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Joanne Vanderzalm
CSIRO Land and Water

Kerry Levett
CSIRO Land and Water

Declan Page
CSIRO Land and Water

Peter Dillon
CSIRO Land and Water

Simon Toze
CSIRO Land and Water

See next page for additional authors

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Keywords

urban, stormwater, potable, supply, via, aquifer, assessing, recycling, risks

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Authors

Joanne Vanderzalm, Kerry Levett, Declan Page, Peter Dillon, Simon Toze, Konrad Miotlinski, Jatinder Sidhu, Karen Barry, and Kim Alexander

ASSESSING THE RISKS OF RECYCLING URBAN STORMWATER FOR POTABLE SUPPLY VIA AN AQUIFER

Author/s:
Joanne Vanderzalm, Research Scientist, CSIRO Land and Water, Water for a Healthy Country Flagship
Kerry Levett, Research Projects Officer, CSIRO Land and Water, Water for a Healthy Country Flagship
Declan Page, Senior Research Scientist, CSIRO Land and Water, Water for a Healthy Country Flagship
Peter Dillon, Principal Research Scientist, CSIRO Land and Water, Water for a Healthy Country Flagship
Simon Toze, Principal Research Scientist, CSIRO Land and Water, Water for a Healthy Country Flagship
Konrad Miotlinski, Research Scientist, CSIRO Land and Water, Water for a Healthy Country Flagship
Jatinder Sidhu, Research Scientist, CSIRO Land and Water, Water for a Healthy Country Flagship
Karen Barry, Research Projects Officer, CSIRO Land and Water, Water for a Healthy Country Flagship
Kim Alexander, Research Scientist, CSIRO Sustainable Ecosystems, Water for a Healthy Country Flagship
Kylie Hyde, Senior Research Engineer, United Water International
Rudi Regel, Senior Research Scientist, United Water International

Abstract

Urbanisation and the subsequent increase in impervious land use generate increased urban stormwater which can be recycled via managed aquifer recharge (MAR) to supplement more traditional surface or ground water supplies. This paper compares the quality of stormwater from two urban catchments in South Australia to assess the risks, in accordance with the Australian Guidelines for Water Recycling, of recycling stormwater via a limestone aquifer for potable water use. In the regional city of Mount Gambier, stormwater MAR in a karstic aquifer has been used to supplement the city's drinking water supply for over 100 years. The source water was generally high quality with some instances of turbidity, iron and lead exceeding the Australian Drinking Water Guidelines (ADWG). Effort was made to constrain the estimate of minimum residence time within the karstic aquifer to at least two years for evaluation of the potential for passive treatment of trace organic chemicals in this system.

In the second example, a purpose built MAR site in Parafield, a northern suburb of Adelaide, has been designed and operated as a full scale trial to determine if wetland treated urban stormwater can be recovered at a standard which meets the ADWG. Based on the analysis undertaken, the source water was generally of high quality with occasional instances of levels of iron and microbial indicators in excess of the ADWG. After a mean residence time in the aquifer of 240 days, recovered water quality met the ADWG with the exception of iron. However, given the uncertainty in pathogen concentrations in the treated stormwater post-recovery from the aquifer, disinfection and aeration for iron removal would be necessary to ensure that the ADWG were met if the water was to be utilised for potable water supply.

Introduction

Stormwater is increasingly being recognised as a valuable resource in urban areas where urban growth and the subsequent increase in impervious surfaces increases the volume of stormwater available at a time when more traditional surface or ground water supplies are limited. The quality of stormwater is affected by the type of land use and the potential sources of hazard (i.e. particulate, microbial, chemical) in the catchment, rainfall frequency and intensity and treatment measures such as settling pits, detention basins and constructed wetlands. Using stormwater in managed aquifer recharge (MAR) provides storage without a large urban footprint or evaporative losses, while also providing the potential for passive treatment in the aquifer.

MAR has previously been used to recycle stormwater and wastewater for non-potable use in South Australia (Herczeg et al., 2004; Vanderzalm et al., 2006), but more recently the focus has moved to recycling stormwater for drinking water supply (Page et al., 2009) where more stringent targets are placed on the recovered water

(NHMRC-NRMMC, 2004). The Australian Guidelines for Water Recycling: Managing Health and Environment Risks (NRMMC-EPHC-AHMC, 2006) and its supporting Phase 2 Guidelines including the Australian Guidelines for Water Recycling: Managed Aquifer Recharge ("MAR Guidelines"; NRMMC-EPHC-AHMC, 2009) provide a framework to assess the risk posed by water recycling via aquifers to both human health and environmental end-points. The MAR Guidelines use twelve hazard categories and apply successive stages of risk assessment which increase in complexity and enable investigative efforts to focus on the highest priority hazards. This paper utilises the MAR Guidelines to assess the potential for recycling stormwater for drinking water supply via MAR in a limestone aquifer. The specific objectives of this paper are to:

- Compare the stormwater quality from two South Australian urban catchment areas.
- Apply the MAR Guidelines to assess the risks associated with stormwater recycling for drinking water supply in each catchment.

Materials and methods

Study sites

In the regional city of Mount Gambier, South Australia stormwater recycling via a tertiary karstic aquifer has been used to supplement a drinking water supply for over 100 years (Wolf et al., 2006; Vanderzalm et al., 2009; Page et al., 2010). The stormwater drainage network consists of several hundred wells that recharge the underlying karstic Gambier Limestone aquifer, which in turn recharges the city's drinking water supply, known as the Blue Lake. Minimal pre-treatment is undertaken prior to recharge using simple three chambered settling pits or gross pollutant traps, in conjunction with catchment management programs to protect the quality of the city's stormwater. The urban catchment area of approximately 11 km^2 impervious surfaces is divided into over 400 stormwater drainage catchments (Figure 1) varying in size from 0.2 to 58 ha. Residential land use dominates the city area, which also contains industrial and commercial land uses. The volume of annual stormwater discharge of approximately 2.9-4.2 Mm^3/year is comparable to the volume extracted for drinking water supply of 3.6 Mm^3/year (Wolf et al., 2006). The maximum groundwater velocity determined by tracer tests in the vicinity of the Blue Lake was 1-4 m/d (Vanderzalm et al., 2009).

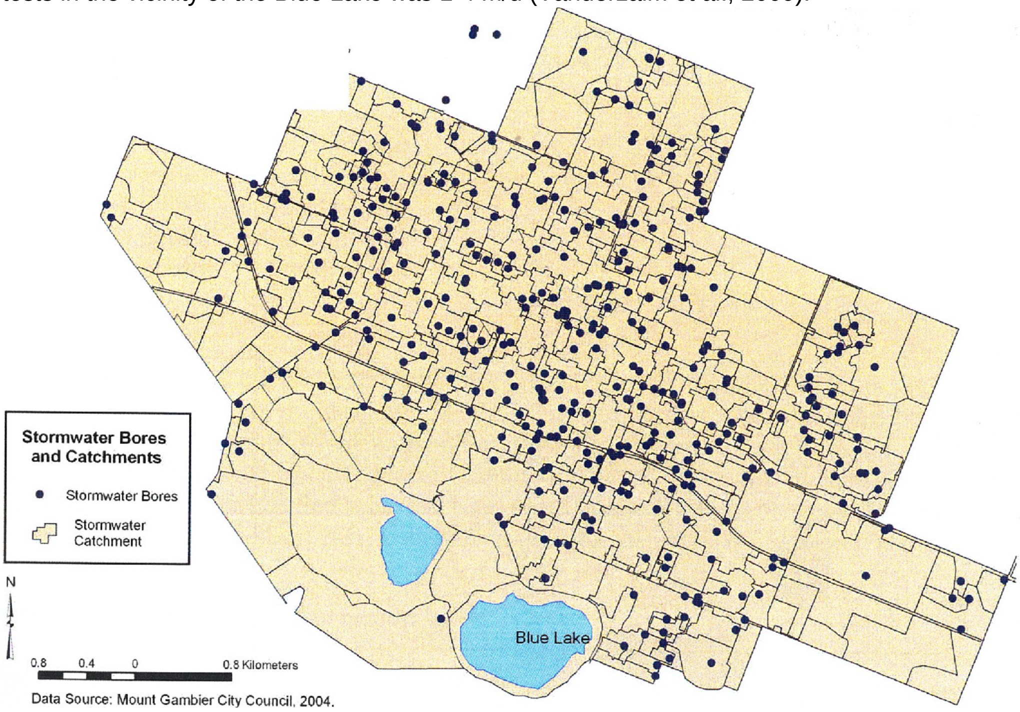

Figure 1 Stormwater draining wells and catchments areas in the City of Mount Gambier (Wolf et al., 2006)

In a second case study, a purpose built MAR site in Parafield, a northern suburb of Adelaide, has been designed and operated by the City of Salisbury as a full scale trial to recycle wetland treated urban stormwater for drinking water supply (Page et al., 2009, 2010; Vanderzalm et al., 2010). The land use in the catchment is mainly residential but also contains commercial and industrial areas. The Parafield stormwater harvesting scheme comprising a receiving stormwater drain, in-stream basin, holding storage and a constructed cleansing wetland provides both stormwater capture and pre-treatment via sedimentation, filtration, volatilisation, aerobic degradation and phyto remediation (Figure 2). The harvesting system has the capacity to capture 1.1 Mm^3/year, but recently this has been limited by rainfall availability to 1.6 Mm^3 over a 2 year period (2006-2008). The target aquifer is a confined tertiary limestone with separate injection and recovery wells designed to provide a minimum of 240 days residence in aquifer. Karstic features were not identified at this site.

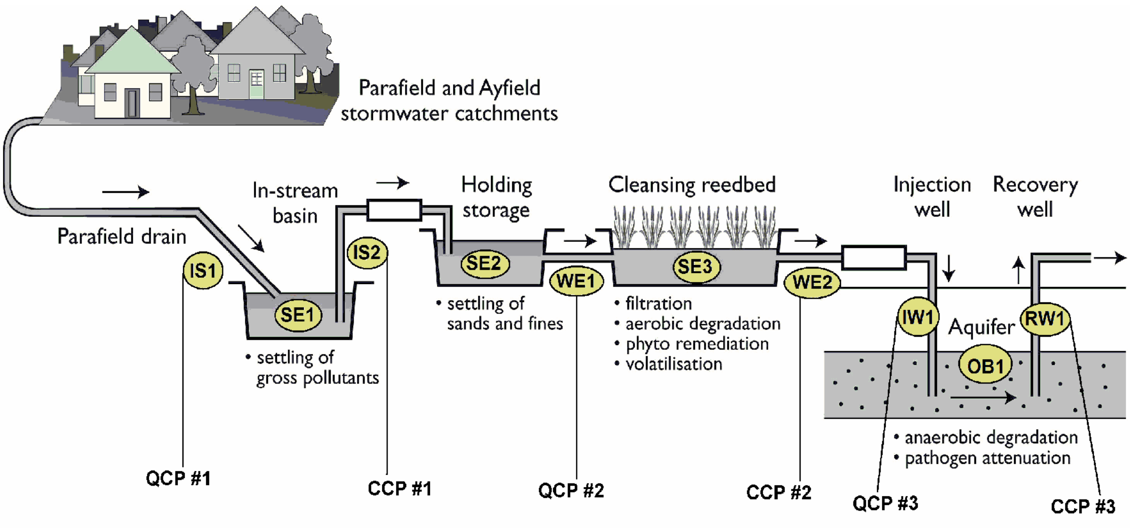

Figure 2 Conceptual diagram of the Parafield ASTR site showing critical control points (CCPs), quality control points (QCPs), water and sediment sampling points (Page et al., 2009)

Risk assessment

The quality of stormwater in Mount Gambier has been monitored periodically in 1978-1982 (Emmett, 1982), 1999-2002 (URS, 2000, 2003) and 2004 (Wolf et al., 2006). The number of samples varied from 10 for physico-chemical parameters measured in the field and major ions to 80 for metals and nitrate.

The quality of stormwater collected in the Parafield harvesting scheme was monitored between 2006-2008 at several locations, including the entry to the in-stream basin prior to any treatment (IS1 in Figure 2) and the exit of the constructed wetland after cleansing reedbed treatment (WE2 in Figure 2) (43 samples).

A maximal risk assessment was undertaken using the source water for MAR at both Mount Gambier and Parafield (WE2 after cleansing reedbed treatment). Twelve hazard categories were assessed against relevant human (drinking water) and environmental (aquifer or Blue Lake) endpoints (NRMMC-EPHC-NHMRC, 2009).

Results and Discussion

Mount Gambier's stormwater is of good quality and meets the Australian Drinking Water Guideline (ADWG) values (NHMRC-NRMMC, 2004) for most parameters (Table 1). Turbidity, iron and lead, largely associated with particulates, show the potential to exceed the guideline values. Comparing the untreated and treated stormwater at Parafield illustrates an improvement in quality for all parameters aside from a marginal increase in total iron, which can be generated in the wetland itself (Page et al., 2009). Despite the mixed industrial, commercial and residential land use in the catchment, the Parafield source water quality for MAR is generally of high quality but the average stormwater quality following wetland treatment is above the ADWG for colour, turbidity, iron and microbial indicators. Comparing the maximal risk assessment for each site reveals several hazard groups that are deemed high or uncertain risk (Table 2). Uncertain or high risk hazards require additional investigation or protective measures to reduce the assessment of residual risk to low.

Initially pathogens are considered uncertain in the maximal risk assessment for Mount Gambier as there is no data available for microbial hazards in Mount Gambier's stormwater. The residual risk is considered to be low as the drinking water supply extracted from the Blue Lake is disinfected via chlorination following extended storage of approximately eight years within the lake which may also provide sufficient time for attenuation of microbial hazards (Herczeg et al., 2003). Faecal indicators were detected in the Parafield source water, but there was no data for the reference pathogens, *Campylobacter*, rotavirus, adenovirus and *Cryptosporidium parvum*, adopted within the Australian Guidelines for Water Recycling (NRMMC-EPHC-AHMC, 2006; NRMMC-EPHC-NHMRC, 2009). A quantitative microbial risk assessment (QMRA) was undertaken for the Parafield site using reference pathogens to determine the treatment steps necessary to provide adequate human health protection. This indicated that the water recovered from MAR would require post-treatment disinfection by UV to reduce the risk from viruses which are more persistent in the aquifer than bacteria and protozoa.

Table 1 Summary of average water quality for urban stormwater from two catchments in comparison to drinking water guideline values

	ADWG[A]	Mount Gambier	Parafield	
mg/L unless stated		SW source water	IS Basin inflow-untreated	SW source-wetland treated
SS		200	930	3.7
TDS	500	49	**510**	140
pH (pH units)	6.5-8.5	7.9	7.6	7.1
Colour (HU)	15	nd	**70**	**50**
Turbidity (NTU)	5	**79**	**10**	**6**
Sodium	180	8.8	96	19
Potassium		1.3	7.3	3.5
Calcium		14	46	23
Magnesium		1.2	26	4.4
Chloride	250	6.2	200	27
Sulfate	250	86	34	10.4
Bicarbonate		47	149	89
Fluoride	1.5		0.45	0.18
Iron-total	0.3	**0.84**	**0.53**	**0.58**
Manganese-total	0.1		0.082	0.072
Arsenic-total	0.007	0.002	0.004	0.001
Cadmium-total	0.002	<0.0005	<0.0005	<0.0005
Chromium-total	0.05 as Cr(VI)	0.01	<0.01	<0.01
Copper-total	1	0.02	<0.05	0.002
Nickel-total	0.02	0.005	0.0012	0.0012
Lead-total	0.01	**0.020**	0.0033	0.001

Zinc-total	3	0.15	0.092	0.024
Total OC			14	7
Dissolved OC		10	13	6
NH_3-N	0.5 as NH_3	nd	0.10	0.023
NO_3^--N	50 as NO_3^-	0.44	0.10*	0.008*
TKN		1.0	1.0	0.41
Total P		0.6	0.14	0.054
Faecal coliforms (cfu/100 mL)	0	nd	**460**	**40**
E-coli (cfu/100 mL)	0	nd	**460**	**40**

bold indicates value exceeds guideline; nd=not determined; *NO_3^-+NO_2^--N; [A]NHMRC-NRMMC, 2004

Table 2 Maximal risk assessment summary for stormwater recycling via the aquifer at Mount Gambier and Parafield

		Mount Gambier		**Parafield**	
MAR Hazards		**Human endpoint**	**Environmental endpoint**	**Human endpoint**	**Environmental endpoint**
1.	Pathogens	**U**	**L**	**H**	**L**
2.	Inorganic chemicals	**H**	**H**	**H**	**H**
3.	Salinity and sodicity	**L**	**L**	**H**	**L**
4.	Nutrients: nitrogen, phosphorous and organic carbon	**L**	**H**	**L**	**L**
5.	Organic chemicals	**H**	**H**	**H**	**L**
6.	Turbidity and particulates – high in the injectant	**H**	**L**	**H**	**L**
7.	Radionuclides	**L**	**L**	**L**	**L**
8.	Pressure, flow rates, volumes and groundwater levels		**U**		**U**
9.	Contaminant migration in fractured rock and karstic aquifers		**H**		**L**
10.	Aquifer dissolution and stability of well and aquitard		**L**		**U**
11.	Aquifer and groundwater-dependent ecosystems		**H**		**L**
12.	Energy and greenhouse gas considerations		**L**		**L**

L=low risk; **U=**uncertain risk; **H=**high risk; a blank cell indicates the hazard does not apply to that endpoint

Stormwater turbidity and particulate matter pose a high risk and rely on removal during aquifer storage. Inorganic chemicals are also considered high risk in both examples of stormwater, due to high concentrations of iron and lead. In Mount Gambier, the high metal concentrations are largely associated with particulate matter, which are expected to be removed by filtration and sedimentation during aquifer and lake storage, resulting in acceptable water quality in Blue Lake (Vanderzalm et al., 2009). In contrast, at Parafield, the high iron concentrations are present in the soluble phase which is not likely to be removed during aquifer storage.

Thus recovered water would need iron removal by aeration as a post-treatment step to meet the aesthetic guideline value for iron of 0.3 mg/L.

The potential for the presence of organic chemicals in stormwater is considered a high risk within both catchment areas arising from land use activities (herbicides, hydrocarbons). The organic chemicals monitored within stormwater at Mount Gambier included pesticides, phenols, hydrocarbons and polyaromatic hydrocarbons (PAH). At Parafield, a more comprehensive monitoring suite for organic chemicals included herbicides, pesticides, hydrocarbons, PAH, detergents, industrial solvents, pharmaceuticals and personal care products (Page et al., 2009). However the monitoring data provides very few incidences of detection of organic chemical hazards within stormwater. Simazine was the most frequently detected organic chemical in the source water at Parafield, with the average concentration after wetland treatment of 0.2 μg/L remaining below the drinking water guideline value of 5 μg/L. Due to the lack of data for organic chemical concentrations in stormwater, the potential for natural treatment via biodegradation during MAR is assessed using literature values for source water concentrations and half-life under the relevant redox condition.

Salinity is a concern for the Parafield site only due to the salinity of the ambient groundwater, at approximately 2000 mg/L. This is managed by flushing the storage zone prior to operating the MAR scheme to recycle stormwater.

Specific to the Mount Gambier case study is that the receiving environment for stormwater, the Blue Lake, is a groundwater-dependent ecosystem to be protected. Thus while the level of nutrients in stormwater is reasonably low, nutrients and organic chemical hazards are considered to pose an environmental risk to the Blue Lake (environmental endpoint) due to the potential for eutrophication with the addition of phosphorus or degradation of the lake aesthetics or annual colour change cycle through addition of organic chemicals in particular hydrocarbons. In addition the karstic aquifer at Mount Gambier provides additional risk due to the potential for rapid transport of stormwater (and hazards) within the aquifer.

Initially the effect of each MAR scheme on groundwater level (unconfined aquifer) and pressure (confined aquifer) is uncertain, but is managed by operational controls such as abstraction volumes or injection rates. Some dissolution of carbonate minerals is expected when stormwater, not in equilibrium with the mineral phases, enters the storage zone (Vanderzalm et al., 2010). This is expected to have greater impact at the Parafield site, where injection occurs via four wells, than at Mount Gambier where hundreds of wells are used for stormwater discharge.

Radionuclides are low risk due to the low potential for their presence within the stormwater or to be mobilised from the aquifer sediments. Energy and greenhouse gas considerations are also deemed as low risk, as the energy requirement of the stormwater reuse applications is lower than that of alternatives for pumped supply over large distances.

Conclusions

Two urban catchments, Mount Gambier and Parafield, in South Australia have been examined to illustrate the application of the MAR Guidelines in assessing the risks posed by stormwater recycling via aquifers to human health and the environment. Mount Gambier's stormwater has been recycled via MAR for drinking water supply since the regional city was settled in the late 1800s. High quality stormwater pre-treated by settling pits receives sufficient residence time in the aquifer and the receiving lake to ensure the quality of drinking water is suitable for supply with disinfection. A purpose built MAR scheme to recycle stormwater in Parafield illustrates high quality source water and water quality improvements through the harvesting scheme and also during aquifer storage. However supplementary disinfection and aeration are recommended as post-treatment measures to ensure the residual risk from microbial hazards and iron are acceptable for use as a drinking water supply.

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