# Water recycling Via Aquifers – ‘Hidden’ Storage and Treatment for Cities

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Abstract: Urbanization and population growth results in a greater demand for future water supply, whilst at the same time increases the volume of urban stormwater and wastewater to be managed. Some means of storage is required to recycle stormwater and wastewater in order to balance demand and supply which can often be counter cyclical. Aquifers should be considered as ‘hidden’ storage for cities; underlying the city they minimize the urban footprint required to store significant quantities of water, are low cost alternatives to surface storage and can provide natural passive treatment analogous to that provided by a slow sand biofilter.

This paper documents recent research, which assessed the technical, economic and social feasibility of stormwater and wastewater recycling for both potable and non-potable end-uses. Stormwater harvesting and use at Parafield in Salisbury, South Australia was the main focus of this study and revealed that exposure controls were adequate for stormwater use in public open space irrigation, but appropriate treatments were needed to address health and aesthetic quality for residential third-pipe non-potable supplies and for reticulation within drinking water mains. Stormwater quality data from Parafield were found to be typical of other urban sites, including Orange (NSW), Mount Gambier (SA), and Fitzgibbon (QLD).

## Introduction

Water supply is a key challenge for future cities which need to support increased population under drying climatic conditions. While urbanization and population growth result in a greater demand for water supply, cities also generate water resources, such as urban stormwater and wastewater, that can be used to augment traditional sources. However, some means of storage is required to recycle stormwater and wastewater in order to balance the wet season supply and dry season demand. Aquifers can be considered as ‘hidden’ storage for cities; underlying the city the urban footprint required for storage is minimal in comparison to surface storage, are low cost alternatives to surface storage and can provide natural passive treatment analogous to that provided by a slow sand biofilter.

Managed aquifer recharge (MAR) is the purposeful recharge of water to aquifers for subsequent recovery or environmental benefit (NRMMC-EPHC-NHMRC, 2009a). MAR offers a wide range of benefits and in an urban setting a key benefit is the small land footprint required for storage of billions of litres of water, necessary to provide resilience in city water supplies. Other benefits include reduced evaporation of stored water, no algae or mosquitoes, natural treatment during storage, maintenance of groundwater-dependent ecosystems, prevention of saltwater intrusion in coastal areas and replenishment of exploited groundwater resources (Dillon *et al.*, 2009).

Stormwater use via the aquifer commenced at Andrews Farm, South Australia in 1992 and by 2009 was contributing to ~$18x10^6$ $m^3$/yr with potential to expand to $60x10^6$ $m^3$/yr in South Australia (Wallbridge & Gilbert 2009). Currently managed aquifer recharge provides ~$28x10^6$ $m^3$/yr of water supply in urban Australia, in Adelaide, Melbourne, Perth and regional towns in South Australia, Western Australia, Queensland and Northern Territory (Dillon, 2015). Groundwater replenishment, a form of MAR using highly treated wastewater, has been chosen as the next climate resilient water supply option for Perth and a $14x10^6$ $m^3$/yr scheme is currently under construction (Water Corporation, 2015).

Suitable aquifers for storage are not available beneath all urban areas, but nonetheless the potential for aquifer storage in urban settings in Australia exceeds $400x10^6$ $m^3$/yr (Dillon, 2015). To date, less two per cent of the potential for aquifer storage has been realized, due to a lack of understanding of when managed aquifer recharge schemes are feasible in comparison to alternative water supply options. This paper demonstrates the value of aquifer storage through a technical, economic and social feasibility assessment of stormwater recycling for both potable and non-potable end-uses.

## Methodology

Stormwater harvesting and use at Parafield in Salisbury, South Australia was the focus of this study. A number of stormwater harvesting and MAR schemes in Salisbury are connected via a ring main pipeline (Figure 1). The 2003-2012 mean average rainfall at the Parafield Airport Bureau of Meteorology weather station (station 23013, latitude 34.80 °S longitude 138.63 °E) was 414 mm.

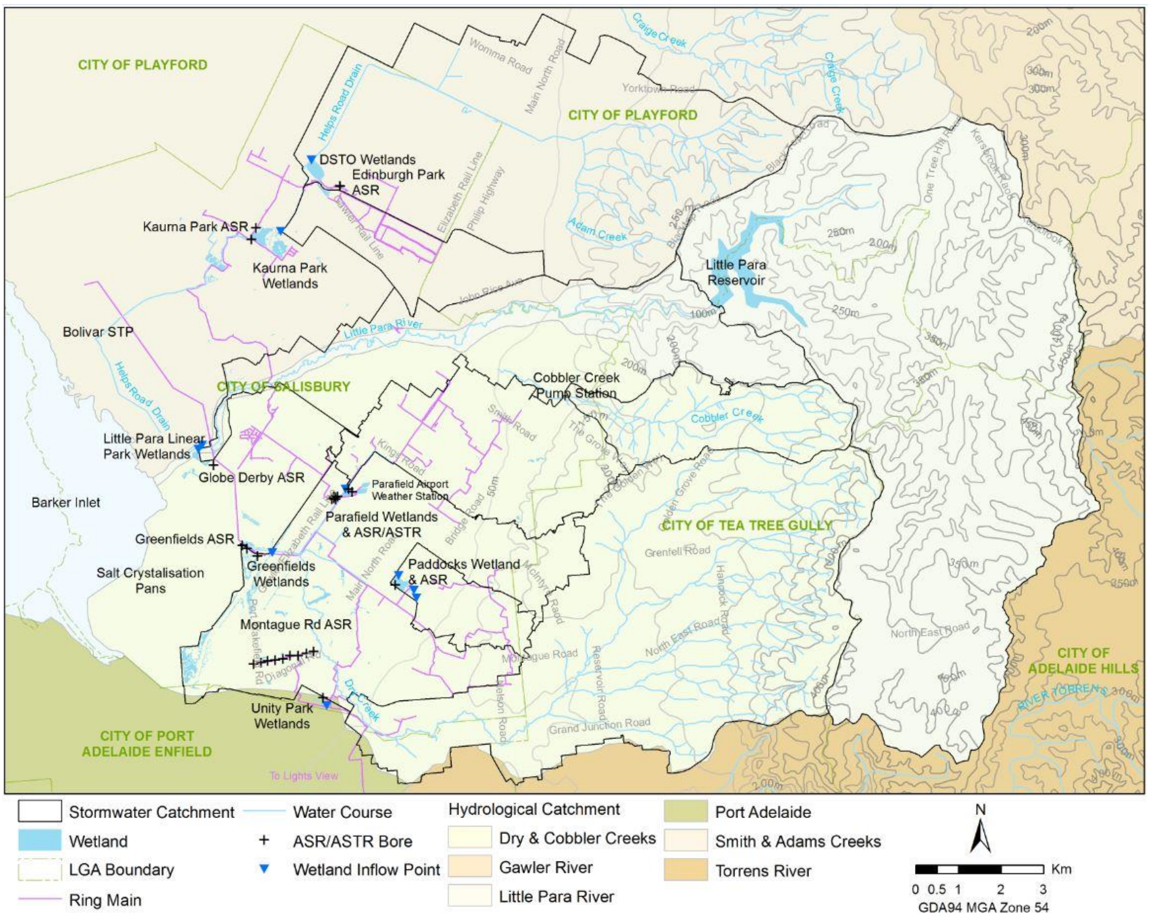


**Figure 1 Salisbury stormwater harvesting catchments and managed aquifer recharge (MAR) schemes showing the location of the Parafield wetlands and MAR (ASR/ASTR) schemes (Page *et al.*, 2013). ASR=Aquifer storage and recovery; ASTR=Aquifer storage transfer and recovery.**

The aquifer targeted for storage is a confined Tertiary limestone aquifer known locally as the "T2". The aquifer is approximately 60 m thick, is located approximately 160 m below ground surface and contained by a 7 m thick clay aquitard of Munno Para Clay. The aquifer mineralogy is mainly calcite (65% on average) and quartz (30% on average) with traces of ankerite, goethite, hematite, albite and microcline.

Well injection techniques are used to inject and recover water. Aquifer storage and recovery (ASR) refers to the use of a single well for injection and recovery and is the most common technique used in South Australia, while Aquifer storage transfer and recovery (ASTR) refers to the use of separate wells for injection and recovery (Figure 2). ASTR can provide longer and more consistent residence time in the aquifer which is favourable for water quality treatment. In the period of 2003 to 2012 (end October), $4.2\times10^6$ $m^3$ harvested stormwater had been injected into the Tertiary T2 aquifer via the Parafield ASR and

ASTR operations. A total of 2.9x10$^6$ m$^3$ had been recovered in the same period, leaving a net volume of 1.6x10$^6$ m$^3$ within storage in the aquifer.

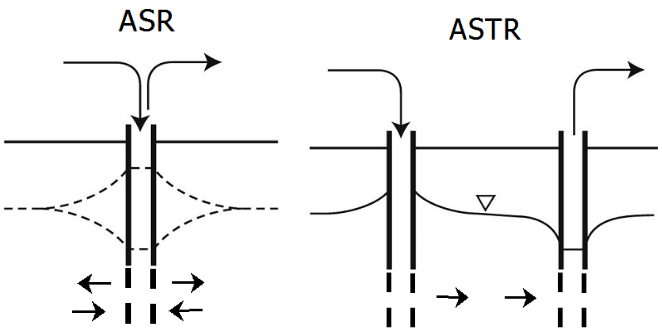


**Figure 2 Schematic illustrating Aquifer storage and recovery (ASR) where a single well is used for injection and recovery and Aquifer storage transfer and recovery (ASR) where separate wells are used for injection and recovery.**

Risk assessment and management was undertaken according to the *Australian Guidelines for Water Recycling: Managed Aquifer Recharge* (NRMMC-EPHC-NHMRC, 2009a). Seven categories of potential water quality hazards were assessed: pathogens; inorganic chemicals: salinity and sodicity; nutrients; organic chemicals; turbidity and particulates; and radionuclides (NRMMC-EPHC-NHMRC, 2009a). Risk assessment addressed the potential health and environmental risks associated with stormwater recycling and the preventative measures necessary to manage these risks, including the role of the aquifer as a barrier in the treatment train. In this sense, the subsurface storage component can be identified as one of seven components that are common to all MAR schemes, regardless of the type of water or method for recharge used (NRMMC-EPHC-NHMRC, 2009a) (Figure 3).

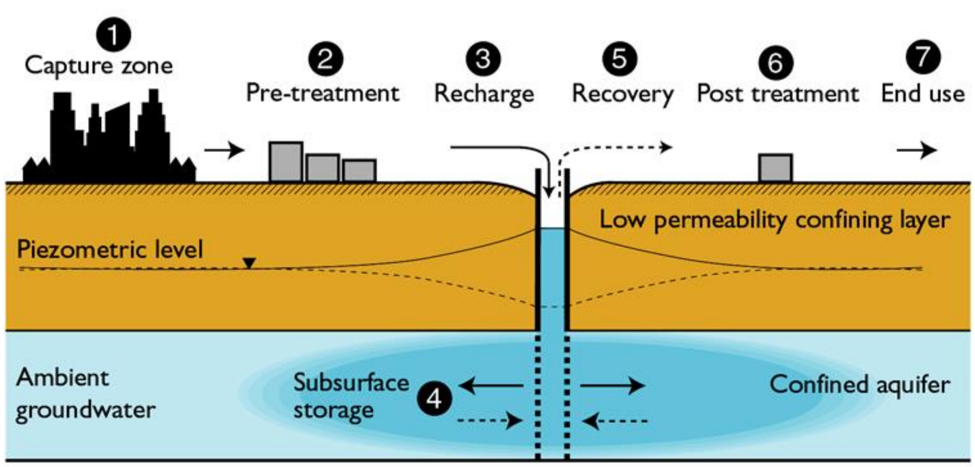


**Figure 3 Seven elements common to all managed aquifer recharge projects (shown for a confined aquifer) (NRMMC-EPHC-NHMRC, 2009a).**

To broaden the perspective of the research findings, Parafield stormwater quality data was compared with stormwater quality data from other urban sites in Australia that have previously assessed or used stormwater to supplement drinking water supplies, including Orange (NSW), Mount Gambier (SA), and Fitzgibbon (QLD).

An assessment of public acceptance of treated stormwater for non-potable use via third pipe systems and drinking water supplies was conducted through focus groups and web-surveys (Mankad *et al.,* 2013). The major web-survey included two different proposed uses for stormwater (non-potable and potable use) and three different information frames (generic, environmental, safety), resulting in six different versions of the survey. The sample of 1218 respondents were recruited through a third party company, from a panel list of over 300,000 individuals, and was assessed to be representative of Adelaide residents (Mankad *et al.,* 2013).

The net benefits of twelve different options for stormwater use were evaluated for the Parafield case study site by Dandy *et al.* (2013). The economic analysis was based on market benefits and costs. Non-market values related to environmental and social impacts were assessed using environmental and social criteria in an ecosystems services framework, in categories of provisioning services, amenity and regulation services.

## Urban stormwater as a resource

Urban stormwater quality is impacted by catchment stormwater quality hazards, which may be point or diffuse sources and by rainfall characteristics. This paper does not attempt to relate stormwater quality to land use, but instead compares stormwater quality from the Parafield catchment (SA) to other Australian urban stormwater catchments. Indicator parameters for three of the seven water quality hazard groups, *E. coli* (pathogens), turbidity and total iron (inorganic chemicals) are discussed below. Note that the parameters monitored varied between catchments.

Pathogen risks to human health can arise when stormwater is contaminated by sewage or animal faeces. Pathogen risks are applicable to all uses of stormwater where human contact occurs, but the most prominent risk would be for drinking water supply where human exposure is greatest. Pathogen numbers are required for human health risk assessment (NRMMC-EPHC-NHMRC 2009b), but currently there are very few data for pathogen numbers in stormwater.

Here the numbers of the faecal indicator parameter, *E. coli* are compared for Parafield, Fitzgibbon and Orange stormwater (Figure 4). Parafield stormwater had a similar range to Fitzgibbon and Orange and therefore it is concluded that the assessment of pathogen risks undertaken at Parafield is broadly relevant to Australian stormwater, based on the presence of *E. coli* as a faecal indicator. It should be noted that the 95$^{th}$ percentile *E. coli* numbers for Parafield stormwater were an order of magnitude lower than those reported for Australian stormwater in the Stormwater Harvesting and Reuse Guidelines (NRMMC-EPHC-NHMRC 2009b).

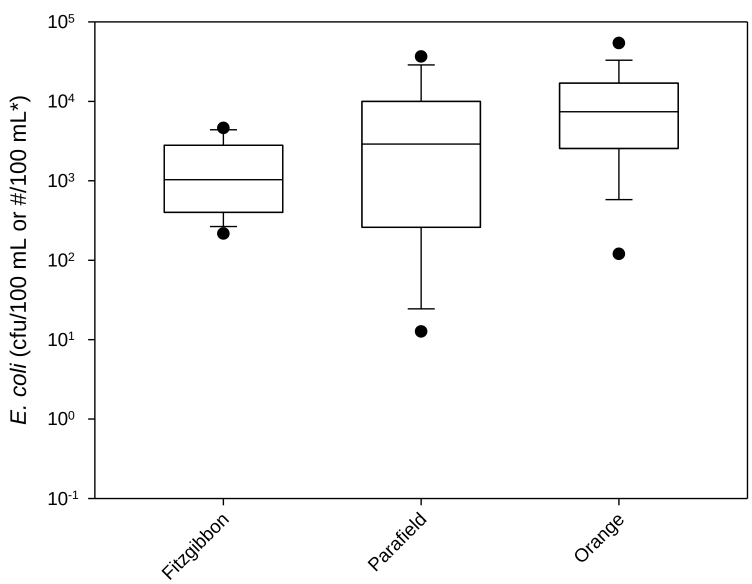


**Figure 4 *E. coli* in stormwater from various catchments (Drinking water guideline is 0 cfu/ 100 mL; Limit of detection is 1 cfu/ 100 mL).**

Turbidity or particulates in stormwater can present clogging hazards, in irrigation infrastructure and the aquifer and are also generally associated with potentially elevated levels of other contaminants such as inorganic chemicals (NRMMC-NHMRC-EPHC, 2009a). The turbidity measured in Parafield's stormwater exhibited a greater range of data, but a lower median value than at Mount Gambier and Orange (Figure 5). It is apparent that raw urban stormwater is likely to exceed the Australian Drinking Water Guidelines for turbidity of 5 NTU (NHMRC-NRMMC, 2011).

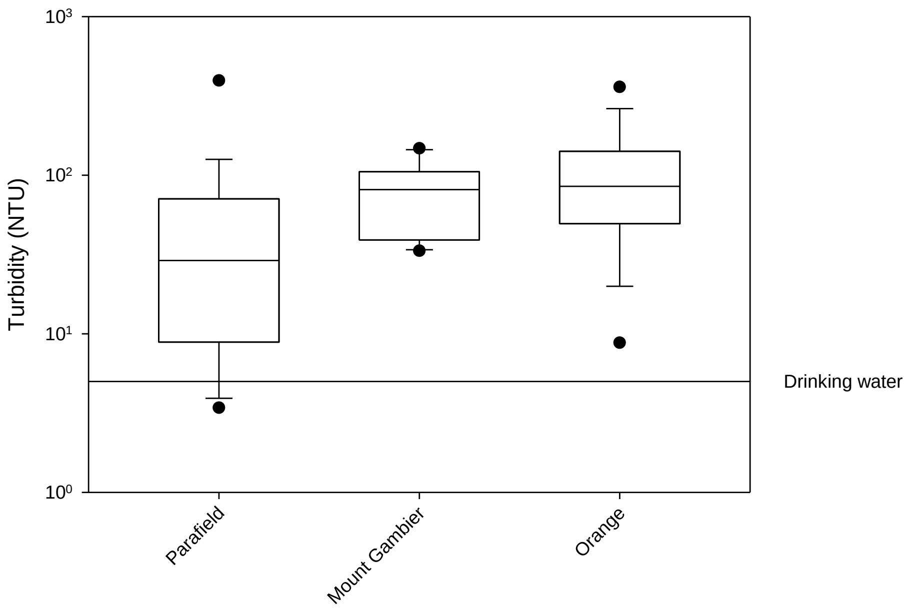


**Figure 5 Turbidity in stormwater in stormwater from various catchments (Drinking water guideline is 5 NTU).**

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 roof water or stormwater (NRMMC-EPHC-NHMRC, 2009a).

Total iron (Figure 6) in Parafield stormwater lies within the range reported for Mount Gambier and Orange stormwater catchments. The median total iron for Parafield's stormwater of 0.9 mg/L is considerably lower than that 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 were 0.68 mg/L in Mount Gambier, 0.87 mg/L in Parafield and 2.8 mg/L in the City of Orange.

The 95$^{th}$ percentile soluble iron concentration was one order of magnitude less than total iron at Parafield, (Page *et al*., 2013), indicating that iron in untreated stormwater is predominantly insoluble and may therefore be managed by filtration or sedimentation.

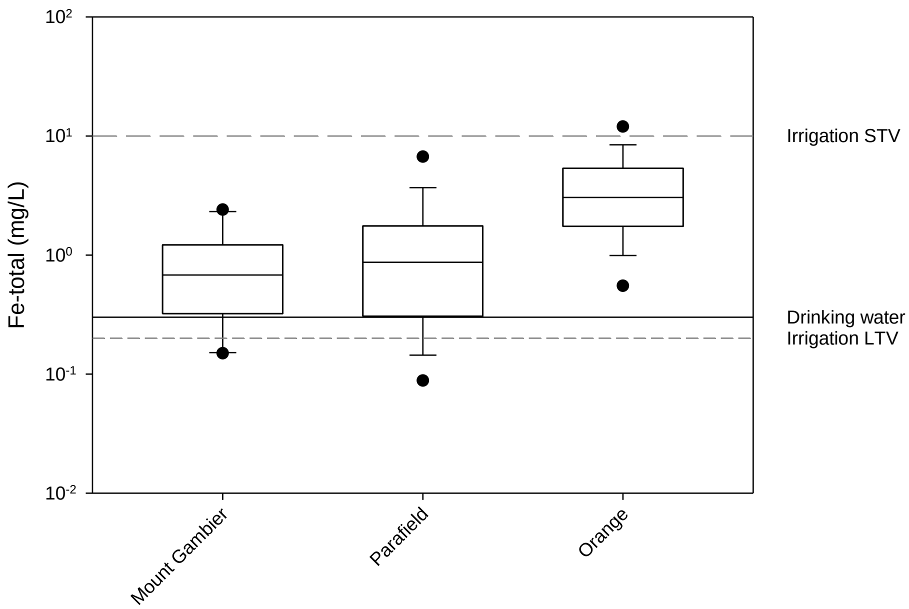


**Figure 6 Total iron in stormwater from various catchments (Drinking water guideline is 0.3 mg/L; Irrigation LTV is 0.2 mg/L, Irrigation STV is 10 mg/L).**

## Stormwater quality and risk assessment

Qualitative and quantitative risk assessment was undertaken based on extensive monitoring of stormwater quality in the Parafield catchment. Seven categories of potential water quality hazards were assessed (NRMMC-EPHC-NHMRC, 2009a) for both non-potable and potable end uses of stormwater.
It was found that exposure controls alone were adequate for managing risk for public open space irrigation and similar low exposure industrial applications. However, it was identified that appropriate treatments were needed to address health and aesthetic quality for residential third-pipe non-potable supplies and for reticulation within drinking water mains where the exposure rates are higher. Based on the Parafield stormwater quality data, 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). These treatment processes were similar to those used for drinking water supplies when the raw water was sourced from open catchments.

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. Parafield stormwater quality data were compared and found to be typical of other urban sites where stormwater is used, or has been assessed for use, as a source for drinking water supplies. Despite significant climate and catchment variability between Australian stormwater catchments, Parafield stormwater quality data were compared and found to be typical of other urban sites where stormwater is used, or has been assessed for use, as a source for drinking water supplies. Despite significant climate and catchment variability the evaluated stormwater quality data were consistent from a risk assessment perspective; in all cases requiring treatment for removal of pathogens, iron, turbidity and colour before being suitable as a drinking water supply.
For the stormwater investigated, 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.

## Public acceptance

Participants in focus groups and in web surveys indicated that both potable and non-potable stormwater use options were acceptable. There was a clear preference for stormwater use over alternative water options, such as desalination and increasing the allocation of water taken from the River Murray, for future water supply augmentation of Adelaide's water supply (Table 1). Therefore, the use of treated stormwater for drinking water supplies did emerge as an acceptable option. However, participants were not willing to pay more for stormwater, particularly if it was of non-potable quality (Mankad *et al*., 2013).

There was a preference that government owned water utilities undertake such projects if treated stormwater is to be used for drinking water systems, due to the trust the community holds for water suppliers and regulators to provide safe water over the long term. Knowledge of more common stormwater terms appeared to contribute to acceptance of stormwater via managed aquifer recharge. This suggests familiarity with certain basic concepts may contribute to increased acceptance but a high degree of technical knowledge is not needed. If stormwater is intended to be harvested for potable use or for residential non-potable use for any project an appropriate public information and consultation process would be needed.

**Table 1 Most preferred option for increasing Adelaide's future water supply (from Mankad *et al.*, 2013).**

| Treated stormwater use | Taking more River Murray water | Desalination | Treated Stormwater |
|---|---|---|---|
| Non-potable use | 22.2% | 17.7% | 60.1% |
| Potable use | 23.1% | 10.7% | 66.1% |
| Total | 22.7% | 14.2% | 63.1% |

*Note:* Non-potable use $n$ = 604, Potable use $n$ = 614, Total $N$ = 1218

## Economic assessment of stormwater use

For the stormwater use options considered at the Parafield case study site, at a scale of between 370 and $1100x10^3$ $m^3$/yr and including the costs of existing infrastructure, the least costs were found to be for non-potable use in public open space irrigation and industry, followed by drinking water supplies. The most costly use options were third pipe non-potable residential supplies (Dandy *et al*., 2103) due to the cost of constructing infrastructure to reticulate this non-potable supply. When costs of existing infrastructure were excluded from the analysis, levelised costs were reduced considerably.

Public open space irrigation and industrial use had the lowest levelised costs at approximately $1.57/$m^3$ and this was lowered to $1.31/$m^3$ for stormwater blended with recycled water (from the Bolivar Sewage Treatment Plant). The costs for drinking water supply augmentation ranged from $1.47/$m^3$ to $2.51/$m^3$, with the variation in cost influenced by the storage and treatment options assessed. Residential non-potable third pipe options started at $2.74/$m^3$, for stormwater blended with recycled water.
For comparison with traditional supply and storage options, the capital cost of a $250x10^3$ $m^3$/yr ASR well is ~$1M, while the cost of constructing a wetland to harvest the stormwater for a scheme of this capacity is ~$3M (Vanderzalm *et al.* 2015). Stormwater harvesting costs may be offset by benefits associated with provision of necessary flood protection measures, improvement in urban amenity and ecosystem services.

The reliability of stormwater supply under future predictions of climate variability must be considered before investing in a stormwater recycling scheme. Climate change effects to the year 2050 have been estimated to reduce the yield of urban stormwater from catchments in Adelaide by between 10 and 20% (Wallbridge and Gilbert, 2009). This degree of reduction is likely to be compensated by an increase in impervious land in urban catchments, including those that feed the Parafield stormwater harvesting system, due to urban consolidation. Furthermore, Clark *et al.* (2105) reported that urban catchments will be less impacted by reduced rainfall than pervious natural catchments that are currently used for drinking water supply.

## Role of the aquifer in recycling stormwater

The role of the aquifer can be examined with respect to water quality, as aquifer storage can provide natural treatment whilst it can also lead to water quality degradation (NRMMC-EPHC-NHMRC, 2009a). At Parafield, median *E. coli*, turbidity and total iron concentrations were all reduced after storage in a limestone aquifer, when compared to raw stormwater (Figure 3-5) and stormwater after wetland treatment. Median *E. coli* was reduced from 2,900 cfu/100 mL in raw stormwater, to 33 cfu/100 mL after wetland treatment and <1 NTU cfu/100 mL after aquifer storage. Median turbidity was reduced from 29 NTU in stormwater, to 4 NTU after wetland treatment and 1 NTU after aquifer storage. Similarly, median total iron was reduced from 0.87 mg/L in stormwater, to 0.45 mg/L after wetland treatment and 0.38 mg/L after aquifer storage (Page *et al*., 2013; Vanderzalm *et al*., 2015). Only total iron remained above water quality target values for beneficial end uses, suggesting additional treatment such as aeration may be required prior to use.

Aquifer storage was also shown to influence interactions between stormwater and water distribution infrastructure. Residence in a carbonate aquifer was shown to be beneficial by reducing labile carbon concentrations (restricting biofilm growth), reducing suspended solids concentrations and reducing the potential for dissolution of cement linings, in comparison to stormwater with limited aquifer contact.

## Conclusion

Currently wasted urban water resources play an important role in provision of water for future cities facing challenges of population growth and a reduction in traditional water supplies. Increased urbanization will continue to generate these under-utilized ‘waste’ streams of urban stormwater and wastewater. Storage is an essential element to provide security of supply, to ensure cities are resilient to seasonal or long-term variability in water resource availability. Suitable aquifers, beneath many of our urban areas, can be considered as ‘hidden’ storage. Currently limited understanding of when aquifer recharge is feasible in comparison to alternative water supply options limits the uptake of aquifers for water storage and treatment. Recent research demonstrated that aquifers can provide natural passive treatment and reduce the risks of potential hazards that may be contained within stormwater. This means that aquifers, hidden beneath cities, represent low cost, low energy alternatives to surface storage, where considerable energy may be required for treatment and reticulation. However, the ‘hidden’ nature of aquifers also means that it can be challenging to characterize the characteristics that can influence the safety of water storage and supply options. Demonstration projects and documentation and sharing practical experience is necessary to build confidence in the use of managed aquifer recharge.

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