metals and metalloids, and various trace organic compounds including THMs, herbicides and pharmaceuticals.

4.2 Mount Gambier, SA

Stormwater quality monitoring in Mount Gambier was undertaken between 1978 and 1982 (Emmet, 1985) and more recently between 1999 and 2002 (URS, 2000; 2003) and in 2004 (Wolf *et al.,* 2006). Sampling was undertaken by grab sampling at numerous locations. Grab samples were obtained at 5-10 minute intervals during a rainfall event, along with passive or integrated sampling at two locations in 2004.

Grab samples were collected from a road side entry pit or the into a stormwater drainage bore (after triple chamber settling pit) on most occasions. However, samples collected 1999 and 2000 were sampled within the drainage bore itself and may contain some groundwater.

4.3 Orange, NSW

Sampling during scheme establishment and operation (Jan 9, 2002 - Feb 8, 2010) consisted of manual grab samples and field readings, and time based composite samples from 16 sites across the Blackmans Swamp Creek and Ploughmans Creek catchments. Sites were located along waterways and lined stormwater drains (summary data are presented in Appendix 1).

Field measurements included temperature, electrical conductivity, pH, turbidity and dissolved oxygen. Grab and composite samples were analysed for physiochemical properties, major ions, nutrients, organic carbon, biological oxygen demand, metals, faecal indicators, hydrocarbons and various trace organic chemicals including herbicides, pesticides, PCBs, and PAHs (Appendix 1).

4.4 Fitzgibbon, Qld

Stormwater flow events were sampled between March 2011 and April 2012 using a series of 3 ISCO 6700 automatic samplers to collect 24 x 20 L samples in parallel across a stormwater flow event. Samplers were programmed to trigger sampling at different flow levels throughout a flow event. Large sample volumes were required to allow for concentration to enable pathogen analyses (protozoa and viruses). In addition to pathogen analyses, metals, UV and fluorescence spectroscopy for organic contaminants and bioassays for different toxicological endpoints were conducted. Methods for collection, storage, transport and analyses were according to standard methods; a detailed description of sampling methodology is given in Chong *et al.* (2013). Summary data are presented in Appendix 1. All samples for chemical analysis were filtered through a series of meshes (250 μm, 160 μm and 63 μm) and a 1.2 μm glass fibre filter prior to chemical analysis. Therefore it is not possible to compare 'total' concentrations from the Fitzgibbon catchment, which relate to an unfiltered sample, to data from other stormwater catchments. 'Dissolved' samples are those that have also been filtered through 0.45 μm nylon filter.

4.5 Jinan, China

Grab samples of roof runoff were collected from a ceramic tile roof of a 12 storey teaching building, on the campus of University of Jinan, Jinan during 10 rainfall events between 2008 and 2011 (Weiping *et al.,* in press). The runoff was diverted from a 200 m^2 capture area within the total 1,000 m^2 of available roof area. Data presented includes the first flush. Summary statistics for water quality physical characteristics, nutrients, metals and major ions are reported for unpublished data provided by Weiping Wang.

4.6 Haridwar, India

Haridwar stormwater samples were sampled from the Ganga River and the Upper Ganga Canal and therefore represent surface water, containing variable contributions from runoff from urban and rural areas, groundwater discharge and snow melt from the Himalayas (Saph Pani draft report (which cites Saini, 2011; NIH, 2013; Sandhu, 2013, in prep.); Bartak *et al.,* in press). Summary water quality statistics for physical characteristics, inorganic chemicals, turbidity and microbiological parameters from the Saph Pani draft report are presented.

4.7 Singapore

Stormwater was manually grab-sampled from the Singapore Bedok Reservoir, which receives runoff from several urban catchments. Field measurements were also taken from the reservoir. Summary statistics reported in Dillon *et al.* (2011) are presented in this report.

4.8 International stormwater best management practices (BMP) database

The International Stormwater Best Management Practices (BMP) Database (2010) (version 3.2) includes over 500 studies of water quality resulting from stormwater best management practices. Inflow data is presented within this report to represent untreated stormwater. Reported concentrations were a combination of concentrations in grab samples, flow-weighted composite event mean concentrations (EMCs) and time-weighted composite event mean concentrations (EMCs). The inflow water quality may represent stormwater harvested from catchment areas of varying size, encompassing a variety of practices such as biofilters, grass swales, green roofs or wetlands.

5 Stormwater quality in urban catchments

Catchment stormwater quality hazards can be either from point or diffuse sources. Catchment point sources tend to be easier to identify and manage than non-point pollution sources, but are often eclipsed by diffuse source loadings (e.g. copper and zinc from road surfaces).

Stormwater quality varies considerably between storm events, and between catchments. Stormwater catchment characteristics such as land uses are among the most important factors which influence stormwater quality. Although a number of studies have focused on investigating the influence of catchment characteristics on stormwater quality, the studies were limited to water quality parameters such as TSS and nutrients. Additionally, as reported by Meyers *et al*. (2013) the influence of rainfall on stormwater quality is non stationary. In this context, separating the effect of catchment land use on stormwater quality from the rainfall characteristics is confounded. Furthermore pollution may be event triggered, and land use suggests the types of events that occur but not their frequency or likelihood of occurrence. This report does not attempt to relate stormwater quality to land use, but instead compares stormwater quality across a range of urban stormwater catchments.

Appendix 1 gives a compiled summary of Australian stormwater quality data available at the time of writing (April 2014):

- Australian Guidelines for Water Recycling (Phase 2) Stormwater Harvesting and Reuse (Table A 2.3, untreated stormwater quality summary statistics and Table A 2.4, stormwater quality summary statistics from untreated sewered urban catchments in Sydney [1,213 mm average annual rainfall]).
- Parafield stormwater harvesting system (SA); untreated stormwater quality summary statistics from a mixed residential urban catchment (453 mm average annual rainfall).
- City of Orange (Orange, NSW) untreated stormwater quality summary statistics from mixed urban and semi rural catchment (929 mm average annual rainfall).
- City of Mount Gambier (SA) untreated stormwater quality summary statistics from an urban catchment (713 mm average annual rainfall).
- Fitzgibbon, Brisbane (Qld) untreated stormwater quality summary statistics from an urban catchment (1,017 mm average rainfall).

Appendix 2 gives a summary of international stormwater quality data for comparison with the Australian data.

- Singapore city: summary statistics for untreated urban stormwater from a well managed, highly urbanised catchment sampled prior to treatment and storage in a drinking water reservoir (2,400 mm average annual rainfall).
- City of Jinan, China: summary statistics for untreated roof runoff highly affected by poor air quality (670 mm average annual rainfall).
- Haridwar India: summary statistics for untreated Ganga River water from a highly polluted catchment used for drinking water via river bank filtration (1,256 mm average annual rainfall).
- USA, New Zealand, Taiwan - various sites; the International Stormwater Best Management Practices (BMP) Database (2010) (version 3.2) features water quality data pre and post BMP devices across USA (370 locations), New Zealand (5 locations) and Taiwan (1 location). All inlet data were combined to represent raw stormwater.

The Australian stormwater quality summary identifies where water quality hazards exceed the drinking, ecosystem or irrigation water quality guideline values and reports the percentage detections for all data sets, except those from the Australian Guidelines for Stormwater Harvesting and Use where the information was not reported.

Appendix 3 gives a summary of the numbers of analyses across each of the sites. This gives an indication of the magnitude of effort for each of the stormwater monitoring programs. It also highlights the heterogeneity of effort placed on the different parameters.

Stormwater concentrations were compared to the long-term and short-term trigger value levels for agricultural irrigation for soil and plants (chapter 4, ANZECC-ARMCANZ, 2000); the target values protection of freshwater ecosystems as environmental end points (ANZECC–ARMCANZ, 2000); and the Australian Drinking Water Guidelines for non-potable (aesthetic guideline) and potable (health guideline) domestic uses (NHMRC-NRMMC, 2011). Specifically, the target values for 95% level of species protection in freshwater ecosystems (Table 3.4.1) and default trigger value for freshwater lakes and reservoirs in south central Australia (Table 3.3.8) were used for freshwater ecosystem protection (ANZECC–ARMCANZ, 2000). Australian Guidelines for MAR (NRMMC-EPHC-NHMRC, 2009a) specifically consider the following classes of water quality hazards:

- Pathogens
- Inorganic Chemicals
- Nutrients
- Salinity/sodicity
- Organic chemicals
- Turbidity and Particulates
- Radionuclides.

Hence these hazard classes are employed in the following evaluation of water quality parameters for all sites for which data were available to allow comparisons. The Australian National Water Quality Management Strategy Guidelines direct that risk assessments use the 95th percentile of each source water quality parameter for which there is a guideline value for the relevant environmental values (beneficial uses). For each intervening preventative measure such as treatment or exposure control the mean removal as validated or guideline specified value exposure control is then used to determine the preventative measures required to achieve an acceptable level of risk. Hence 95th percentile values are reported (or maxima if insufficient samples) in the evaluation which follows (section 6).

6 Stormwater quality comparison

Box plots (Figure 2) are used to compare indicative parameters for each class of water quality hazards. Parameters selected were those measured at the largest number of sites.

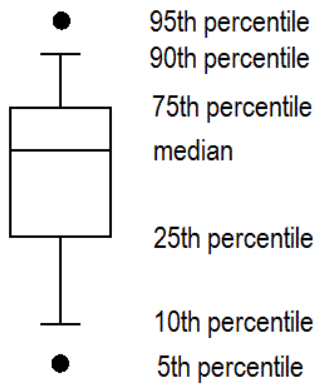


Figure 2 Key to box plots used to compare water quality parameters.

6.1 Pathogens and faecal indicators

Pathogen risks to human health can arise when stormwater is contaminated by sewage or animal faeces. Human pathogens generally enter stormwater through sewer overflows and leakages and the subsequent fate of pathogens varies considerably in the environment. Pathogen risks are applicable to all uses of stormwater where human contact occurs. The most prominent risk would be for drinking water supply where exposure is greatest, but risk is also present in irrigation where exposure may occur.

Pathogen numbers are required for human health risk assessment (Toze *et al*., 2012), but currently there are very few data for pathogen numbers in stormwater. Parafield had calculated 95th percentile pathogen numbers, *Camplylobacter* 11/L, *Cryptosporisium* 1.4/L, and adenovirus 2/L (Page *et al*., 2014a). These numbers were based on a fitted lognormal distribution and were corrected (2 $\log_{10}$ reduction) for infectivity to account for the PCR detection method. Pathogen data in Appendix 1 for Parafield and Fitzgibbon are raw uncorrected data.

The scarcity of data on pathogen numbers in stormwater requires the use of faecal indicator parameters, such as *E. coli* for comparison of stormwater quality across various catchments. The 95th percentile *E. coli* (34,300 cfu / 100 mL) numbers for Parafield stormwater were an order of magnitude lower than the number (240,000 MPN/ 100mL) reported in Australian stormwater in the Stormwater Harvesting and Reuse Guidelines (NRMMC-EPHC-NHMRC 2009b).

E. coli was detected in >90% of stormwater samples at all sites with data except Singapore. Again using *E. coli* as a comparative pathogen indicator, Parafield stormwater has a similar range to Fitzgibbon, Orange and data from sites reported in the BMP database (Figure 3).

Singapore has a lower median and 95th percentile than other sites. This is likely to be due to a number of factors. In spite of Singapore having a greater population density than other catchments, this difference may be due to its deep sewer systems and the location of the sampling point at the reservoir after a residence period, while other sites were event-based samples under flow conditions representing untreated stormwater. Reservoir storage provides an opportunity for pathogen inactivation, as highlighted by one $\log_{10}$ removal times of < 4 days for *E. coli* in a reservoir in Wivenhoe Dam, Queensland (Toze *et al*., 2012). While *E. coli* was not measured in Mount Gambier's stormwater, it has been quantified in the Blue Lake which receives stormwater as a component of groundwater recharge. The median *E. coli* in the Blue Lake is <1 cfu/ 100 mL and the 95th percentile is 6 cfu/ 100 mL. However, in an exposed surface water body there are other more likely sources of *E. coli* than stormwater that has been recharged via the aquifer. In this instance, there is opportunity for inactivation of human pathogens within stormwater during both aquifer and reservoir storage. It will be shown later in this report (section 7.2) that *E. coli* numbers in samples taken at the Parafield site after residence time in detention storage are lower than those in samples of untreated stormwater.

It can be concluded that at all sites treatment for pathogens removal is required based on the presence of *E. coli* as a faecal indicator. It is also concluded that with the exception of Parafield, there is a severe lack of pathogen data on which to base the risk assessments, using the current approach of the Australian National Water Quality Management Strategy Guidelines requiring 95th percentiles for source water quality. This is discussed in section 7.

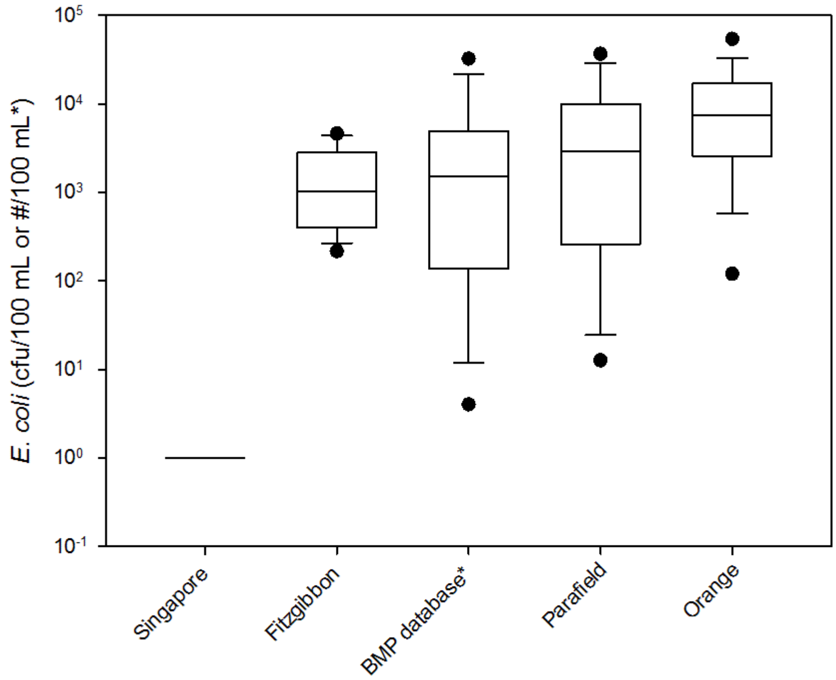


Figure 3 *E. coli* in stormwater from various catchments (Drinking water guideline for *E. coli* is 0 cfu/ 100mL). Limit of detection is 1 cfu/ 100 mL.

6.2 Inorganic chemicals

Inorganic chemical hazards associated with stormwater use and MAR commonly include metals and a range of major ions (NRMMC-EPHC-NHMRC, 2009a). Iron, zinc, cadmium and copper are considered key environmental hazards associated with non-potable use of roofwater or stormwater (NRMMC-EPHC-NHMRC, 2009a).

Total iron (Figure 4) and total zinc (Figure 5) in Parafield stormwater lie within the range reported for both national and international stormwater catchments. Total iron was ubiquitous across all stormwater catchments. The median total iron for Parafield's stormwater of 0.9 mg/L is considerably lower than the median previously reported for Australian stormwater of 2.7 mg/L (NRMMC-EPHC-NHMRC, 2009b), but exceeds the Australian aesthetic drinking water guideline value of 0.3 mg/L (NHMRC-NRMMC, 2011). Median values ranged from 0.68 mg/L and 0.87 mg/L in Mount Gambier and Parafield respectively, to 2.5 mg/L and 2.8 mg/L in Haridwar and the City of Orange (Appendix 2 and 3).

The 95th percentile soluble iron concentration was one order of magnitude less than total iron at Parafield, while at Mount Gambier the median soluble iron concentration was below the limit of reporting. This indicates that iron in untreated stormwater at these sites is predominantly insoluble and may therefore be managed by filtration or sedimentation. In any case, approximately 1 $\log_{10}$ removal of iron would be required to bring stormwater to potable standards.

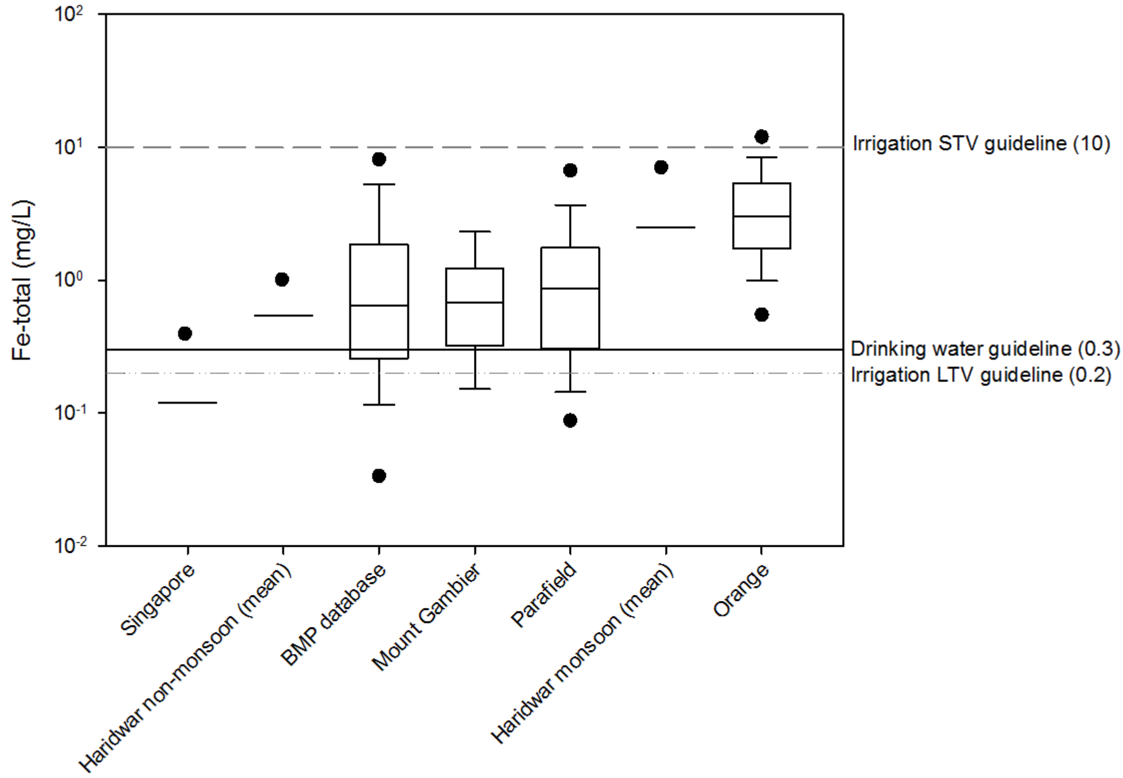


Figure 4 Total iron in stormwater from various catchments.

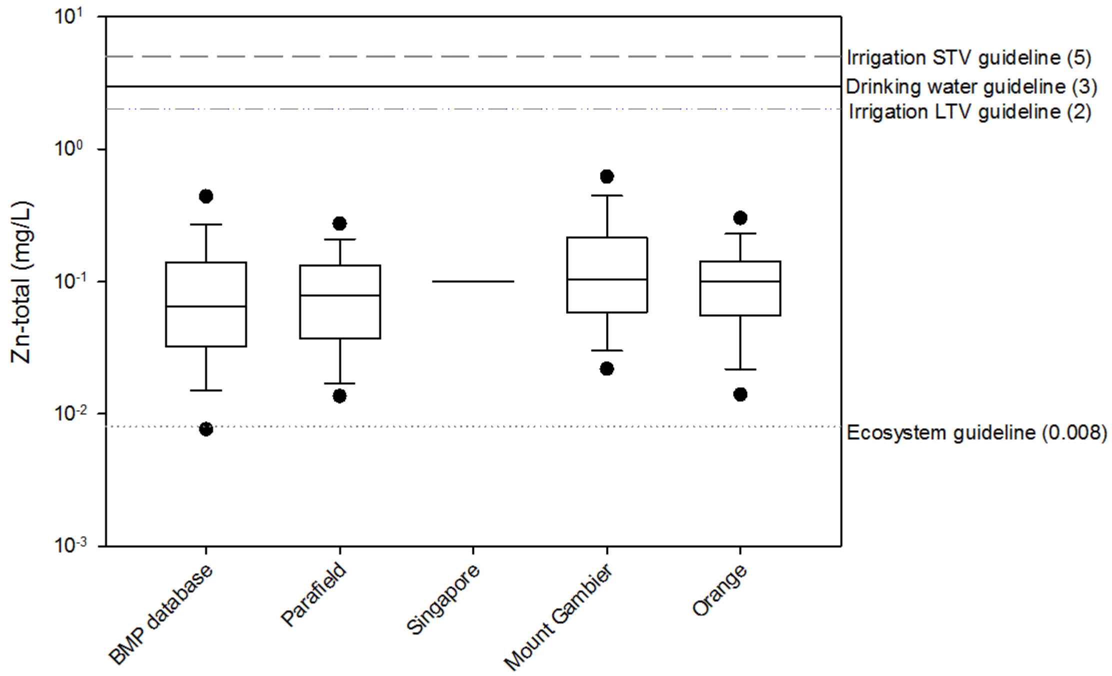


Figure 5 Total zinc in stormwater from various catchments.

Median total zinc concentrations were similar across all sites, with the greatest variability within the BMP database, which encompasses multiple stormwater catchments. Total zinc concentrations in stormwater were below Australian irrigation and drinking water guideline values, but in excess of the Australian freshwater ecosystem guidelines based on protection of 95% of species.

Total cadmium and copper concentrations were comparable across the Parafield, Orange, Mount Gambier and Singapore catchments and were lower than previously reported for Australian stormwater (NRMMC-EPHC-NHMRC, 2009a).

In summary, 95th percentile for iron exceeded drinking water guidelines at all sites, whereas the 95th percentile for zinc and cadmium were lower than the drinking water guideline at all sites with the exception of roof runoff in Jinan. All other measured metals had 95th percentile values lower than drinking water guidelines with the exception of soluble aluminium, lead and manganese, which exceeded at all measured sites and nickel which exceeded only at Mount Gambier. In general the similarities were much greater than anticipated among the diverse sites for 95th percentile (and median) metal concentrations with respect to drinking water guideline values.

6.3 Salinity

The salinity of stormwater should be considered in relation to the intended use. If irrigation is planned, there may be specific salinity guidelines for sensitive crop plants. The sodium adsorption ratio (SAR) should also be considered in relation to soil structure and aquifer permeability impacts.

Stormwater generally represents a fresh water source. Reported median or mean values of electrical conductivity in various stormwater catchments varied between 84 and 228 μS/cm (Appendix 1 and 2), thus meeting the guideline value calculated for irrigation use on salt sensitive plants (650 μS/cm), based on an average root zone leaching factor of 0.33 relevant to loam and light clay soils (see Table 4.2.3 and 4.2.4 ANZECC-ARMCANZ, 2000). The Australian Drinking Water Guidelines (NHMRC-NRMMC, 2011) have total dissolved solids aesthetic guideline of 600 mg/L with greater than 1,200 mg/L being regarded as unacceptable. The position of the total dissolved solids aesthetic guideline value, shown as ~895 μS/cm electrical conductivity (based on EC (μS/cm) x 0.67 = TDS (mg/L), ANZECC-ARMCANZ, 2000), is plotted in Figure 6.

While Parafield stormwater was predominantly fresh with a median total dissolved solids of 130 mg/L and electrical conductivity of 177 μS/cm, this catchment illustrated higher salinity than previously reported for Australian stormwater, but within the range reported in the BMP database.

All stormwater sites for which measurements were obtained had 95th percentile values salinity values (based on electrical conductivity) less than the drinking water guidelines and also the irrigation guidelines.

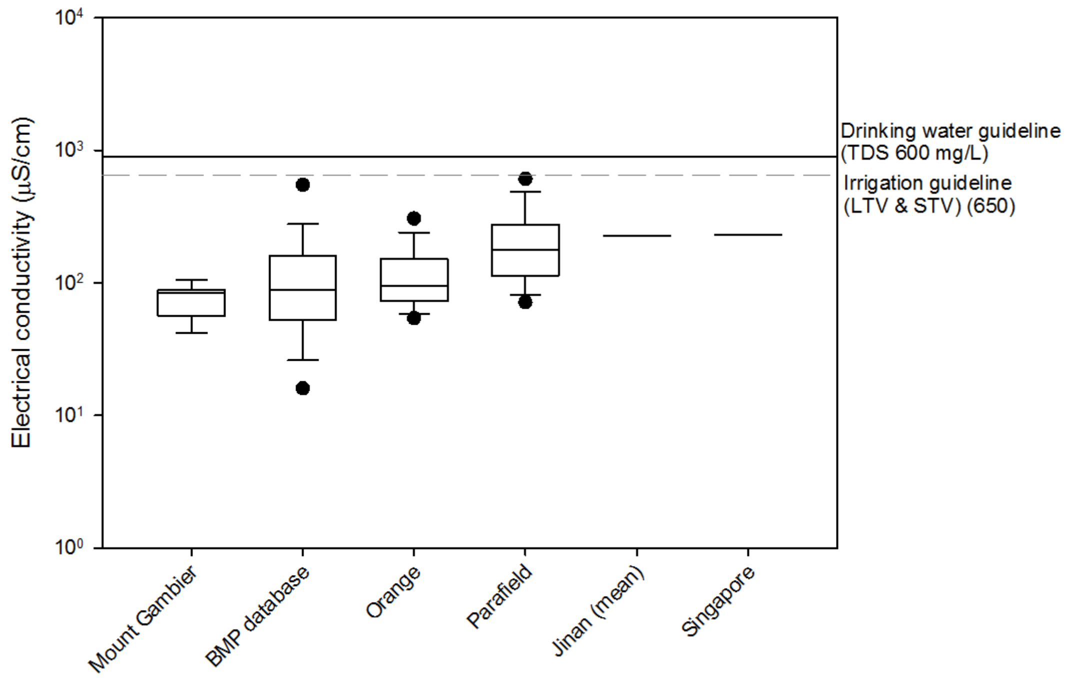


Figure 6 Electrical conductivity in stormwater from various stormwater catchments.

6.4 Nutrients

Nitrogen and phosphorus are considered key environmental hazards associated with stormwater use based on the risks of contamination of receiving environments, eutrophication, toxic effects on plants or nutrient imbalances (NRMMC-EPHC-NHMRC 2009a; Page *et al.*, 2013a).

Nitrogen in stormwater is comprised of a mixture of oxidised (NO_x) and reduced nitrogen species, but organic nitrogen (Organic nitrogen =Total Kjeldahl Nitrogen minus ammonia-N) and nitrate are generally present in higher concentrations than ammonia and nitrite (Appendix 1 and 2). Elevated nitrate-N concentrations in roofwater in Jinan highlight the impact of poor air quality on stormwater (Figure 7). In general, the 95th percentile of nitrate-N concentrations were well below Australian drinking water guidelines.

Total nitrogen values at all sites for which it was measured were similar with 95th percentile values clustered between 3.0 and 5.4 mg/L, close to the long term irrigation guideline value (5 mg/L) (Figure 8). This does not take into account nutrient requirements for specific crops. In all cases median values were similar to, or exceeded, guideline values for protection of high conservation value ecosystems. This suggests that where urban stormwater discharges to such ecosystems there would be value in treating or harvesting the stormwater.

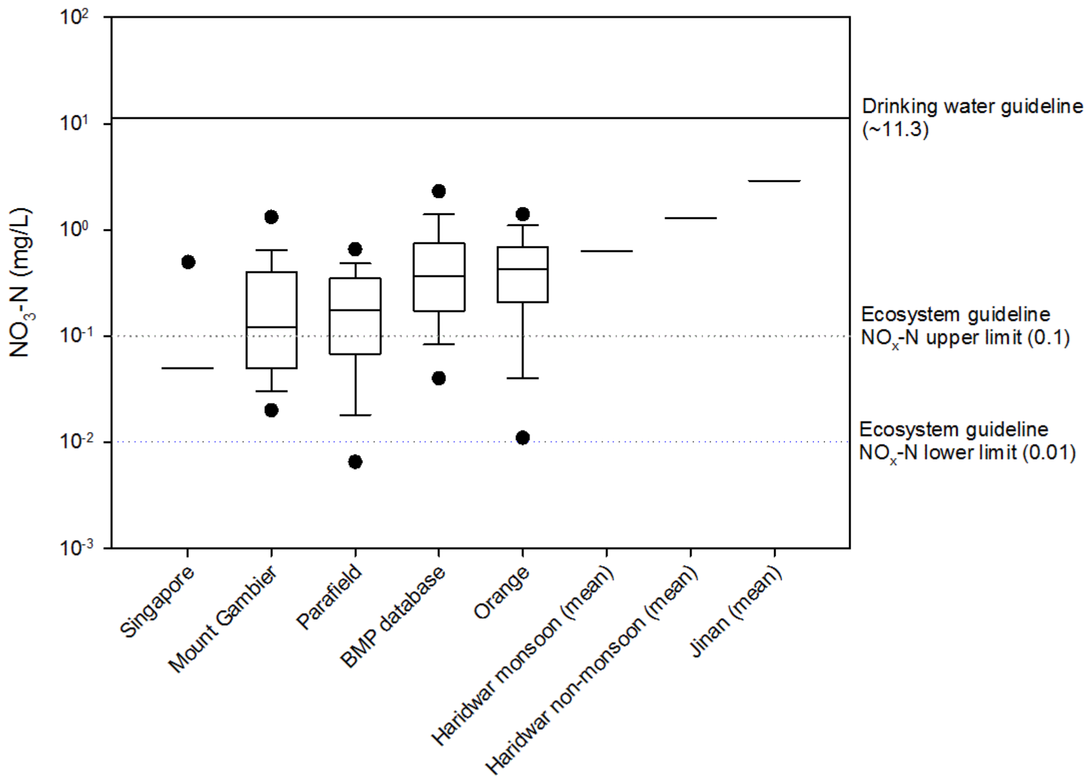


Figure 7 Nitrate-N in stormwater from various catchments (NO_x-N refers to oxides of nitrogen reported as nitrogen).

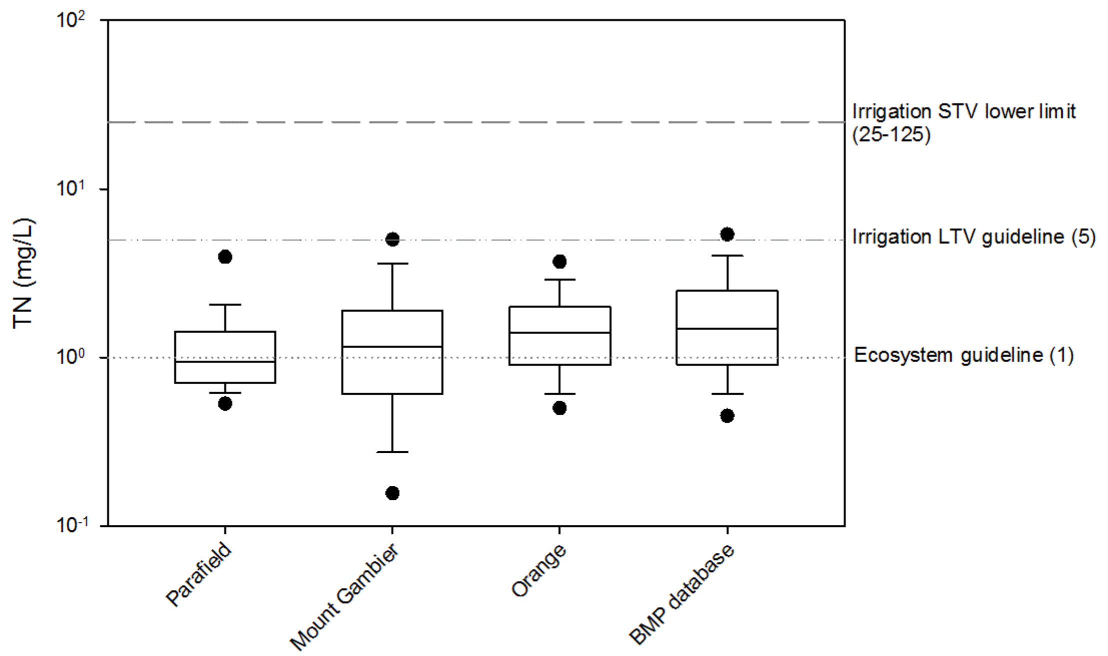


Figure 8 Total nitrogen in stormwater from various catchments.

Total phosphorus concentrations in stormwater from all sites with data showed there is a risk of bioclogging in irrigation equipment for long term irrigation, which has a stringent guideline value of 0.05 mg/L (ANZECC-ARMCANZ, 2000) (Figure 9). There is no drinking water guideline for phosphorous.

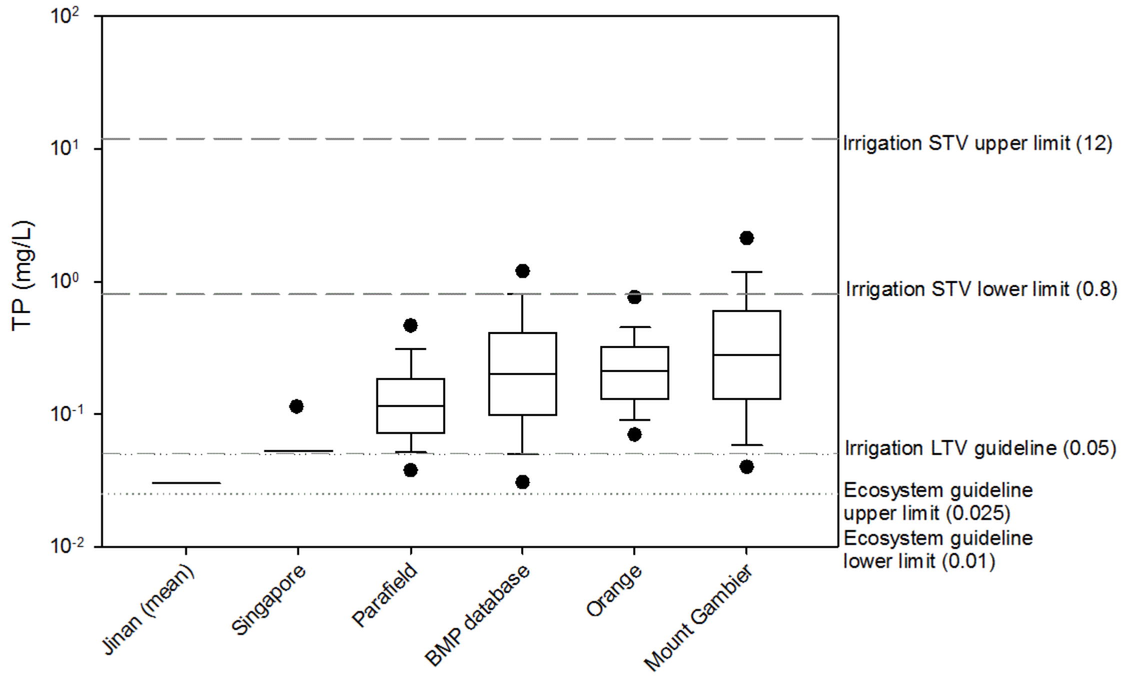


Figure 9 Total phosphorus in stormwater from various catchments.

6.5 Organic chemicals

A broad suite of organic chemicals can be assessed within stormwater quality monitoring and the monitoring suite is generally informed by an assessment of catchment land use hazards. For the Parafield site this was based on evidence from historical monitoring of the Parafield Aquifer Storage Transfer and Recovery (ASTR) system as well as regulatory compliance. Simazine was chosen as an organic chemical indicator parameter for comparison as it was the most prevalent organic chemical measured at Parafield (45% detection) and Mount Gambier (14% detection) (Table 6). The 95th percentile for stormwater from Parafield and Mount Gambier catchments was 1.4 μg/L and 1.5 μg/L respectively (Figure 10). As the majority of simazine concentrations for Parafield and Mount Gambier stormwater were reported as below the limit of reporting, the median value is represented by the limit of reporting (detection limit) in Figure 10. The BMP database included 6 measurements for simazine in Sun Valley Park, California and all were < 1 μg/L. The median value for simazine reported from the Singapore site was also < 1 μg/L.

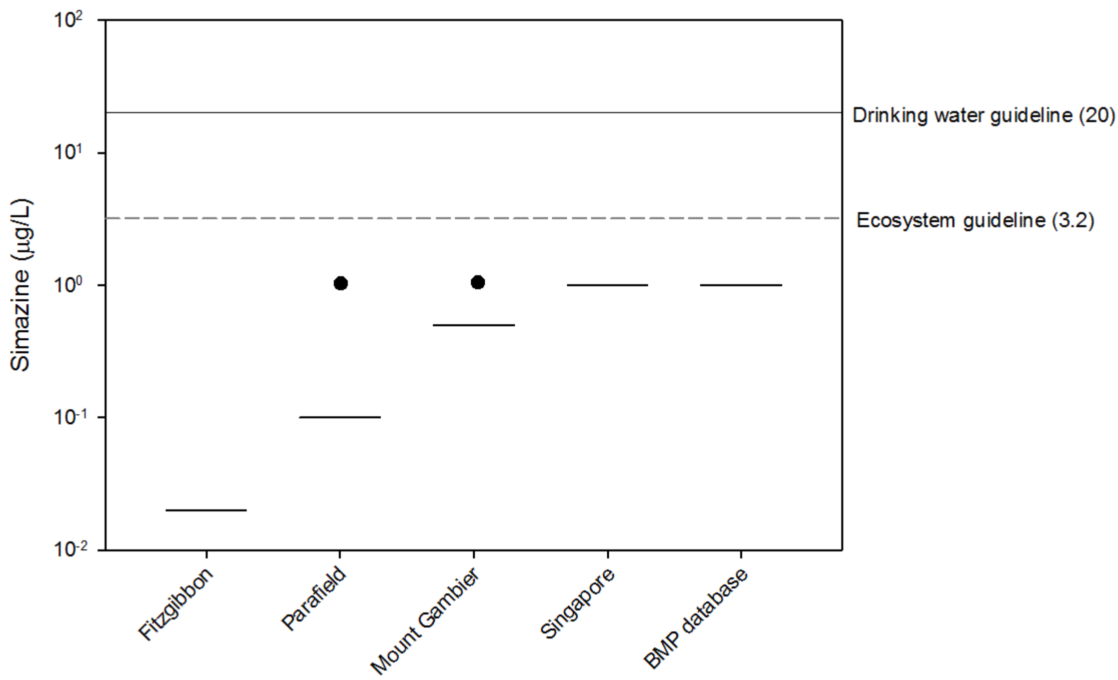


Figure 10 Simazine in stormwater from various catchments (drinking water health based guideline 20 µg/L). The median value is represented by the limit of reporting for Parafield, Mount Gambier, Singapore and the BMP database.

All organic chemicals analysed at the sites are reported in Appendix 2. Sterols which are produced by biota in the catchments and wetlands were detected in up to 100% of samples at Parafield. At Orange and Fitzgibbon various other herbicides and hydrocarbon related products were also detected. The only polyaromatic hydrocarbon analyte that had a 95th percentile concentration exceeding the drinking water value in the Augmentation of Drinking Water Supply Guidelines (NRMMC-EPHC-NHMRC, 2008) was benzo(a)pyrene at City of Orange. Its median concentration also exceeded the value (0.01 µg/L) at this site.

Herbicides, and notably simazine were the most detected organic chemicals, but at no site did the 95th percentile of herbicide analytes exceed the drinking water guideline. However, chemicals whose 95th percentile concentration exceeded the drinking water guideline were found;

- 1-2 dichloroethane and dichloromethane at Parafield.
- Cyanide and benzo(a)pyrene at City of Orange.

In the case of 1-2 dichloroethane and dichloromethane, these halogenated aliphatic compounds were single one off detections. Though these compounds are commonly used solvents no known sources exist in the catchment based on land use. Subsequent sampling did not detect these chemicals again at any locations.

In the case of benzo(a)pyrene, its median concentration of 0.07 µg/L exceeded the NRMMC-EPHC-NHMRC (2008) guideline value (0.01 µg/L) at City of Orange, but was undetected in 5 samples, filtered to <1.2 µm, at a detection limit of 0.01 µg/L at Fitzgibbon. Benzo(a)pyrene was not detected at a higher detection limit of 10 µg/L at the Parafield site. Polyaromatic hydrocarbons, including benzo(a)pyrene, are common products of combustion and are ubiquitous in the environment. There are no key combustion sources identified within the City of Orange catchment that would result in localised polyaromatic hydrocarbon pollution (Chris Devitt, pers. comm.). For comparison, Herngren *et al.* (2010) reported comparable mean concentrations of benzo(a)pyrene in runoff sampled at the Gold Coast, Queensland to the median value at City of Orange. The mean concentration of benzo(a)pyrene in the 0.45-75 µm particle size fraction ranged from 0.11 µg/L in runoff from residential and industrial land use to 0.26 µg/L in runoff from commercial land use. This suggests a benzo(a)pyrene analytical limit of detection of 0.01 µg/L is required for maximal risk assessment for potable use. Polyaromatic hydrocarbons are predominantly particle bound and therefore can be removed via conventional coagulation and filtration treatment processes, or via aquifer passage. Benzo(a)pyrene has a K_{oc} of 6.07, indicating it is highly hydrophobic and will be strongly adsorbed to particulates, including aquifer minerals and a Henry's Law constant of 4.6×10^{-5}, making it unlikely to volatilize to the atmosphere.

These exceedances pose a warning of the potential for organic chemical concentrations to impair the use of stormwater for drinking water supplies unless suitable preventative measures are in place. Preventative measures include isolating sources of contamination, such as putting barriers in place to contain the chemical or excluding use within the catchment.

Treatment for removal of turbidity (section 6.6) is expected to also be effective in removal of some organic chemicals that partition strongly to particulate matter. In aquifer replenishment systems and with stormwater pumped to reservoirs, the 95th percentile concentrations are reduced below guideline values by mixing with bulk stormwater if median concentrations are lower than the guideline value. If following these preventative measures, the 95th percentile concentrations are still excessive then targeted treatments, such as advanced oxidation or granular activated carbon would need to be used.

6.6 Turbidity and particulates

High turbidity can present clogging hazards, in irrigation and MAR operations and is also generally associated with potentially elevated levels of other contaminants (NRMMC-NHMRC-EPHC, 2009a). According to the Australian Drinking Water Guidelines, turbidity can present aesthetic risks (affect visual quality of the water) at >5 NTU and inhibit effective disinfection treatment e.g. chlorination and UV at levels >1 NTU (NHMRC-NRMMC, 2011). The target turbidity for stormwater used for injection via ASR or ASTR in Parafield, after residence time in detention and wetland basins, is ≤5 NTU to avoid well clogging and reduced injection performance (City of Salisbury, pers. comm.).

The median turbidity in Parafield's raw stormwater (prior to detention and wetland residence) was lower than the median for stormwater from Orange and Mount Gambier, but was more variable (Figure 11). Nonetheless, turbidity and suspended solids in Parafield did not exceed the range reported within the BMP database (Figure 12). Elevated turbidity in roofwater, shown for Jinan where turbidity exceeded 1,800 NTU, can be managed by diversion of the first flush.

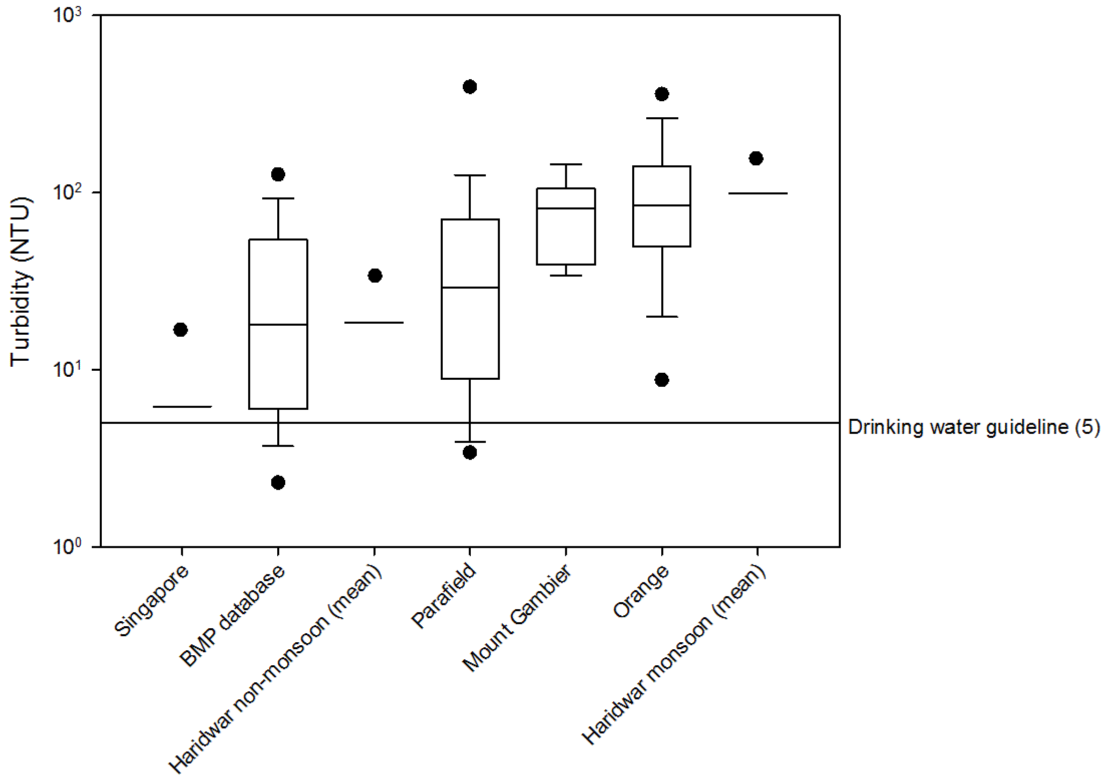


Figure 11 Turbidity in stormwater in stormwater from various catchments.

Suspended solids (and turbidity) may be of inorganic and organic origin. Elevated suspended solids often coincide with higher insoluble metal concentrations. Suspended solids can be managed through filtration or sedimentation, illustrated by the low median turbidity and suspended solids for Singapore after reservoir storage.

The stormwater data from a diversity of sites shows that preventative measures are required at all sites to reduce turbidity to achieve drinking water aesthetic guidelines.

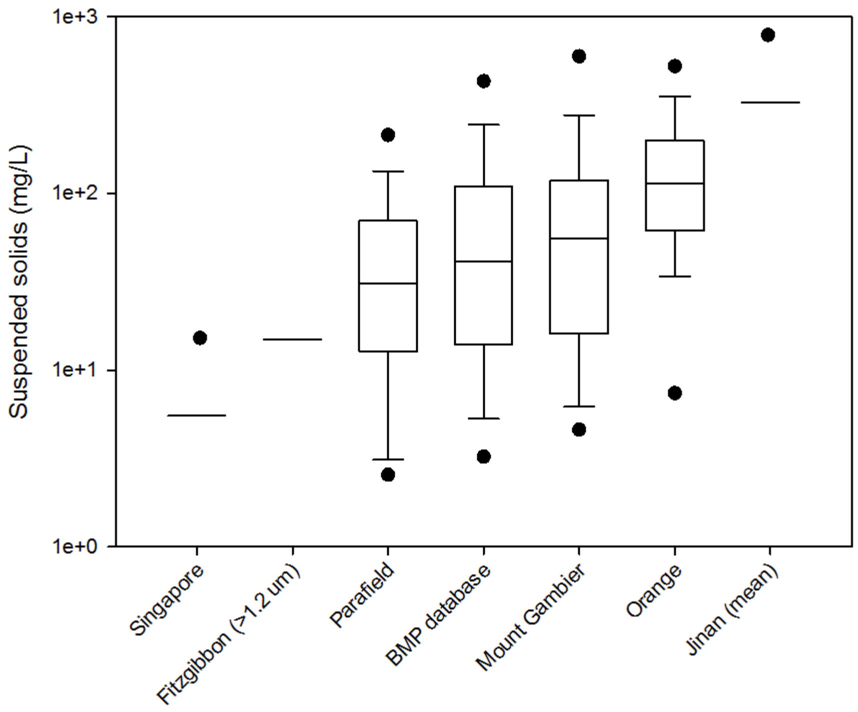


Figure 12 Suspended solids in stormwater in stormwater from various catchments.

6.7 Radionuclides

Radionuclides are not widely assessed as a risk associated with stormwater use. They may be catchment specific in relation to a land use risk assessment, such as in a catchment subject to sewer leaks containing hospital waste or in the vicinity of phosphate mining for fertilizer production. More commonly radionuclide hazards are considered in relation to groundwater use. This would be applicable to the radionuclide content in recovered water when stormwater is used in Managed Aquifer Recharge. Due to the site specific nature of this hazard group, radionuclide data is only available for Parafield and Singapore stormwater. Stormwater gross alpha and gross beta activity remained below 0.5 Bq/L , the screening level recommended within the Australian Drinking Water Guideline prior to analysis of individual radionuclide activity (Page *et al.*, 2013a) in seven samples for the Parafield catchment and in two samples for the Singapore catchment.

7 Discussion

E. coli, iron and turbidity in stormwater from all sites exceeded Australian drinking water guideline values. For other parameters with drinking water guideline values; zinc, total dissolved solids (as indicated by electrical conductivity), nitrate (as indicated by total nitrogen), simazine and radiological activity, had 95th percentile values that met those guidelines (at all sites with measurements). While this is not an exhaustive list of parameters, the similarity of stormwater quality across sites in relation to achieving or not achieving water quality requirements for drinking water is noteworthy.

7.1 Transferability of the Parafield data for risk assessment at other stormwater MAR sites

A summary of the water quality data of Parafield and the other sites is shown in Table 3. Parafield was notable in that it had the lowest rainfall (453 mm) of the sites, but similar levels of impervious areas draining the catchment.

The Parafield monitoring data was generally similar to that of other reported sites. For example, 95th percentile *E. coli* counts ranged between 20 – 54,600 cfu/ 100 mL (or number/100 mL for data reported in the BMP database) across all stormwater sites, compared to 34,300 cfu/ 100mL for Parafield. Even though there is a large variability of stormwater quality within sites, Parafield was found to lie within the 95th percentile value ranges for iron, turbidity, total suspended solids and nitrate. Parafield had the highest 95th percentile concentration for electrical conductivity and also simazine. By contrast Parafield had the lowest 95th percentile concentrations for zinc and total nitrogen.

The Parafield stormwater quality data are not atypical of data from a predominantly residential urban catchments and the risk assessment and risk management methodology could be broadly applicable across Australia when contemplating stormwater harvesting via aquifers.

Intensive catchment sampling may be required if there are suspected point sources of hazards entering the stormwater system that are identified in the stormwater catchment land use risk assessment (e.g. for Parafield in Page *et al*., 2013a).

Table 3 Summary of water quality across urban stormwater catchments.

	Parafield, SA	Mount Gambier, SA	Orange, NSW	Fitzgibbon, Qld	Jinan, China	Haridwar, India	Singapore
Catchment characteristics							
Rainfall	453	713	929	1017	670	1256	2400
Climate	temperate	temperate	temperate	subtropical	temperate	subtropical	tropical
Size (km^2)	26	27	58	3.3	0.0002	294364	62
Total Impervious Area (%)	40	41	33	30	100	na	60

Water quality summary	Parafield, SA				Mount Gambier, SA				Orange, NSW				Fitzgibbon, Qld				Jinan, China		Haridwar, India				Singapore	
																			monsoon		non-monsoon			
	mean	stdev	50^{th}	95^{th}	mean	stdev	50^{th}	95^{th}	mean	stdev	50^{th}	95^{th}	mean	stdev	50^{th}	95^{th}	mean	max	mean	mean	mean	95^{th}	50^{th}	95^{th}
E. coli (cfu/100mL)	23063	103325	2900	34300					15567	28686	6100	54600	2818	1639	3560	4506							1	20
Fe-total (mg/L)	1.8	3.6	0.87	4.7	0.84	0.70	0.68	2.0	3.9	3.8	2.8	11							2.5	5.1	0.54	1.1	0.12	0.36
Zn-total (mg/L)	0.10	0.10	0.079	0.25	0.21	0.33	0.10	0.58	0.12	0.10	0.11	0.30					1.1	5.7					0.1	0.1
EC (uS/cm)	229	159	177	554	77	21	84	100	198	143	143	469					227		148	172	228	281	232	394
TN (mg/L)	1.3	1.2	0.97	5.4	1.6	1.5	1.2	4.9	1.4	1.1	1.1	3.2												
NO_3-N# (mg/L)	0.25	0.30	0.19	0.79	0.37	0.81	0.11	1.1	1.3	0.5	0.43	1.4	0.07	0.03	0.06	0.10	13	57	0.63	0.79	1.3	2.1	0.05	0.48
TP (mg/L)	0.16	0.14	0.11	0.45	0.59	1.2	0.28	1.9	0.2	0.2	0.14	0.52					0.03							
Simazine (µg/L)	0.3	1.0	<0.1	1.4	1.8	1.5	<0.5	1.5					0.02	0.01	0.020	0.028							<1	<1
Turbidity (NTU)	79	185	29	360	79	37	81	136	85	127	45	321					197	1875	99	142	18	39	6	16
SS (mg/L)	63	104	31	184	177	575	56	530	130	188	72	509					329	726					6	14

#NO_x-N at Parafield

7.2 Water treatment requirements for stormwater harvesting via aquifers and potable use

Stormwater quality, though highly variable both within a particular catchment and between catchments, has similarities in terms of those parameters that exceed a guideline value. For the stormwater investigated in this report, all waters exceeded the Australian Drinking Water Guidelines for *E. coli*, turbidity, iron and colour (originating from iron). In the absence of data it should be assumed that the presence of the faecal indicators such as *E. coli* necessitates that pathogen removal for protozoa and viruses would also be required.

A combination of treatment systems, or 'treatment train', may be necessary to optimise the removal of all water quality hazards so as to meet the requirements for the intended use. Based on the Parafield data set, which is not atypical of urban stormwater, treatment for potable use could include filtration with membrane or media filtration or via aquifer storage; iron removal (either by aeration or chemical oxidation); and disinfection with UV (specifically for protozoa) as well as chlorine (for viruses and bacteria). Such a combination may be required at all satellite sites to meet the health-based targets for potable use. A full discussion of the health-based targets is given for the Parafield site in Page *et al*. (2013a).

The Parafield site was the only stormwater site with sufficient pathogen data to allow a quantitative microbial risk assessment for potable water supplies. Pathogen inactivation credits ($\log_{10}$ removal requirements) were determined to be 5.8 $\log_{10}$ for viruses, 4.8 $\log_{10}$ for protozoa and 5.3 $\log_{10}$ for bacteria. It cannot be assumed on the basis of this report alone that the $\log_{10}$ removals are applicable elsewhere, but they do provide an indication of what is likely to be required. In addition, the treatment requirements for Parafield are comparable to those determined (5.5 $\log_{10}$ for viruses, 4.9 $\log_{10}$ for protozoa and 5.5 $\log_{10}$ for bacteria) using default numbers for pathogens in stormwater given in the Stormwater Harvesting and Reuse Guidelines (NRMMC, EPHC, NHMRC 2009a).

A suite of treatment measures will generally be appropriate to suit the characteristics of a site and proposed end use. Appropriate treatment measures can be selected during the development of a stormwater management plan, which can identify the site constraints and means of stakeholder involvement (particularly the community). The associated stormwater quality management plan (e.g. for non-potable use at Parafield (Page *et al.,* 2013b) and for potable use at Mount Gambier (Vanderzalm *et al*., 2014) incorporates these considerations.

7.3 Recommendations for sampling of pathogens and other source water hazards during water recycling via aquifers

Event-based stormwater quality monitoring at the Parafield data station of the Parafield catchment was very resource intensive. It required an event based auto sampler, stormwater flow gauging linked to a SCADA system, a high volume (200 L) refrigerated storage system for pathogens and organic chemicals and a team of dedicated and trained personnel who were effectively on call over the harvesting period. Attempts to obtain grab samples of stormwater further up in the catchment were logistically difficult due to the very short duration of flow following a storm. Only a few integrated samples of any one storm event could be gathered, due to the transient nature of the storm event hydrograph at the Parafield site. Furthermore, samples from storms could only be received by the analytical laboratory for three days each week and needed to be delivered within 24 hours of sampling.

The large resource cost for monitoring to allow a quantitative microbial risk assessment and the likely stormwater treatment recommendations above suggests a simplification of the monitoring process could be recommended. Sampling of pathogens (especially viruses) at the Parafield Drain to calculate a 95th percentile for the number of viruses in stormwater was undertaken over a 28 month period between August, 2010 and November, 2012. A minimum number of 20 samples was advised by the water quality expert panel and the results are documented in the human health risk assessment report (Page *et al*., 2013a). This assessment follows the approach recommended by the Australian Guidelines for Water Recycling, to characterise the source stormwater quality and calculate the specific pathogen inactivation credits required for specific end uses.

Originally, it was intended to use the pathogen monitoring program to characterise the treatment capacity of the aquifer, which would allow integration between natural and engineered treatment systems. However in the absence of accepted validation methods for natural treatment systems for pathogen reduction, in addition to the high proportion of source water samples without detections, and the high cost of pathogen analyses, the aquifer treatment component at Parafield could not be validated. This very resource intensive stormwater sampling protocol together with the current lack of natural treatment validation for pathogens has lead to recommendation for a revised approach to pathogen sampling for stormwater recycling via aquifers.

As an example, consider the changes in the *E. coli* and turbidity numbers (95th percentile and median), variability (coefficient of variation) and percentage detection across the Parafield system (Figure 13). Harvested stormwater was treated in a wetland then either stored in the aquifer via ASR (single well) system or via an ASTR (separate injection and recovery wells) system.

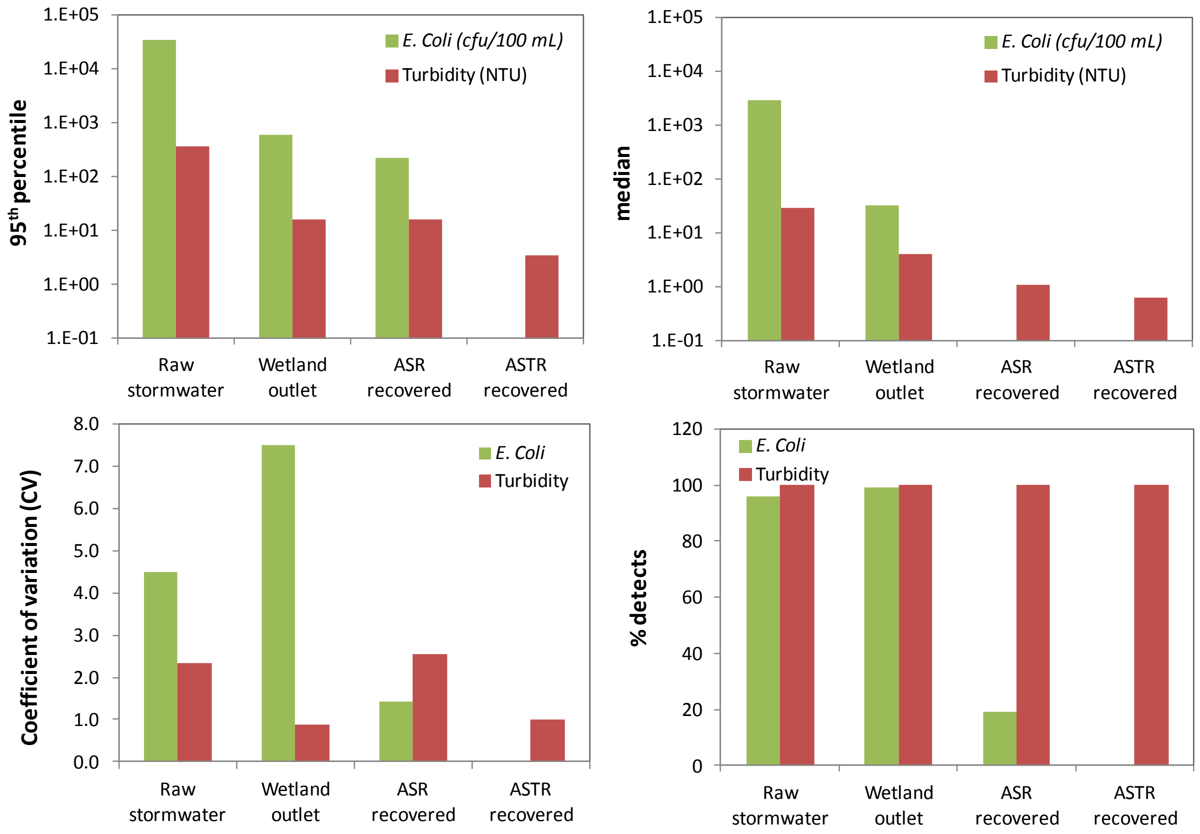


Figure 13 Variability of *E. coli* and turbidity throughout the Parafield stormwater harvesting system.

It was found that for each sampling site in sequence downstream across the Parafield system there was a decrease in the 95th percentile for both *E. coli* and turbidity (Figure 13), data in Table 4. For example, raw stormwater *E. coli* 95th percentile decreased by 2 orders of magnitude (10^5 to 10^3 cfu/ 100 mL) after the wetland, and a further 1 to 2 orders of magnitude by the time it was recovered from the ASTR wells. This trend is also reflected in the turbidity values but is more confounded as the recovery process from the aquifer can also be a source of turbidity, unlike *E. coli* which is exclusively from the catchment. This decrease in 95th percentile numbers is however not reflected in traditional measures of variability such as use of coefficient of variation (Figure 13). The main reason for this in the case of *E. coli* is the large number of non detections that are not captured by use of a coefficient of variation approach. As an alternative approach for visualisation of the *E. coli* data, the cumulative probability function curves can be plotted for the raw stormwater, wetland outlet and recovered ASR water as shown in Figure 14; this excludes ASTR as there were no detections of *E. coli* from the ASTR site in the 15 samples collected (Detection limit is 1 cfu/ 100 mL).

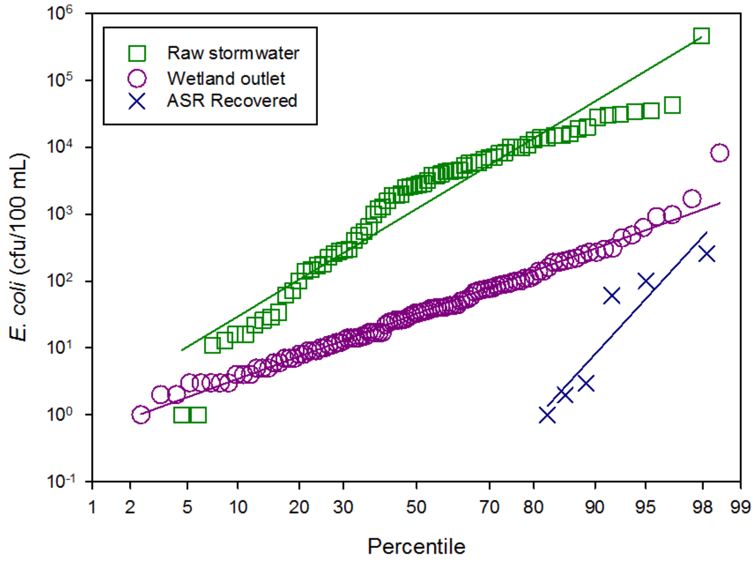


Figure 14 Lognormal cumulative probability plot for *E. coli* throughout the Parafield stormwater harvesting system (Parafield ASTR not plotted as there were no detections in the 15 samples collected).

This method, as described by Vanderzalm *et al.* (2013) allows for fitting of the distributions with a lognormal curve and incorporates the non detects consistent with the lognormal function. Using this method the *E. coli* 95th percentile decreases from ~67,000 cfu/ 100 mL in the stormwater to ~100 cfu/ 100 mL in the ASR recovered water (a 2.8 $\log_{10}$ reduction). Similarly the 50th percentile drops from ~23,000 to < 1 cfu/ 100 mL (a 4.3 $\log_{10}$ reduction). This decrease in variability across the system is the result of not only dispersion, but an average of all the catchment and subsurface processes that can occur.

However not all parameters follow this trend, Figure 15 shows the 95th percentile numbers and coefficient of variation for total iron for the ASR and ASTR systems. For the ASR system there is an increase in the 95th percentile for iron after recovery from the aquifer, as described by Vanderzalm *et al.* (2010). This is also reflected in the variability with an increase in coefficient of variation after aquifer storage.

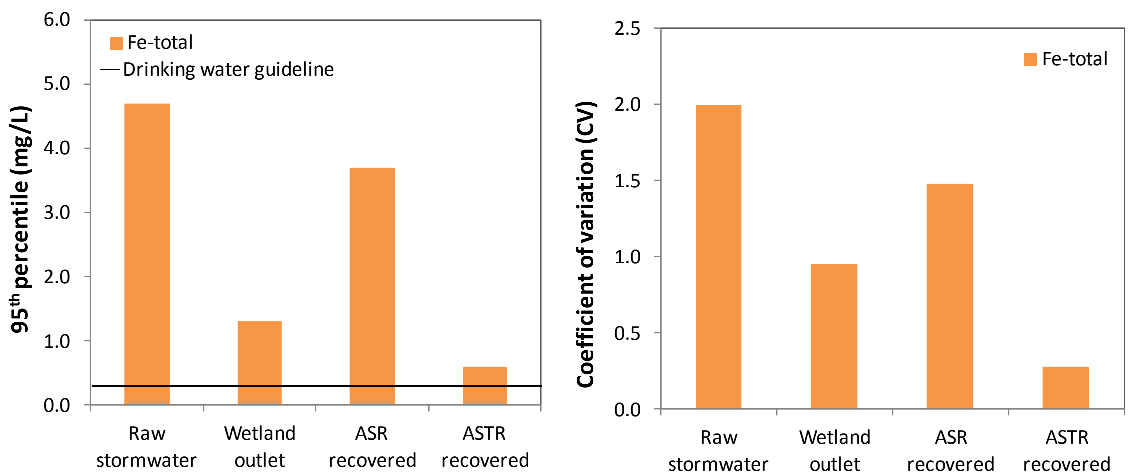


Figure 15 Variability of total iron throughout the Parafield stormwater harvesting system. (Drinking water aesthetic guideline for iron is 0.3 mg/L; NHMRC-NRMMC, 2011).

Table 4 Summary of water quality throughout the Parafield stormwater harvesting system.

	Raw stormwater							Wetland outlet							ASR recovered							ASTR recovered*						
	n	% detects	mean	stdev	50^{th}	95^{th}	cv	n	% detects	mean	stdev	50^{th}	95^{th}	cv	n	% detects	mean	stdev	50^{th}	95^{th}	cv	n	% detects	mean	stdev	50^{th}	95^{th}	cv
E. coli (cfu/100mL)	78	96	23063	103325	2900	34300	4.5	108	99	611	4578	33	581	7.5	32	19	71	101	<1	220	1.4	13	0			<1		
Fe-total (mg/L)	84	100	1.8	3.6	0.87	4.7	2.0	110	100	0.61	0.58	0.45	1.3	0.95	36	100	0.88	1.3	0.38	3.7	1.5	17	100	0.40	0.11	0.36	0.60	0.28
Zn-total (mg/L)	95	94	0.10	0.10	0.08	0.25	1.0	108	98	0.11	0.47	0.019	0.20	4.3	35	89	0.024	0.032	0.008	0.090	1.3	13	64	0.0026	0.0058	0.001	0.010	2.2
EC (μS/cm)	47	100	229	159	177	554	0.69	49	100	279	159	235	513	0.57	5	100	546	243	646	801	0.45	16	100	515	110	552	619	0.21
TN (mg/L)	82	100	1.3	1.2	0.97	5.4	0.92	96	100	0.46	0.30	0.36	0.86	0.66	23	100	0.35	0.42	0.18	0.98	1.2	18	100	0.37	0.31	0.29	0.88	0.84
TP (mg/L)	97	94	0.16	0.14	0.11	0.45	0.88	101	100	0.058	0.059	0.042	0.12	1.0	28	100	0.056	0.10	0.029	0.11	1.8	18	100	0.031	0.014	0.028	0.056	0.45
DOC (mg/L)	62	100	8.9	6.0	6.9	23.4	1.2	69	100	6.0	3.0	4.7	12	0.50	5	100	2.6	0.61	2.3	3.3	0.23	18	100	3.6	1.7	3.2	5.0	0.47
BDOC# (mg/L)	20	100	7.1	5.9	4.7	18.6	1.5	22	100	2.8	1.7	2.1	5.0	0.63	4	100	1.0	0.35	1.0	1.3	0.37	7	100	0.73	0.70	0.4	1.7	0.96
Simazine (μg/L)	62	45	0.30	1.0	<0.1	1.4	3.3	55	29	0.078	0.12	<0.5	0.32	1.5	12	17			<0.05			15	0			<0.05		
Turbidity (NTU)	81	100	79	185	29	360	2.3	108	100	5.2	4.5	4.0	16	0.87	35	100	5.4	14	1.1	16	2.6	15	100	1.2	1.2	0.62	3.4	1.0
SS (mg/L)	90	100	63	104	31	184	1.7	110	84	6	10	4	16	1.7	34	71	27	69	5	103	2.6	15	31			<1	10	

biodegradable dissolved organic carbon (BDOC); *excluding samples collected on 2/2/2009 prior to continuous extraction from the recovery wells, which had been used for injection during the aquifer flushing phase

For contaminants such as pathogens and organic chemicals which have their origin in the catchment Figure 16 represents a conceptual diagram of hazard concentration or numbers in a stormwater harvesting system that recycles water via an aquifer. Figure 16 is illustrative of the MAR systems described in the human health risk assessment report, where stormwater is harvested via a wetland prior to subsurface storage. Recovered stormwater is then post treated to ensure it meets the appropriate guideline value/s for the intended use (e.g. during mixing with recycled water prior to distribution in the third pipe system at Mawson Lakes). Other uses of recovered stormwater, such as irrigation, may require an end use control such as a withholding period.

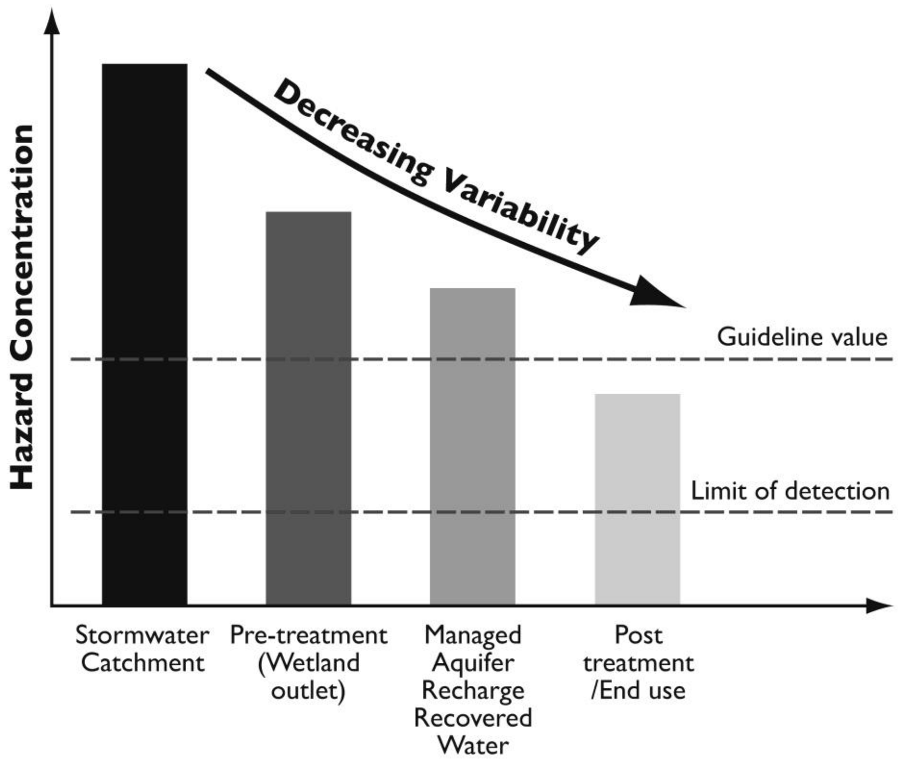


Figure 16 Conceptual diagram of stormwater hazard concentrations during water quality monitoring.

Table 5 summarises the considerations for choice of sampling location in harvesting stormwater for drinking water supplies.

Operational monitoring used at a critical control point (CCP, e.g. turbidity) to divert unacceptable quality from a stormwater harvesting system is desirable, but currently not all relevant hazards are capable of being detected in real time monitoring systems. It is recommended that future stormwater sampling for maximal risk assessment to protect human health (e.g. pathogens or organic chemicals) should occur where sampling is possible from reliable flows. Using wetland outlet / aquifer injectant samples in maximal risk assessment is a much more efficient use of resources than sampling intermittent flows of raw stormwater. This allows sampling to be planned when logistically most appropriate and a smaller number of samples can be acquired for the same information content due to mixing and dispersion during detention. This also provides more reliable volume-integrated samples for environmental risk assessment for aquifer protection.

Table 5 Relative advantages of different sampling locations for harvesting urban stormwater via aquifers for potable use.

	Stormwater catchment sampling	Sampling of water recharging the aquifer – after pre-treatment (wetland outlet)	Sampling of water recovered from the aquifer
Proportion of time sampling can be undertaken	Only during storm flow (typically < 5%)	100%	100%
Hazard variability	High	Moderate	Low
Cost of data to support human health risk assessment	Very high	Moderate	Moderate
Utility in detecting potential impacts on aquifer	Moderate	High	Low
Utility in detecting hazards originating in the aquifer	Low	Low	High
Utility in demonstrating treatment capability of aquifer	Low	High	High
Utility in verifying water quality acceptable for potable use	Low	Moderate	High
Benefit/cost ratio for health and environmental risk assessment and management	Low*	High	High

* High b/c for continuously monitored parameters that trigger a critical control point (CCP) for flow diversion

If characterisation of aquifer treatment is required, sampling of both the injectant and recovered water is necessary. Aquifer treatment would also require validation using an approved validation methodology, such as a challenge test based on injection and recovery of pathogen surrogates. Use of *E. coli* as a surrogate is not recommended as *E. coli* die off more quickly than viral and protozoan pathogens in aquifers and therefore may give a misleading impression of the safety of recovered water. However their presence in recovered water indicates that the water is not fit for potable use without further treatment.

Sampling recovered water quality also addresses hazards that are potentially generated in the aquifer, such as inorganic chemicals (e.g. iron); or salinity through mixing with native groundwater; turbidity from mobilisation of sediments; and radionuclides. Figure 16 represents fate of hazards present in stormwater but may not represent aquifer-generated hazards as these may increase during aquifer storage (e. g. iron, Figure 15). However for hazards present in stormwater, aquifer storage and recovery allows dispersion and diffusion within the storage zone, giving more homogeneous water quality which is easier to treat and also reduces 95th percentiles and hence treatment requirements, contains less biodegradable dissolved organic carbon (BDOC, Table 4) and therefore results in less biofilm growth in distribution systems (Tjandraatmadja *et al.,* 2014).

8 Conclusions

Stormwater quality data assessed for the Parafield catchment and used within the Public Health and Environmental Risk Assessment Report (Page *et al*., 2013a) are within the range of urban stormwater from other Australian and international satellite sites. The Parafield catchment is representative of a higher risk urban stormwater mixed land use site and harvested stormwater has a similar median and 95th percentile values to other sites for which raw stormwater quality analyses were reported. In spite of very large variations in climate and catchments of the sites for which stormwater quality was assessed, there was an unexpected similarity in the 95th percentiles concentrations for all hazards evaluated across sites.

Hazards for which 95th percentile values exceeded the Australian health or aesthetic drinking water quality criteria, *E. coli*, total iron, turbidity and colour, did so at all sites for which data were available. Comparing 95th percentiles with guideline values, suggests typically for *E. coli* 5 $\log_{10}$ removal is required, for turbidity 2 $\log_{10}$ and for total iron ~1 $\log_{10}$. Similarly, hazards for which 95th percentile values were lower than drinking water quality criteria, total zinc, total dissolved solids (as indicated by electrical conductivity), nitrate (as indicated by total nitrogen) and simazine, were so at all sites for which data were available. In general ecosystem support guidelines were exceeded by zinc and nitrate (as indicated by total nitrogen) and total phosphorous exceeded long term but not short term irrigation trigger values.

Based on catchment land use, organic chemicals were expected to be of much greater concern as drinking water hazards than evidenced by the stormwater quality data. Several hundred different organic chemical analytes were evaluated with most data originating from Parafield and the City of Orange. These revealed two organic chemicals at Parafield (1,2-dichloroethane and 1,2-dichloromethane) and at City of Orange, benzo(a)pyrene (as well as cyanide and iodine) whose 95th percentile concentrations exceeded drinking water guideline values. Catchment management and water quality monitoring to reveal the need for subsequent treatment after recovery from the aquifer should be incorporated into the risk management plans for stormwater based potable supplies.

Very few sites were monitored for pathogens and only Parafield had sufficient data to allow a quantitative microbial risk assessment. The reasons for this become apparent when considering the effort required to acquire sufficient 50 L samples, to keep samples refrigerated until analysis and to sample at suitable times for laboratory analysis from intermittent stormwater flows of short duration. Consequently, refinements to sampling procedures for urban stormwater are proposed to more efficiently assess maximal risks and treatment requirements for potable supplies. Significantly fewer resources are required for sampling where flow is reliable (e.g. wetland outlet), than sampling stormwater directly. Therefore, it is recommended that guidelines be refined so that sampling of injectant water quality (i.e. after surface detention) may be used in maximal risk assessment for human health.

Analyses after recovery from the aquifer continue to provide the best representation of treated urban stormwater quality as this location integrates mixing and treatment processes in the wetland and aquifer, while also addressing hazards of geogenic origin. Aquifer treatment evaluation will require sampling of both the injectant and recovered water. An approved validation methodology, such as a challenge test based on injection and recovery of virus and protozoan surrogates remains to be developed. This is recommended as a high priority for future research.

In summary, using the Parafield more complete data set as a reference, a generalised set of default treatment requirements for potable use can be suggested with required $\log_{10}$ removals for viruses 5.8, protozoa 4.8, and bacteria 5.3 (c.f. 5.5, 4.9 and 5.5 respectively, NRMMC, EPHC, NHMRC 2009a). Stormwater treatment for potable use would include disinfection equivalent to that achievable by UV and chlorination. In addition, if aquifer storage is not used to reduce turbidity, either membrane or media filtration would be required to meet guideline values. Iron removal may also be addressed by chlorine oxidation during disinfection and filtration.

References

ANZECC–ARMCANZ (2000a). Australian and New Zealand Guidelines for Fresh and Marine Water Quality: Volume 1 - The Guidelines, National Water Quality Management Strategy Document 4. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra. http://www.environment.gov.au/system/files/resources/53cda9ea-7ec2-49d4-af29-d1dde09e96ef/files/nwqms-guidelines-4-vol1.pdf, accessed 19 February, 2014.

ANZECC–ARMCANZ (2000b). National Water Quality Management Strategy. Australian Guidelines for Water Quality Monitoring and Reporting, 7, Commonwealth of Australia, Canberra.

ASRIS (2013). Australian Soil Resource Information System. CSIRO Land and Water. http://www.asris.csiro.au/, accessed 19 February, 2014.

Bartak, R., Page, D., Sandhu, C., Grischek, T., Saini, B., Mehrotra, I., Jain, C. and Ghosh, N. (in press) Application of risk-based assessment and management to riverbank filtration sites in India. Accepted by Journal of Water and Health.

CGWB (2009). Groundwater brochure of Hardwar district, Uttarakhand. Central Ground Water Board (CGWB). Government of India, Ministry of Water Resources.

Chong, M. N., Sidhu, J., Aryal, R., Tang, J., Gernjak, W., Escher, B., and Toze, S. (2013). Urban stormwater harvesting and reuse: a probe into the chemical, toxicology and microbiological contaminants in water quality. Environmental Monitoring and Assessment, 185, 6645-6652.

City of Orange (2008). Stormwater management plan for the City of Orange. City of Orange, NSW. April, 2008. http://www.orange.nsw.gov.au/site/index.cfm?display=147111, accessed 19 February, 2014.

City of Orange (2013). Blackmans Swamp stormwater harvesting scheme. City of Orange, NSW. http://www.orange.nsw.gov.au/site/index.cfm?display=147115, accessed 19 February, 2014.

Dillon, P., Page, D., Lim, M. H., Lee, E., Lim, P. Y., Devitt, C., Vanderzalm, J., Toze, S. and Hyde, K. (2011). Health risk assessment for use of urban stormwater as a drinking water supply. Proc. Singapore International Water Week 4-8 July 2011.

Gangwar, K. K. and Joshi B. D. (2004). A preliminary study on solid waste generation at Har Ki Pauri, Haridwar, around the Ardh-Kumbh period of sacred bathing in the river Ganga in 2004. Environmentalist, 28(3), 297-300.

Herngren, L., Goonetilleke, A., Ayoko, G. A. and Mosert, M. M. M. (2010). Distribution of polycyclic aromatic hydrocarbons in urban stormwater in Queensland, Australia. Envionmental Pollution, 158, 2848-2856.

International Stormwater BMP Database (2010) (version 3.2) [Internet]. Developed by Wright Water Engineers Inc. and Geosyntec Consultants for the Water Environmental Research Foundation (WERF), the American Society of Civil Engineers (ASCE)/Environmental and Water Resources Institute (EWRI), the American Public Works Association (APWA), the Federal Highway Administration (FHWA) and the U. S. Environmental Protection Agency (EPA). Available at http://www.bmpdatabase.org , accessed 19 December 2013.

Kumar, R. (unpublished report). Post-Tehri Dam Irrigation Service And Modernization Of Upper Ganga Canal System. State Water Resources Agency, Lucknow, Uttar Pradesh, India.

NIH (2013). Hydrogeological evaluation of bank filtration case study site Haridwar: water quality, isotope and flood analysis. Report, National Institute of Hydrology (NIH) Roorkee, Ground Water Hydrology Division, Roorkee 247 667, Uttarakhand, India.

NRCDMEF (2009). Status Paper on River Ganga. State of Environment and Water Quality. August, 2009. National River Conservation Directorate Ministry of Environment and Forests (NRCDMEF). Government of India.

NRMMC-EPHC-AHMC (2006). National Water Quality Management Strategy Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1), National Water Quality Management Strategy Document 21. Natural Resource Management Ministerial Council, Environment Protection and Heritage Council and Australian Health Ministers' Conference, National Water Quality Management Strategy, Canberra. http://www.environment.gov.au/system/files/resources/044e7a7e-558a-4abf-b985-2e831d8f36d1/files/water-recycling-guidelines-health-environmental-21.pdf, accessed 19 February, 2014.

NRMMC-EPHC-NHMRC (2008). National Water Quality Management Strategy Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Augmentation of Drinking Water Supplies , National Water Quality Management Strategy Document 22. Natural Resource Management Ministerial Council, Environment Protection and Heritage Council and Australian Health Ministers' Conference, National Water Quality Management Strategy, Canberra. http://www.environment.gov.au/system/files/resources/9e4c2a10-fcee-48ab-a655-c4c045a615d0/files/water-recycling-guidelines-augmentation-drinking-22.pdf, accessed 19 February, 2014.

NRMMC-EPHC-NHMRC (2009a). National Water Quality Management Strategy Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Managed Aquifer Recharge), National Water Quality Management Strategy Document 24. Natural Resource Management Ministerial Council, Environment Protection and Heritage Council and Australian Health Ministers' Conference, National Water Quality Management Strategy, Canberra. http://www.environment.gov.au/system/files/resources/d464c044-4c3b-48fa-ab8b-108d56e3ea20/files/water-recycling-guidelines-mar-24.pdf, accessed 19 February, 2014.

NRMMC-EPHC-NHMRC (2009b). National Water Quality Management Strategy Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Stormwater Harvesting and Reuse , National Water Quality Management Strategy Document 23. Natural Resource Management Ministerial Council, Environment Protection and Heritage Council and Australian Health Ministers' Conference, National Water Quality Management Strategy, Canberra. http://www.environment.gov.au/system/files/resources/4c13655f-eb04-4c24-ac6e-bd01fd4af74a/files/water-recycling-guidelines-stormwater-23.pdf, accessed 19 February, 2014.

NHMRC-NRMMC (2011). National Water Quality Management Strategy Australian Drinking Water Guidelines, National Water Quality Management Strategy Document 6. National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra. http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/eh52_aust_drinking_water_guidelines_update_131216.pdf, accessed 19 February, 2014.

Page, D. W., Khan, S. J., and Miotlinski, K. (2011). A systematic approach to determine herbicide removals in constructed wetlands using time integrated passive samplers. Journal of Water Reuse and Desalination, 1(1), 11-17.

Page, D., Gonzalez, D., Dillon P., Vanderzalm, J., Vadakattu, G., Toze, S., Sidhu, J., Miotlinski, K., Torkzaban, S., and Barry, K. (2013a). Managed Aquifer Recharge and Stormwater Use Options: Public Health and Environmental Risk Assessment Final Report. Goyder Research Institute Technical Report 13/17. http://goyderinstitute.org/index.php?id=20, accessed 19 February, 2014.

Page, D., Gonzalez, D., Naumann, B., Dillon P., Vanderzalm, J., and Barry, K. (2013b) Stormwater Managed Aquifer Recharge Risk-Based Management Plan, Parafield Stormwater Harvesting System, Stormwater supply to the Mawson Lakes Recycled Water Scheme, Industrial Uses and Public Open Space Irrigation. Goyder Research Institute Technical Report 13/18. http://goyderinstitute.org/index.php?id=20, accessed 19 February, 2014.

Pitt, R., Maester, A. and Morquecho, R. (2004). The National Stormwater Quality Database (NSQD, version 1.1) [Internet]. Available at http://rpitt.eng.ua.edu/Research/ms4/Paper/Mainms4paper.html, accessed 19 February, 2014.

Rahardjo, H., Aung, K. K., Leong, E. C., and Rezaur, R. B. (2004). Characteristics of residual soils in Singapore as formed by weathering. Engineering geology, 73(1), 157-169.

Saini, B. (2011). Water quality improvement during riverbank filtration at Haridwar. Master's thesis, Environmental Engineering Section, Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee, India.

Sandhu, C., Grischek, T., Kumar P. and Ray C. (2012). Promise of bank filtration in India. J Indian Water Works Association, Special Issue Dec. 2012: 5-12.

Sandhu, C. (in prep.). Prospects and limitations of riverbank filtration in India (provisional title) Ph. D. Thesis, in preparation, Dresden University of Technology, Institute of Waste Management and Contaminated Site Treatment, and Dresden University of Applied Sciences, Faculty of Civil Engineering / Architecture, Division of Water Sciences.

Sidhu, J., Gernjak, W. and Toze, S. (Editors) (2012). Health Risk Assessment of Urban Stormwater. Urban Water Security Research Alliance Technical Report No. 102.

Stevens, D. (2014). Managed Aquifer Recharge and Stormwater Use Options: Audit of the Parafield Stormwater Harvesting and Managed Aquifer Recharge System for Non-Potable Use against the Stormwater Risk-Based Management Plan. Goyder Institute for Water Research, Technical Report. http://goyderinstitute.org/index.php?id=20.

Telfer, A. L. and Emmett, A. J. (1994). The artificial recharge of stormwater into a dual porosity aquifer, and the fate of selected pollutants, In Proceeding of Water Down Under '94, 21-25 November, Adelaide, Australia.

Tjandraatmadja, G, Kaksonen, A.H., Gonzalez, D., Barry, K., Vanderzalm, J.V., Puzon, G., Sidhu, J., Wylie, J., and Goodman, N. (2014). Investigation of stormwater impact on water quality and distribution infrastructure, , Goyder Institute for Water Research Technical Report. http://goyderinstitute.org/index.php?id=20.

Toze, S., Hodgers, L., Palmer, A., Sidhu, J., Page, D., Williams, M., Kookana, R., Bartkow, M., Sedlak, D., Stratton, H., Ahmed, W., Schroeder, S. and Christie, M. (2012). Natural Attenuation of Pathogens and Trace Contaminants in South East Queensland Waterways. Urban Water Security Research Alliance Technical Report No. 87.

UDDU (2007). City Development Plan: Haridwar. Revised under Jawaharlal Nehru National Urban Renewal Mission, May, 2007. Urban Development Department, Government of Uttarakhand (UDDU). http://nagarnigamharidwar.com/CDP_HARIDWAR.PDF, accessed 3 March, 2014.

Vanderzalm, J., Dillon, P., Page, D., Marvanek, S., Lamontagne, S., Cook, P., King, H., Dighton, J., Sherman, B., and Adams, L. (2009). Protecting the Blue Lake from land use impacts. CSIRO: Water for a Healthy County National Research Flagship, CSIRO. http://www.clw.csiro.au/publications/waterforahealthycountry/2009/wfhc-protecting-blue-lake.pdf, accessed 3 March, 2014.

Vanderzalm, J.L., Page, D.W., Barry, K.E. and Dillon, P.J. (2010) A comparison of the geochemical response to different managed aquifer recharge operations for injection of urban storm water in a carbonate aquifer, Applied Geochemistry, 25, 1350-1360.

Vanderzalm, J. L., Page, D. W., Barry, K. E. and Dillon, P. J. (2013), Application of a probabilistic modelling approach for evaluation of nitrogen, phosphorus and organic carbon removal efficiency during four successive cycles of aquifer storage and recovery (ASR) in an anoxic carbonate aquifer, Water Research, 47(7), 2177-2189.

Vanderzalm, J. L. Page D. W., and Dillon, P.J. (2011) Application of a risk management framework to a drinking water supply augmented by stormwater recharge, Water Science and Technology, 63(4), 719-726.

Vanderzalm, J., Page, D., Dillon P., Lawson, J., Grey, N., Sexton, D. and Williamson, D. (2014). A Risk-Based Management Plan for Mount Gambier Stormwater Recharge System: Stormwater recharge to the Gambier Limestone aquifer. Goyder Institute for Water Research Technical Report http://goyderinstitute.org/index.php?id=20.

Weiping, W., Page, D., Zhou, Y., Vanderzalm, J. and Dillon, P. (in press). Towards roof runoff replenishment of groundwater in Jinan, China. Accepted by Journal of Hydrologic Engineering.

Wolf, L., Morris, B., and Burn, S. (2006). AISUWRS: Urban Water Resources Toolbox. A karstic aquifer system: Mount Gambier, Australia. Chapter 3.4, pp. 217-250. IWA Publishing, London.

Appendix 1 Stormwater quality from Australian sites

Table 6 Summary of stormwater quality data from Parafield, SA, City of Orange, NSW, City of Mount Gambier, SA, Fitzgibbon, QLD and published literature.

Analyte	Units	Guidelines				SW Guidelines Table A2.3 (urban catchments)		SW Guidelines Table A2.4 (sewered Sydney catchment)				Parafield, SA*				City of Mount Gambier, SA				City of Orange, NSW				Fitzgibbon, QLD			
		Drinking	Freshwater Ecosystems 95% species protection	Irrigation LTV	Irrigation STV	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th
Physical characteristics																											
Temperature	°C											43	100	16	23	10	100	16.5	19.4	115	100	11	22				
pH	pH units	6.5-8.5[a]		6.5-8.5	6.5-8.5	6.3	7.3					48	100	7.8	***8.7***	47	100	7.8	8.3	445	100	7.5	8.4	10	100	7.4	7.8
Electrical Conductivity (field)	µS/cm			650[e]	650[e]							47	100	177	554	10	100	84	100	393	100	143	469				
Electrical Conductivity (lab)	µS/cm			650[e]	650[e]							95	100	222	*1039*												
Total Dissolved Solids	mg/L	600[a]				139	170					89	100	130	576					134	100	75	215				
SAR	SAR units			2[f]	2[f]							80	100	1.1	3.1	10	100	0.6	0.9	134	100	0.3	0.5				
Dissolved Oxygen	mg/L							59	100	7.1	8.9	46	100	7.5	12	10	100	5.2	5.3								
Redox potential	mV SHE											48	100	383	489	10	100	230	297								
Suspended Solids	mg/L					77	254	59	100	20	118	90	100	31	184	111	100	56	530	225	100	72	509				
Suspended Solids>1.2 µm																								2	100	15	16
Turbidity	NTU	5[a]				*41*	*128*	59	100	*20*	*121*	81	100	*29*	*360*	10	100	*81*	*136*	373	100	*45*	*321*				
True Colour (456nm)	HU	15[a]						59	100	*34*	*85*	56	100	*47*	*118*					134	100	*25*	*57*				
Biochemical Oxygen Demand	mg/L					43	141					24	79	5	21					158	80	5	12				
Chemical Oxygen Demand	mg/L					56	89					8	100	76	95												
Anions and cations (mg/L)																											
Alkalinity as Calcium Carbonate	mg/L					35	41					61	100	57	152												
Bicarbonate	mg/L											76	100	71	172	10	100	40	77	87	100	45	125				
Bromide	mg/L	7[d]										65	45	0.14	1.1					63	75	0.03	0.12				
Sulphate	mg/L	250[a] (500[b])										78	99	13	64	10	100	8.2	14	135	100	4.2	13.7	15	100	15	23
Chloride	mg/L	250[a]				11	13					85	93	29	171	40	88	4	14	135	100	3.4	13.4	15	100	86	125
Fluoride	mg/L	1.5[b]										82	72	0.26	0.79					127	67	0.06	0.18				
Cyanide as CN - Total	mg/L	0.08[b]	0.004									6	0	<0.05						86	12	<0.004	*0.12*				
Calcium	mg/L											83	100	17	54	10	100	14	23	135	100	9	25				
Magnesium	mg/L											83	100	4	22	10	100	1.3	1.5	135	100	4	13				
Potassium	mg/L											80	99	3	11	10	70	1.3	2.3	87	100	2	5				
Sodium	mg/L	180[a]		115[f]	115[f]	10	16					80	100	20	99	10	100	8	11	135	99	4	13				

Analyte	Units	Guidelines: Drinking	Guidelines: Freshwater Ecosystems 95% species protection	Guidelines: Irrigation LTV	Guidelines: Irrigation STV	SW Guidelines Table A2.3 (urban catchments) 50th	SW Guidelines Table A2.3 (urban catchments) 95th	SW Guidelines Table A2.4 (sewered Sydney catchment) n	% detects	50th	95th
Microbiological indicators											
Thermotolerant coliforms	/100 mL	0[b]				*44168*	*215568*				
E. coli	cfu/100 mL unless stated	0[b]				*37511 #/100 mL*	*184382 #/100 mL*	58	100	*5800 MPN/ 100 mL*	*240000 MPN/ 100 mL*
Enterococci	/100 mL	0[b]				*11229*	*34465*	59	100	*740*	*12100*
Faecal Streptococci	/100 mL	0[b]				*25212*	*70894*				
Clostridium perfringens	/100 mL	0[b]				*614*	*2748*	59	71	*140*	*905*
Bacteriophage	/10 mL										
Somatic coliphages	1pfu/100 mL					1115	54704				
Pathogens											
Campylobacter	/L	0[b]				*3*	*7*	59	3	<2	<2
Cryptosporidium - Confirmed	oocycts/10L	0[b]						59	37	<13	*102*
Giardia - Confirmed	cysts/10L	0[b]						59	19	<25	*220*
Rotavirus	PDU/L	0[b]									
Adenovirus	/50L	0[b]						59	3	<1	<1
Nutrients (mg/L)											
Nitrate as N	mg/L	11.3[b]	0.16								
Nitrite as N	mg/L	1[b]									
Nitrate + Nitrite as N	mg/L					0.59	1.52				
Ammonia as N	mg/L	0.5[a]	0.9			*0.65*	*2.70*	59	100	0.1	0.8
Organic Nitrogen	mg/L					0.37	1.87				
Total Kjeldahl Nitrogen	mg/L					1.59	8.82	59	100	1.1	3.2
Total Nitrogen	mg/L		1.0	5	25-125	2.51	**7.46**				
Filterable Reactive Phosphorus	mg/L		0.010			0.43	2.04				
Total Phosphorus	mg/L		0.025	0.05[g]	0.8-12	**0.36**	**1.26**				
Biodegradable Dissolved Organic Carbon	mg/L										
Dissolved Organic Carbon	mg/L										
Total Organic Carbon	mg/L					16.6	22.8				
Silica	mg/L										
UV Absorbance - 254 nm Filtered	cm^{-1}										

Analyte	Parafield, SA* n	% detects	50th	95th	City of Mount Gambier, SA n	% detects	50th	95th	City of Orange, NSW n	% detects	50th	95th	Fitzgibbon, QLD n	% detects	50th	95th
Microbiological indicators																
Thermotolerant coliforms	59	97	*4600*	*80400*												
E. coli	78	96	*2900*	*34300*					196	100	*6100*	*54600*	29	100	*1033*	*4460*
Enterococci	20	95	*1000*	*31500*												
Faecal Streptococci	19	95	*805*	*32750*									29	100	*10633*	*24800*
Clostridium perfringens	3	100	*400*	*2740*					138	88	*2500*	*6890*				
Bacteriophage	43	93	*69*	*723*												
Somatic coliphages									101	90	830	5100				
Pathogens																
Campylobacter	22	32	*4*	*110*												
Cryptosporidium - Confirmed	18	56	*5*	*16*												
Giardia - Confirmed	15	67	*24*	*61*												
Rotavirus	3	0	absent													
Adenovirus	18	28	<10	*3604*									24	79	*64*	*2195*
Nutrients (mg/L)																
Nitrate as N					114	96	0.11	1.1	292	96	0.43	1.4	4	100	0.058	0.10
Nitrite as N					38	69	0.02	0.12	247	55	0.02	0.50	2	100	0.038	0.041
Nitrate + Nitrite as N	93	92	0.19	0.79					86	98	0.5	0.9				
Ammonia as N	84	77	0.04	0.41	34	97	0.070	0.43	281	88	0.1	0.40				
Organic Nitrogen																
Total Kjeldahl Nitrogen	91	100	0.70	3.0	120	94	0.95	3.7	158	99	1.0	2.8				
Total Nitrogen	82	100	0.95	**3.8**	110	100	1.2	4.9	277	100	1.1	3.2				
Filterable Reactive Phosphorus	66	100	0.04	0.13	39	95	0.09	0.31	287	94	0.04	0.16				
Total Phosphorus	97	94	**0.11**	**0.45**	123	98	**0.28**	**1.90**	286	99	**0.14**	**0.52**				
Biodegradable Dissolved Organic Carbon	20	100	4.65	18.6												
Dissolved Organic Carbon	62	100	6.85	23.4	10	100	8.8	18.9								
Total Organic Carbon	86	100	10.4	24.7					158	99	6.5	15.0				
Silica	53	100	3.00	6.4												
UV Absorbance - 254 nm Filtered	16	100	0.35	0.71												

Analyte	Units	Guidelines				SW Guidelines Table A2.3 (urban catchments)		SW Guidelines Table A2.4 (sewered Sydney catchment)				Parafield, SA*				City of Mount Gambier, SA				City of Orange, NSW				Fitzgibbon, QLD			
		Drinking	Freshwater Ecosystems 95% species protection	Irrigation LTV	Irrigation STV	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th
UV Absorbance - 254 nm Unfiltered	cm^{-1}											9	100	0.39	0.69												
Metals and metalloids (mg/L)																											
Aluminium - Soluble	mg/L	0.2[a]										60	98	0.14	*1.18*	7	100	0.12	*0.42*					10	100	0.034	*0.74*
Aluminium - Total	mg/L		0.055	5	20	1.07	2.29					58	100	1.04	**7.6**	10	100	0.62	1.98	136	99	2.6	**9.9**				
Antimony - Soluble	mg/L											10	30	<0.0005	0.0006									1	100	0.0066	
Antimony - Total	mg/L	0.003[b]										9	78	0.001	0.002					124	10	<0.001	0.001				
Arsenic - Soluble	mg/L											43	72	0.001	0.006	30	7	<0.005	<0.005					1	100	0.010	
Arsenic - Total	mg/L	0.01[b]	0.024 As(III) 0.013 As(V)	0.1	2	0.009	*0.011*					86	77	0.001	0.006	34	24	<0.005	0.007	136	85	0.002	0.004				
Barium - Soluble	mg/L											4	100	0.035	0.051												
Barium - Total	mg/L	2[b]				0.028	0.038					6	100	0.026	0.036					136	100	0.041	0.104				
Beryllium - Soluble	mg/L											4	0	<0.0005	<0.0005												
Beryllium - Total	mg/L			0.1	0.5							9	0	<0.0005	<0.0005					88	2	<0.001	<0.001				
Boron - Soluble	mg/L	4[b]	0.37	0.5[h]	0.5[h]							10	100	0.033	0.053	10	50	0.07	0.13								
Cadmium - Soluble	mg/L											11	0	<0.0001	<0.0001	2	0	<0.0005						10	100	0.0072	0.0291
Cadmium - Total	mg/L	0.002[b]	0.0002	0.01	0.05	***0.013***	***0.061***					75	32	<0.0001	0.001	10	0	<0.0005		136	56	<0.0001	0.001				
Chromium - Soluble	mg/L											10	10	<0.003	0.004	32	9	<0.001						10	100	0.0087	0.021
Chromium (VI) - Soluble	mg/L	0.05[b]	0.001	0.1	1							7	0	<0.010	<0.010												
Chromium - Total	mg/L	0.05[b]				0.008	0.017					46	89	0.003	0.009	95	75	0.004	0.023	136	62	0.009	0.03				
Cobalt - Soluble	mg/L											10	10	<0.05	0.05									10	100	0.011	0.028
Cobalt - Total	mg/L			0.05	0.1							9	67	0.001	0.001					88	85	0.003	0.014				
Copper - Soluble	mg/L											13	54	0.003	0.006	32	94	0.003	0.006					10	100	0.0073	0.019
Copper - Total	mg/L	1[a](2[b])	0.0014	0.2	5	0.041	0.141					84	93	0.007	0.027	99	97	0.013	0.070	136	95	0.012	0.031				
Iron - Soluble	mg/L											62	100	0.13	0.40	2	0	<0.03						10	100	0.10	0.90
Iron - Total	mg/L	0.3[a]		0.2	10	***2.7***	***5.1***					84	100	***0.87***	***4.7***	10	100	***0.68***	***2.0***	206	100	***2.8***	***11***				
Lead - Soluble	mg/L											13	15	<0.0005	0.002	32	25	<0.001						10	100	0.012	0.023
Lead - Total	mg/L	0.01[b]	0.0034	2	5	*0.063*	*0.162*					89	98	0.004	*0.028*	99	99	*0.014*	*0.25*	206	90	0.008	*0.034*				
Lithium - Soluble	mg/L											4	100	0.004	0.005												
Lithium - Total	mg/L			2.5	2.5							10	90	0.003	0.006												
Manganese - Soluble	mg/L											38	82	0.012	0.053					37	95	0.003	0.022	10	100	0.0035	0.030

Analyte	Units	Guidelines				SW Guidelines Table A2.3 (urban catchments)		SW Guidelines Table A2.4 (sewered Sydney catchment)				Parafield, SA*				City of Mount Gambier, SA				City of Orange, NSW				Fitzgibbon, QLD			
		Drinking	Freshwater Ecosystems 95% species protection	Irrigation LTV	STV	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th
Manganese - Total	mg/L	0.1[a] (0.5[b])	1.9	0.2	10	0.10	*0.20*					86	100	0.042	***0.24***					207	100	*0.15*	***0.64***				
Mercury - Soluble	mg/L											4	0	<0.0003	<0.0003									1	100	0.0063	
Mercury - Total	mg/L	0.001[b]	0.0006	0.002	0.002	0.0002	0.0004					51	18	<0.0003	0.0003					201	1	<0.0001	<0.0001				
Molybdenum - Soluble	mg/L											10	10	<0.0005	<0.0005												
Molybdenum - Total	mg/L	0.05[b]		0.01	0.05							10	80	0.0008	0.0033					136	1	<0.001	<0.001				
Nickel - Soluble	mg/L											10	10	<0.0005	0.0008	32	3	<0.001						10	100	0.029	0.079
Nickel - Total	mg/L	0.02[b]	0.011	0.2	2	0.009	0.017					58	97	0.002	0.010	85	74	0.002	*0.029*	129	67	0.006	0.018				
Selenium - Soluble	mg/L											10	10	<0.003	0.006												
Selenium - Total	mg/L	0.01[b]	0.011	0.02	0.05							9	33	<0.003	0.006					136	0	<0.01	<0.01				
Silver - Soluble	mg/L											9	0	<0.0002	<0.0002												
Silver - Total	mg/L	0.1[b]	0.00005									9	0	<0.0002	<0.0002					136	2	<0.001	0.004				
Sulphur as S - Total	mg/L											9	100	7.7	22.7												
Thallium - Soluble	mg/L											4	0	<0.0005	<0.0005												
Thallium - Total	mg/L											9	0	<0.0005	<0.0005												
Vanadium - Soluble	mg/L											4	25	<0.003	0.004									10	100	0.0086	0.012
Vanadium - Total	mg/L			0.1	0.5							10	80	0.004	0.005												
Zinc - Soluble	mg/L											7	86	0.027	0.046	32	100	0.033	0.171					10	100	0.013	0.051
Zinc - Total	mg/L	3[a]	0.008	2	5	0.272	0.57					95	94	0.079	0.25	100	98	0.10	0.58	136	94	0.11	0.30				
Sterols																											
24-ethylcholestanol	ng/L											36	97	286	1423												
24-ethylcholesterol	ng/L											36	100	3280	10325												
24-ethylcoprostanol	ng/L											36	33	151	472												
24-ethylepicoprostanol	ng/L											36	17	186	765												
Cholestanol	ng/L											36	81	165	1163												
Cholesterol	ng/L	7000[d]										35	100	1620	3853												
Coprostanol	ng/L	700 [d]										35	34	165	578												
Epicholestanol	ng/L											34	15	140	400												
Epicoprostanol	ng/L											34	6	311	404												
Disinfectants																											
Iodine	mg/L	0.15[c]																		86	2	<0.1	*0.78*				
Halogenated Aliphatics Hydrocarbons																											
1,2-Dichloroethane	µg/L	3[b]										5	20	<1	*120*					84	0	<1	<1				

Analyte	Units	Guidelines				SW Guidelines Table A2.3 (urban catchments)		SW Guidelines Table A2.4 (sewered Sydney catchment)				Parafield, SA*				City of Mount Gambier, SA				City of Orange, NSW				Fitzgibbon, QLD			
		Drinking	Freshwater Ecosystems 95% species protection	Irrigation LTV	STV	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th
Dichloromethane	µg/L	4[b]										5	20	<1	*10*												
Trichloroethene	µg/L											5	20	<1	10					84	0	<1	<1				
Herbicides and Pesticides																											
2,4-D	µg/L	30[b]	280									6	33	0.04	0.049					193	32	<0.01	0.24	5	100	0.060	1.1
4-Chlorophenoxy acetic acid	µg/L																			156	1	<0.01	0.02				
Aldrin	µg/L															23	26	0.01	0.03								
Atrazine	µg/L	20[b]	13									61	5	<0.1	0.70	73	14	<0.5	0.90					5	0	<0.01	
Azinophos-methyl	µg/L											61	5	0.43	0.727												
Chlorpyrifos	µg/L	10[b]	0.01									7	14	<0.05	0.08												
Dalapon	µg/L											5	60	0.03	0.03												
Desethyl Atrazine	µg/L											5	80	0.045	0.0585												
Desisoprpyl Atrazine	µg/L											5	80	0.02	0.0455												
Dicamba	µg/L											5	60	0.18	0.252												
Diuron	µg/L	20[b]										5	80	0.21	0.37									5	100	0.040	0.24
Glyphosate/AMPA	µg/L	1000[b]	1200																	156	4	<10	30.5				
Lindane	µg/L															23	70	0.07	0.15								
MCPA	µg/L	40[b]										5	80	0.35	1.1					3	0	<0.5	<0.5	5	100	0.020	0.13
Mecoprop	µg/L											5	40	<0.01	0.039					156	10	<0.01	0.06	1	0	<0.01	
Metolachlor	µg/L											5	20	<0.1	0.02												
Picloram	µg/L	300[b]																		191	1	<0.05	0.07	1	0	<0.02	
Simazine	µg/L	20[b]	3.2									62	45	<0.1	1.4	73	14	<0.5	1.5					5	100	0.020	0.028
Terbutryn	µg/L											5	20	<0.01	0.01												
Triclopyr	µg/L	20[b]										5	80	0.020	0.063					193	37	<0.01	0.37	5	80	0.015	0.090
Phenols																											
2-Chlorophenol	µg/L	0.1[a] (300[b])	490									9	0	<10						61	3	<1	*1.1*				
3-& 4-Methylphenols	µg/L	600[d]										9	11	<0.1	0.44					61	0	<2	<2				
Poly Aromatic Hydrocarbons																											
2-Methylnaphthalene	µg/L											9	0	<10		78	1	<2	<2								
Acenaphthylene	µg/L											9	0	<10						84	20	<0.02	0.13	5	0	<0.01	
Acenaphthene	µg/L											9	0	<10													
Anthracene	µg/L	150[d]										9	0	<10						84	30	<0.02	0.13	5	0	<0.01	
Benzo(a)anthracene	µg/L											9	0	<10						84	38	<0.02	0.24	5	0	<0.01	

Analyte	Units	Guidelines				SW Guidelines Table A2.3 (urban catchments)		SW Guidelines Table A2.4 (sewered Sydney catchment)				Parafield, SA*				City of Mount Gambier, SA				City of Orange, NSW				Fitzgibbon, QLD			
		Drinking	Freshwater Ecosystems 95% species protection	Irrigation LTV	STV	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th	n	% detects	50th	95th
Benzo(a)pyrene	µg/L	0.01[b]										9	0	<10						84	55	*0.07*	*0.47*	5	0	<0.01	
Benzo(b)fluoranthene	µg/L																			84	40	<0.02	0.40	5	0	<0.01	
Benzo(g.h.i)perylene	µg/L											9	0	<10						84	37	<0.02	0.17	5	0	<0.01	
Benzo(k)fluoranthene	µg/L																			84	55	0.06	0.12	5	0	<0.01	
Benzo(b.k)fluoranthene	µg/L											9	0	<10													
Chrysene	µg/L											9	0	<10						84	40	<0.02	0.22	5	0	<0.01	
Dibenz(a.h)anthracene	µg/L											9	0	<10										5	0	<0.01	
Fluoranthene	µg/L											9	0	<10		78	1	<2	<2	84	46	<0.02	0.46	5	0	<0.01	
Fluorene	µg/L											9	0	<10						84	5	<0.02	0.03	5	0	<0.01	
Indeno(1.2.3.cd)pyrene	µg/L											9	0	<10						84	32	<0.02	0.20	5	0	<0.01	
Naphthalene	µg/L	70[d]	16									9	0	<10		79	3	<2	<2	84	14	<0.02	0.19	5	40	22	24
Phenanthrene	µg/L	150[d]										9	11	<0.1	0.14	79	1	<2	<2	84	38	<0.02	0.13	5	20	24	24
Pyrene	µg/L	150[d]										9	0	<10		79	1	<2	<2	84	48	<0.02	1.01	5	0	<0.01	
Total PAHs	µg/L					0.17	0.81																				
Total Petroleum Hydrocarbons **																											
C6-C9 Fraction	µg/L															75	3	<20	<20	122	0	<20	<20				
C10-C14 Fraction	µg/L															75	17	<50	72	122	3	<50	<50				
C15-C28 Fraction	µg/L															75	72	224	566	122	42	<100	529				
C29-C36 Fraction	µg/L															75	73	129	367	122	39	<50	310				
Total C10-C36	µg/L															61	100	395	991								
Trihalomethanes																											
Bromoform	µg/L											9	0	<1	<1												
Bromodichloromethane	µg/L	250[b]										9	11	<1	2.5					84	0	<5	<5				
Chloroform	µg/L	250[b]										9	11	<1	3.9					84	0	<5	<5				
Dibromochloromethane	µg/L	250[b]										9	11	<1	1.2					84	0	<5	<5				
Miscellaneous																											
Detergent as MBAS	mg/L											5	60	0.24	0.25												
Radiological																											
Gross Alpha Activity	Bq/L	0.5[i]										8	25	<0.005	0.16												
Gross Beta Activity	Bq/L	0.5[i]										8	63	0.026	0.30												

Bold values exceed the irrigation guidelines; *italic values* exceed the drinking water guidelines; underlined values exceed the freshwater ecosystem guidelines (95% of species level of protection from Table 3.4.1 and default trigger value for freshwater lakes & reservoirs in south central Australia from Table 3.3.8, ANZECC-ARMCANZ 2000); Drinking = guideline from Australian Drinking Water Guidelines (ADWG) (NHMRC–NRMMC 2011), or Augmentation of Drinking Water Supplies Guidelines (AugDWSG) (EPHC-NRMMC-NHMRC 2008); STV = short term value for irrigation from ANZECC-ARMCANZ (2000); LTV = long term value for irrigation from ANZECC-ARMCANZ (2000).

SW Guidelines data source: Stormwater Harvesting and Reuse Guidelines (NRMMC–EPHC–NHMRC 2009a); Table A2.3 is "Lognormal summary statistics for untreated stormwater quality, excluding AWQC (2008)"; Table A2.4 is "Stormwater quality summary statistics from untreated sewered urban catchments in Sydney taken from AWQC (2008)". Parafield data source: Page *et al.* 2008; 2009; 2013a; Barry *et al*. 2010. City of Orange data source: unpublished data from Chris Devitt, City of Orange. Mount Gambier data source: Wolf *et al.* 2006; Vanderzalm *et al.* 2009. Fitzgibbon data source: Sidhu *et al*. 2012; unpublished data from Jatinder Sidhu, CSIRO.

a = aesthetic guidelines from ADWG; b = health guideline from ADWG; c = taste threshold from ADWG; d = health guideline from AugDWSG; e = For sensitive crops; moderately sensitive 0.65-1.3, moderately tolerant 1.3-2.9 based on an average root zone leach factor of 0.33. See Tables 4.2.3 and 4.2.4 ANZECC-ARMCANZ (2000) for a detailed tolerance of different crops; f = A value greater to that stated can cause foliar damage in sensitive crops; g = To avoid bioclogging in irrigation equipment; h = 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; i = screening level to identify requirement for radionuclide analysis; j = raw stormwater entering wetland, after pond storage.

* calculations based on all available data from databases at CSIRO and City of Salisbury since 2000, including locations: **PDS, CCk, PC, BC, ISB** ** multiple screens carried out with 'zero detects' refer to Table 7, for details.

Table 7 Summary of number of non detects in stormwater quality data screens from Parafield, SA, City of Orange, NSW, City of Mount Gambier, SA, Fitzgibbon, QLD (data not included in Table 6).

Parafield - non detects			Mount Gambier - non detects			City of Orange - non detects			Fitzgibbon – non detects		
	# samples	# parameters		# samples	# parameters		# samples (range)	# parameters		# samples	# parameters
AWQC Laboratory			PAHs	49	8	Organochlorine Pesticides	193	1	BTEX	1	5
Herbicides/Pesticides	58	7	BETX	74	5	OC Pestocides	153 ave. (2-193)	26			
NMI Laboratory			Halogenated phenols	8	13	Phenoxyacetic Acid Herbicides by LCMS	140 ave. (3 – 193)	11			
Organochlorine (OC) Pesticides	9	22				Organophosphorus Pesticides (Ultra-trace)	190	19			
Triazine Hebicides	9	1				EP075(SIM)A: Phenolic Compounds	61	11			
Phenoxy acid herbicides	9	5				Monocyclic Aromatic Hydrocarbons	110 ave. (84 – 156)	14			
Organophosphate (OP) Pesticides	9	27				Halogenated Aliphatic Compounds	84	27			
Fungicides	9	23				Halogenated Aromatic Compounds	84	8			
Herbicides	9	6				Oxygenated Compounds	84	4			
Miscellaneous	9	6				Sulfonated compounds	84 ave. (60 – 84)	2			
Phenols	9	13				Fumigants	84	4			
Monocyclic Aromatic Hydrocarbons NMI 1120 Screen	9	14				Naphthalene	84	1			
Halogenated Aliphatics Hydrocarbons NMI 1120 Screen	9	27				Polychlorinated Biphenyls (as Aroclors)	86	8			
Halogenated Aromatics Hydrocarbons NMI 1120 Screen	9	9									
Phenols NMI 1122 Screen	9	13									
Oxygenated Compounds NMI 1120 Screen	9	6									
Sulfonated Compounds NMI 1120 Screen	9	1									
Phthalates NMI 1122 Screen	9	6									
Chlorinated Hydrocarbons NMI 1122 Screen	9	9									
Ethers NMI 1122 Screen	9	5									
Amines Nitroaromatics & Nitrosamines NMI 1122 Screen	9	12									
Organochlorine Pesticides NMI 1122 Screen	9	16									
Organophosphate Pesticides NMI 1122 Screen	9	2									
Others	9	6									
Miscellaneous	9	2									
QHSS Laboratory											
Phenoxyacid Herbicides, LCMS	4	5									
Herbicides by LCMS	4	5									

Appendix 2 Stormwater quality from international sites and stormwater BMP database

Table 8 Summary of stormwater quality data from Jinan, China, Haridwar, India, Singapore, and the International stormwater BMP database (USA, New Zealand and Taiwan).

Analyte	Units	Guidelines				Jinan, China			Haridwar, India monsoon			Haridwar, India non-monsoon			Singapore			BMP database ‡			
		Drinking	Freshwater ecosystems 95% species protection	Irrigation LTV	Irrigation STV	n	mean	maximum	n	mean	95th	n	mean	95th	n	50th	95th	n	% detects	50th	95th
Physical characteristics																					
Temperature	°C					1	20.3		3	27.8	32.8	4	21.1	26.5							
pH	pH units	6.5-8.5[a]		6.5-8.5	6.5-8.5	6	7.3	7.7	3	7.5	7.8	8	8.2	8.7							
Electrical Conductivity	µS/cm			650[e]	650[e]	1	227		9	148	172	17	228	281	173	232	394	1962	100	89	543
Total Dissolved Solids	mg/L	600[a]				6	428	1412	2	102	119	6	110	155							
Dissolved Oxygen	mg/L					1	9		1	8		1	12								
Suspended Solids	mg/L					7	329	726							195	6	14	5151	100	41	431
Turbidity	NTU	5[a]				10	197	1875	2	99	142	6	18	39	195	6	16	670	100	18	125
Anions and cations (mg/L)																					
Alkalinity as Calcium Carbonate	mg/L								2	56	60	6	68	84							
Bicarbonate	mg/L					1	54		3	34	91	3	1.4	1.7							
Sulphate	mg/L	250[a] (500[b])				9	120	454													
Chloride	mg/L	250[a]				8	9.1	43	8	4.4	9.7	15	3.6	12							
Calcium	mg/L					1	21		9	28	39	18	28	34							
Magnesium	mg/L					1	2.4		9	5.4	9.6	18	7.9	11							
Potassium	mg/L					1	4.0		6	2.0	3.2	17	3.2	6.2							
Sodium	mg/L	180[a]		115[f]	115[f]	1	8.0		9	4.0	9.6	17	6.9	11							
Microbiological indicators																					
Thermotolerant coliforms	/100 mL	0[b]							1	>2400		10	7390	22150	120	4	73				
E. coli	cfu/100 mL unless stated	0[b]													65	1	20	211	100	1505 #/100 mL	31099 #/100 mL
Nutrients (mg/L)																					
Nitrate as N	mg/L	11.3[b]	0.16			8	2.9	13	3	0.63	0.79	5	1.3	2.1	261	0.05	0.48				

Analyte	Units	Guidelines				Jinan, China			Haridwar, India monsoon			Haridwar, India non-monsoon			Singapore			BMP database ‡			
		Drinking	Freshwater ecosystems 95% species protection	Irrigation LTV	Irrigation STV	n	mean	maximum	n	mean	95th	n	mean	95th	n	50th	95th	n	% detects	50th	95th
Nitrite as N	mg/L	1[b]				11	0.60	2.9													
Ammonia as N	mg/L	0.5[a]	0.9			10	6.6	30				4	0.01	0.02	266	0.02	0.14				
Total Kjeldahl Nitrogen	mg/L																	3061	100	1.3	5.4
Total Nitrogen	mg/L		4.0	5	25-125													2185	100	1.5	5.4
Total Phosphorus	mg/L		0.025	0.05[g]	0.8-12	1	0.03								85	0.053	0.13	4407	100	0.2	1.2
Total Organic Carbon	mg/L					2	41	65	1	1		8	0.8	1.3	257	4.4	8.3				
Metals and metalloids (mg/L)																					
Arsenic - Total	mg/L	0.01[b]	0.024 As(III) 0.013 As(V)	0.1	2										19	0.0050	0.0053				
Cadmium - Total	mg/L	0.002[b]	0.0002	0.01	0.05	5	0.0022	0.0025	1	<0.005		2	<0.005		19	0.0005	0.0015				
Chromium - Total	mg/L	0.05[b]							1	<0.002		2	<0.002								
Copper - Total	mg/L	1[a](2[b])	0.014	0.2	5	3	0.023	0.039	1	<0.1		2	<0.1		19	0.007	0.034				
Iron - Total	mg/L	0.3[a]		0.2	10				3	2.5	5.1	3	0.54	1.1	265	0.12	0.36	867	100	0.64	8.0
Lead - Total	mg/L	0.01[b]	0.0034	2	5				1	<0.002		2	<0.002		18	0.002	0.003				
Manganese - Total	mg/L	0.1[a] (0.5[b])	1.9	0.2	10				2	0.2	0.27	3	0.02	0.03	161	0.015	0.033				
Nickel - Total	mg/L	0.02[b]	0.011	0.2	2	2	0.003	0.003	1	<0.002		2	<0.002								
Zinc - Total	mg/L	3[a]	0.008	2	5	7	1.1	5.7							8	0.1		3319	100	0.065	0.44
Herbicides																					
Atrazine	μg/L	20[b]	13												2	<1	<1	7	0	<1	<1
Simazine	μg/L	20[b]	3.2												2	<1	<1	6	0	<1	<1
Radiological																					
Gross Alpha Activity	Bq/L	0.5[i]													2	0.03	0.03				
Gross Beta Activity	Bq/L	0.5[i]													2	0.02	0.02				

SW Guidelines data source: Stormwater Harvesting and Reuse Guidelines (NRMMC–EPHC–NHMRC 2009a); Table A2.3 is “Lognormal summary statistics for untreated stormwater quality, excluding AWQC (2008)”; Table A2.4 is “Stormwater quality summary statistics from untreated sewered urban catchments in Sydney taken from AWQC (2008)”. Jinan data source: unpublished data, Weiping Wang, University of Jinan. Haridwar data source: Saini 2011; Sandhu 2013. Singapore data source: Dillon *et al.* 2011. International BMP data source: WERF. ‡ Note: summary statistics presented for key indicator parameters only, additional parameters are available.

a = aesthetic guidelines from ADWG; b = health guideline from ADWG; e = For sensitive crops; moderately sensitive 0.65-1.3, moderately tolerant 1.3-2.9. See ANZECC-ARMCANZ (2000) for a detailed tolerance of different crops; f = A value greater to that stated can cause foliar damage in sensitive crops; g = To avoid bioclogging in irrigation equipment; h = 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; i = screening level to identify requirement for radionuclide analysis.

Appendix 3 Number of analyses per water quality hazard group*

Table 9 Summary of stormwater analyses performed.

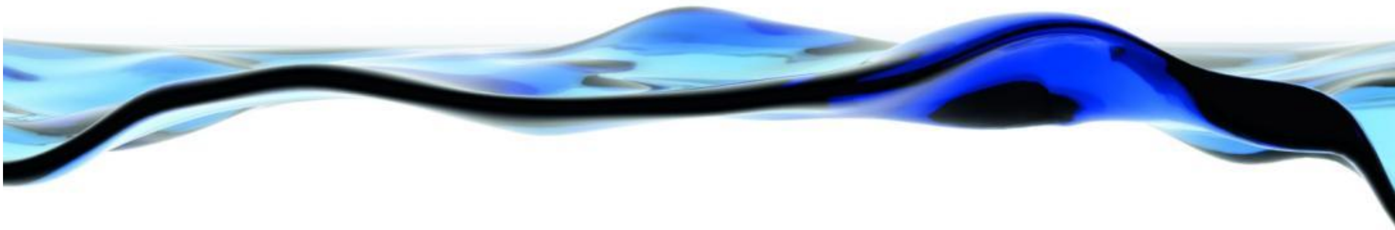
Hazard group (maximum number of parameters)	Parafield (SA)**	City of Mount Gambier (SA)	City of Orange (NSW)	Fitzgibbon (QLD)	Jinan, China	Haridwar, India	Singapore	BMP database[‡]
Physical characteristics (12)	662	218	2111	12	32	62	563	7783
Major ions (11)	779	100	1125	30	22	140		
Microbiological indicators (6)	222		435	10		11	185	211
Pathogens (5)	76							
Nutrients (12)	759	588	2072	6	32	21	869	9653
Metals and metalloids (45)	1268	753	2646	113	17	26	509	4186
Radiological (2)	16						4	15
Basic Herbicides screen (10)	580	192	1544	32			4	
Full Herbicide screen (114)	6612		10561	80				
Sterols (9)	318		22002					
Total Petroleum Hydrocarbons and BTEX (14)	126	825	604	6				
Poly Aromatic Hydrocarbons (17)	153	1890	1344	85			12	
Phenols (15)	135	112	732		3			
Alkyl Phenyls (20)				52				
Pharmaceuticals (56)				280				
Trihalomethanes (4)	36		336					
Halogenated Aliphatic Hydrocarbons (30)	270		2268					
Disinfectants (1)	9		86					
Oxygenated compounds NMI 1120 Screen (6)	54							
Sulfonated compounds NMI 1120 Screen (1)	9		144					
Polychlorinated Biphenyls (as Aroclors (8)			602					
Phthalates NMI 1122 Screen (6)	54							
Chlorinated Hydrocarbons NMI 1122 Screen (9)	81		588					
Ethers NMI 1122 Screen (5)	45							
Amines, Nitroaromatics, Nitrosamines NMI 1122 Screen (16)	144							

*based on classes of analyses from commercial laboratories, does not include sediment samples and organic chemicals sampled via passive samplers at Parafield; [‡] information relating to key indicator parameters only, additional parameters are available.

Glossary

ADWG	Australian Drinking Water Guidelines; undergoes rolling revision to ensure it represents the latest scientific evidence on good quality drinking water.
ANZECC	Australian and New Zealand Environment Conservation Council
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.
ASR	Aquifer storage and recovery; use of a single well for injection and recovery
ASTR	Aquifer storage transfer and recovery; the use of separate injection and recovery wells
BMP database	International Stormwater Best Management Practices (BMP) Database(2010) (version 3.2), accessed at www.bmpdatabase.org
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.
critical control point (CCP)	A step or procedure at which controls can be applied and a hazard can be prevented, eliminated or reduced to acceptable (critical) levels.
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).
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEWNR	Department for Environment, Water and Natural Resources, South Australia
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.
E. coli	*Escherichia coli*; bacterium found in the gut. Used as an indicator of faecal contamination of water.
EPA	Environment Protection Authority, South Australia
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.
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.
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.
MARSUO	Managed Aquifer Recharge Stormwater Use Options
masl	Metres above sea level
maximal risk	The level of risk in the absence of preventive measures.
monitoring	Systematically keeping track of something, including sampling or collecting and documenting information.
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.
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.
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.
SA Water	South Australian Water Corporation
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.
stakeholder	A person or group (eg 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.
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.
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.



The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department of Environment, Water and Natural Resources, CSIRO, Flinders University, the University of Adelaide and the University of South Australia.