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# CHALLENGES OF URBAN STORMWATER REUSE VIA A LOW PERMEABILITY FRACTURED ROCK AQUIFER IN VICTORIA

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**Abstract**

Aquifer storage and recovery (ASR) can be used to store and treat urban stormwater prior to reuse, without the need for large and expensive surface reservoirs. This paper describes the development of an ASR scheme at the Rossdale Golf Club in Aspendale, Victoria, which aims to capture urban stormwater in winter for irrigation of the golf course in summer. This project is the first of its kind in Victoria, and was intended to trial the injection of stormwater into the underlying fractured rock aquifer, with appropriate pre-treatment. The target aquifer at Rossdale is a fractured weathered bedrock with very low transmissivity; the small fracture apertures and matrix pore sizes give a high potential for well clogging during ASR. The brackish native groundwater also meant that a low recovery efficiency could be expected in the fractured rock aquifer.
An injection and recovery trial using mains water showed ASR to be possible at the site if the stormwater could be treated to a suitable quality to minimise ASR well clogging. Studies were conducted to determine the most appropriate pre-treatment method; ultrafiltration followed by granular activated carbon filtration was chosen as the best method considering water quality, ease of use, cost and generation of waste products. An injection trial using treated stormwater was conducted successfully confirming that stormwater reuse via ASR in a low permeability fractured rock formation is feasible.

## Introduction

Aquifer storage and recovery (ASR) can be used to store harvested urban stormwater, without the need for large and expensive surface reservoirs that can result in large evaporative losses. ASR is the process of injecting water into an aquifer via a well, and recovering it at a later period via the same well (Pyne 1995). Two of the major technical issues associated with ASR are the potential for aquifer clogging and the portion of the recovered water suitable for use, defined as the recovery efficiency (NRMMC–EPHC–NHMRC 2009). To date ASR operations in Australia have been conducted in moderate-high permeability limestone aquifers, such as the South Australian schemes at Bolivar (Pavelic *et al*. 2007), Andrews Farm (Pavelic *et al*. 2006) and Parafield (Page *et al*. in press).

In this study the target aquifer is a fractured weathered bedrock with very low transmissivity (1.4 $m^2$/day) and brackish groundwater (2,400-2,800 µS/cm). This posed two challenges. Firstly, the small fracture apertures and matrix pore sizes give a high potential for well clogging during ASR. Secondly, the native groundwater was brackish and in a fractured rock aquifer low recovery efficiency could be expected.

This paper describes the development of the ASR scheme at the Rossdale Golf Club in Aspendale, Victoria, which aims to capture urban stormwater in winter for irrigation of the golf course in summer. This project was the first of its kind in Victoria, and was intended to trial the injection of stormwater into the underlying fractured rock aquifer, with appropriate pre-treatment.

The following sections describe the investigations undertaken to characterise the aquifer and stormwater quality, determine appropriate stormwater pre-treatment methods, and trial stormwater ASR at the Rossdale site.

**Site selection and information**

Prospective demonstration sites for a Smart Water Fund ASR demonstration project needed to use more than 30,000 kL/year of mains water for irrigation supplies; and have a strong commitment to water conservation and environmental sustainability of their operations. A call was issued for expressions of interest firstly from public organisations and subsequently from private organisations. Although there was wide interest, few prospective sites were located where aquifers were likely to be suitable based on broad-scale mapping of the Melbourne area (Dudding *et al.* 2006).

Rossdale Golf Club is situated in Aspendale, a south-eastern suburb of Melbourne, Victoria approximately 1 km from Port Phillip Bay (Figure 1A). Rossdale was selected out of a number of potential sites, as it held a diversion licence for harvesting stormwater in winter from the Centre Swamp Drain for irrigation use, and had commenced construction of a stormwater storage dam (Dillon *et al.*, 2010).
The ASR system consists of a stormwater drain, an off-take pumping system, a dam (10 ML capacity), a pre-treatment unit, an ASR well (BH3) and two observation wells (BH2 and BH4) (Figure 1B). Water is pumped from the dam, through the pre-treatment unit, and into the ASR well. Water is recovered from the ASR well back into the stormwater dam. On-line flow rate, pressure and water quality data (electrical conductivity, turbidity, temperature and water level) sensors are installed in the injection/recovery line. Electrical conductivity measurements were used to monitor the salinity of the injectant and recovered water to determine recovery efficiency, and the water level and flow rate measurements allowed for an evaluation of well clogging.

(A)

(B)

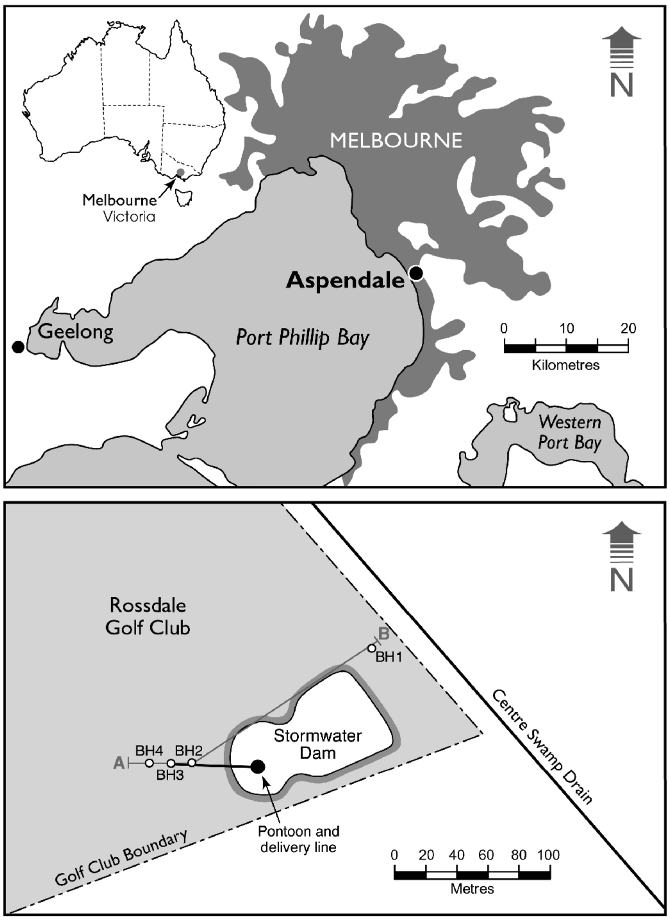


***Figure 1 (A) Map showing location of Rossdale Golf Club in Aspendale; and (B) ASR well (BH3), monitoring wells (BH2, BH4) and stormwater dam in the south-eastern corner of the golf course. Line A-B marks line of hydrogeological cross section in Figure 2. Modified from Dillon et al. (2010).***

**Initial investigations and mains water trial**

The source water for ASR is stormwater from the Centre Swamp Drain (Figure 1B). The catchment area consists predominantly of residential land use, with a small business and industrial area (Sixth Avenue Industrial Area; Dillon *et al.*, 2010). Being stormwater, the water quality is variable, but is generally fresh with a mean salinity of 380 µS/cm (Table 1). After settling in the dam particulate concentrations are relatively low (mean total suspended solids 6 mg/L; turbidity 2.8 NTU). Mean nutrient concentrations are dissolved organic carbon 8.3 mg/L; total nitrogen 2.3 mg/L; total phosphorous 0.14 mg/L.

Broad-scale mapping indicated that the hydrogeology at this site had a medium potential for ASR (Dudding *et al.*, 2006); however, there was uncertainty in this assessment due to the absence of nearby hydrogeological data (Dillon *et al.*, 2010). Drilling and pumping tests were undertaken at the site to identify the most suitable aquifer for ASR; BH3 in the bedrock was deemed to be the most appropriate ASR well, with BH4 and BH2 becoming observation wells (

*Figure 2*; Dillon *et al.*, 2010).

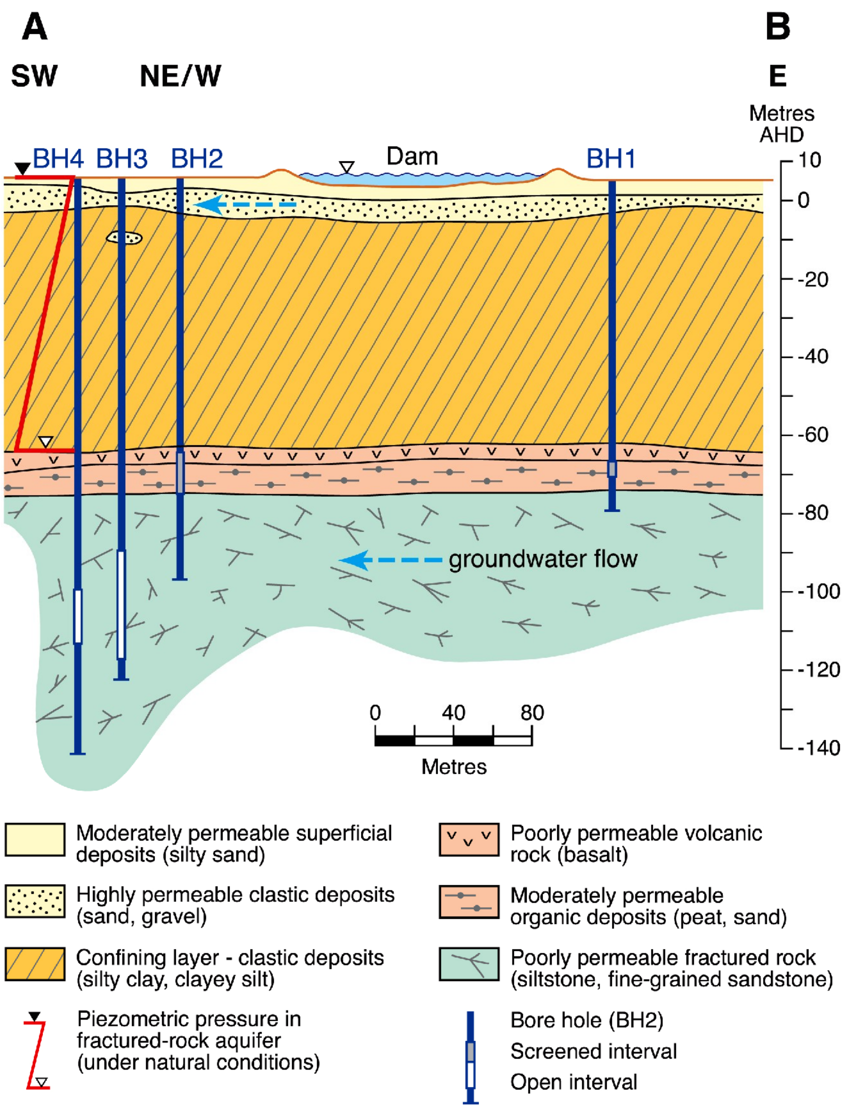

***Figure 2 Hydrogeological cross-section at the Rossdale ASR site. Line of cross-section is marked A-B in Figure 1. Taken from Dillon et al. (2010).***

A feasibility trial using mains water was conducted over four cycles of injection, storage and recovery. The first cycle was conducted over three hours (one hour each for injection, storage and recovery); subsequent cycles increased in duration from three days, to three weeks, to three months. By using a staged approach any technical issues could be identified and resolved before the problem became acute. In total, 1378 $m^3$ of mains water was injected and 1401 $m^3$ was recovered over the four cycles.

***Table 1 Water quality summary for groundwater, stormwater, injectant and recovered water***

| Parameter | Groun d water (BH3) (n = 1) | Stormwater raw | | | Mains water | | | Stormwater treated | | | Recovered (MW phase) | | | Recovered (SW phase)* (n = 1) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | n | mea n | max | n | mea n | max | n | mea n | max | n | mea n | max | |
| **Physical characteristics** | | | | | | | | | | | | | | |
| Electrical Conductivity (µS/cm) | 2880 | 10 | 378 | 565 | 5 | 66 | 70 | 8 | 385 | 579 | 8 | 1380 | 2380 | 2230 |
| pH | 7.7 | 7 | 9.0 | 9.9 | 2 | | 7.7 | 4 | 7.8 | 9.4 | 9.4 | 7.4 | 7.7 | |
| Turbidity (NTU) | | 11 | 2.8 | 5.5 | 4 | 0.6 | 0.9 | 11 | 0.9 | 4.8 | 8 | 500 | 3800 | 3.3 |
| Total Suspended Solids (mg/L) | 73 | 13 | 6 | 24 | 1 | | 2 | 7 | 1 | 4 | | | | |
| **Nutrients (mg/L)** | | | | | | | | | | | | | | |
| Total Nitrogen | 0.34 | 11 | 2.3 | 15.4 | 3 | 0.07 | 0.19 | 5 | 0.51 | 1.0 | | | | 0.31 |
| Total Phosphorus | 0.18 | 11 | 0.14 | 0.5 | 5 | 0.013 | 0.02 | 5 | 0.16 | 0.37 | 8 | 1.4 | 10.1 | 0.08 |
| Dissolved Organic Carbon | 5.1 | 14 | 8.3 | 14.2 | 4 | 1.7 | 1.7 | 112 | 2.0 | 3.4 | 8 | 3.8 | 7.0 | 5.0 |
| Biodegradable Dissolved Organic Carbon | | 4 | 3.9 | 6.0 | 1 | | 0.2 | 10 | 0.56 | 1.0 | | | | |

* Measured on last day of recovery

**Stormwater pre-treatment investigations**

While the required water quality parameters for sustainable injection of stormwater are difficult to define, it was initially assumed that the mains water was of a suitable quality to minimise risks of well clogging (Table 1). Also taking into account the very low permeability of the target aquifer and knowledge of the quality of water that has been successfully (Pavelic *et al*. 2006; 2007) and unsuccessfully (Pavelic *et al*. 2008) injected into aquifers at other ASR sites, the targets were set to maintain turbidity to ≤0.6 NTU, dissolved organic carbon (DOC) to ≤1.7 mg/L and biodegradable dissolved organic carbon (BDOC) to ≤0.2 mg/L.

Stormwater pre-treatment studies were performed in 2007 and 2008 to determine the most appropriate method of treating the stormwater prior to injection to avoid clogging of the ASR well. Pre-treatment methods to be assessed were chosen for their ability to remove TSS, turbidity, and nutrients including DOC and BDOC, and for their effects on the potential for dispersion of clays. Pre-treatments trialled included conventional flocculation with different coagulants; biological filtration consisting of roughing filtration for removal of suspended solids and algae, followed by either slow sand filtration (SSF) or granular activated carbon (GAC) filtration to remove DOC; and membrane filtration technologies.

Two of the conventional coagulation treatments were able to produce the target water quality on a continuous basis. However, the coagulation treatments have major disadvantages as multiple coagulants require skilled operators, and the production of a sludge waste stream that requires a trade waste licence to discharge to sewer. Therefore the conventional treatment options were not considered as suitable for the Rossdale site.

Reverse osmosis (RO) treatment was initially considered as it would consistently produce good quality water, but Emerson dispersion tests (Standards Association of Australia 1980) showed that clay swelling caused by the low ionic strength of RO water would contribute to an increased risk of physical clogging of the ASR well

(Dillon *et al.*, 2010). Instead microfiltration (MF) and ultrafiltration (UF) were trialled as both treatments are capable of good turbidity removal but do not decrease the ionic strength of the water.
Both MF and UF produced good reductions in turbidity of approximately 80%, however GAC filtration was also required to remove DOC. MF followed by GAC filtration was trialled with the aim of determining the optimal grade of GAC to use, size of reactor, and empty bed contact time, and whether or not the treatment could meet the water quality targets (Levett *et al*. 2009). Although the target of producing mains water quality was not achieved during the GAC studies, the results were sufficiently close to justify proceeding to a field trial. While MF-GAC was more economical due to the lower trans-membrane pressures involved, UF-GC was eventually selected as the smaller pore size of the membrane had the ability to reject larger particles and hence lower the risk of physical clogging.

Field testing of an UF-GAC treatment unit from October to December 2008 showed treated water quality was consistently close to the mains water targets (Table 1), with the best quality values being: turbidity 0.25 NTU, DOC 0.4 mg/L and BDOC 0.2 mg/L.

### Stormwater injection and recovery trials

After successful installation and testing of the UF-GAC treatment unit, injection and recovery with treated stormwater was performed over two cycles (Figure 3).

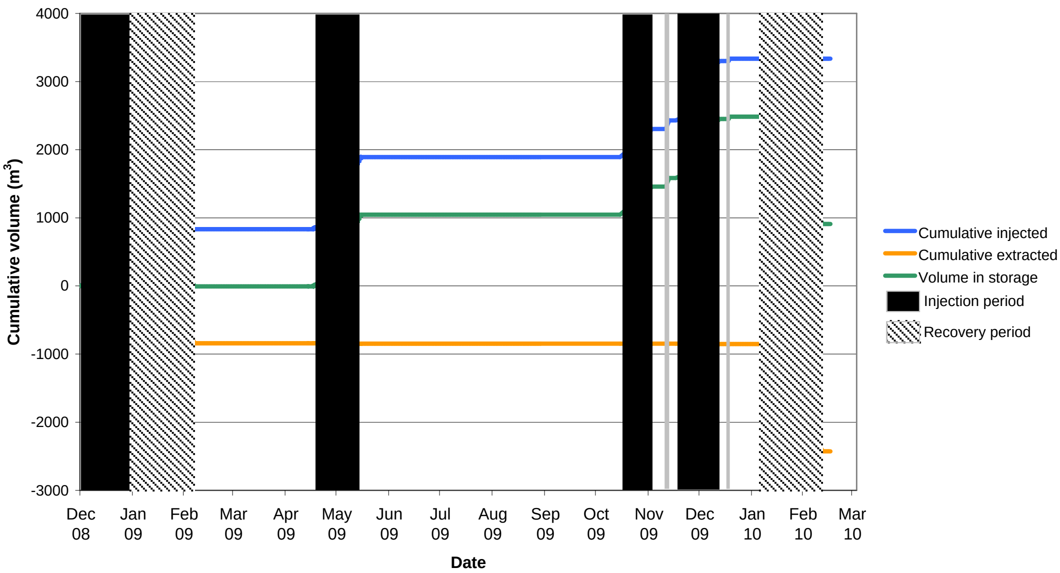


***Figure 3 Cumulative volume injected, recovered and in storage during the two stormwater trials at Rossdale ASR (source Dillon et al. 2010)***

The quality of the recovered water (Table 1) was suitable for irrigation, with lower nutrient concentrations (dissolved organic carbon 5.1 mg/L; total nitrogen 0.31 mg/L; total phosphorous 0.082 mg/L) than the raw stormwater that is also used for irrigation. Electrical conductivity ranged from ~400 to ~1940 µS/cm for the first stormwater trial (

*Figure 4*), and from 880 to 2230 µS/cm for the second trial. Although recovered salinity was generally over the 800 µS/cm limit for irrigation of the golf course, after blending with fresh stormwater in the dam on recovery, the water in the dam was suitable for irrigation.

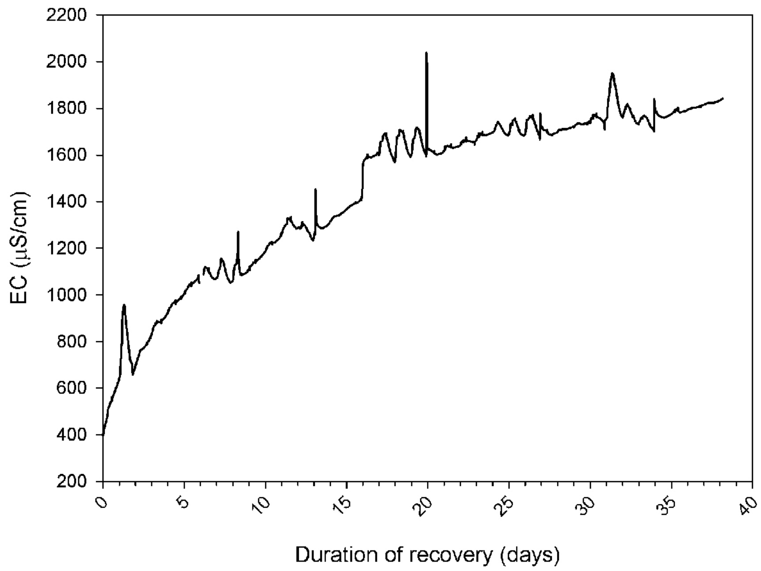


***Figure 4 Electrical conductivity (EC) of recovered water during extraction in the first stormwater trial***

**Clogging evaluation**

Clogging of the ASR well was evaluated by changes in aquifer transmissivity (Dillon *et al*. 2010). There was a similar trend observed for both the Theis and Thiem methods to calculate aquifer transmissivity, with both methods indicating some clogging occurred during each successive ASR cycle, irrespective if mains or treated stormwater was used (Figure 5). However, the rate of transmissivity decline progressively decreased and appears to have stabilised, indicating that clogging may have reached a manageable level. The initial major decline in transmissivity may be due to clogging caused by the swelling of clays present in the aquifer matrix, when fresh mains water was injected into the saline aquifer.

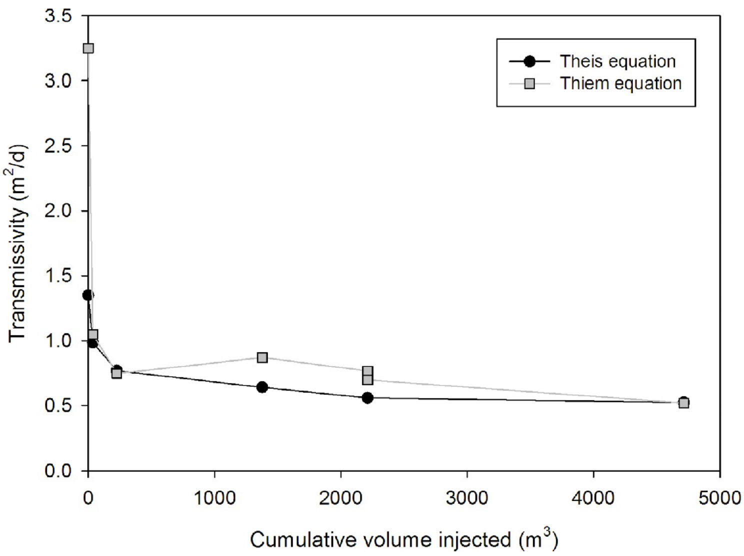


**Figure 5 Changes in transmissivity over the six cycles of injection and recovery for mains and treated stormwater (source Dillon *et al*. 2010)**

**Recovery efficiency evaluation**

Recovery efficiency is the proportion of recovered water that is of suitable quality (usually based on salinity) for its intended use, expressed as a percentage of the injected volume. Poor recovery efficiency is considered a significant risk of operational failure for the Rossdale ASR project, due to the small injection volumes and the fractured nature of the aquifer that encourage mixing of fresh stormwater injectant with the native brackish groundwater (Dillon *et al*. 2010).

As shown in

*Figure 4*, the salinity of recovered water increases as extraction progresses. The maximum salinity for irrigation of the golf course is 800 µS/cm, but as recovered water is blended with fresh stormwater in the dam, higher salinities of recovered water can be allowed. Thus, recovery efficiencies (REs) have been calculated for recovered water at threshold salinities of 800 µS/cm, 1500 µS/cm and 2000 µS/cm (

Table 2). The higher RE in the first stormwater trial was due to no period of storage occurring between injection and recovery. Conversely, the lower RE seen in the second stormwater trial was most likely due to the extended periods of storage in between injection periods allowing more mixing between injectant and groundwater than seen in previous cycles.

The level of mixing between the pumped water and stormwater within the holding dam would ultimately define the RE, and as such it is seasonally dependent upon the volume and salinity of dam water prior to and during recovery. In an extended drought, if there is little water in the dam, the salinity may be unacceptable for irrigation.

***Table 2 Recovery efficiency for salinity thresholds during the 3 month mains water trial and the two stormwater trials (after Dillon et al. 2010)***

| Trial | Injected Volume ($m^3$) | EC injectant (µS/cm) | Recovery Efficiency (%) for | | |
|---|---|---|---|---|---|
| | | | 800 µS/cm | 1500 µS/cm | 2000 µS/cm |
| **MW 3-month** | 1151 | 100 | 5 | 28 | >92 |
| **SW trial #1** | 834 | 402 | 12 | 45 | >100 |
| **SW trial #2** | 2467 | 530 | <1 | 26 | 64 |

## Conclusions

The ASR demonstration at Rossdale was a test of the technical viability of ASR in a low transmissivity fractured rock aquifer. The project encountered two significant challenges.

Firstly, the low aquifer transmissivity leads to a high potential for clogging, hence the water must be treated to a very high quality before injection. In particular, particulate and nutrient concentrations must be maintained at very low levels to avoid physical blocking and biological growth in the vicinity of the well.

Secondly, mixing of fresh injectant with the native brackish groundwater is exacerbated by the small injected volumes and aquifer fractures. The success of this ASR project depends on being able to blend the recovered water with fresh stormwater in the dam, so that the salinity is acceptable for irrigation. Thus, the recovery efficiency will change from year to year depending on the amount of fresh stormwater in the dam available for blending.

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