The Department of Water, Land and Biodiversity Conservation

Aquifer Storage and Recovery

Future Directions for South Australia

Report DWLBC 2002/04

Government of South Australia

AQUIFER STORAGE AND RECOVERY

FUTURE DIRECTIONS FOR SOUTH AUSTRALIA

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Executive Summary

Aquifer Storage and Recovery (ASR) has considerable potential to improve the quality and availability of water resources in South Australia by harvesting waters such as, urban stormwater runoff and treated wastewater, and injecting them into suitable aquifers for later recovery and use.

The South Australian Department for Water Resources has carried out a significant number of investigations into ASR schemes using source water of varying quality. The work is at the International leading edge in the design and implementation of ASR schemes that use low quality waters injected into, and stored in, aquifers of low transmissivity.

This paper reviews the status of ASR in South Australia, describes the experiences to date, highlights emerging issues and looks at some of the future potential for ASR.

In South Australia, because the most suitable host aquifers for the storage and recovery of large quantities of water are the deep confined Tertiary aquifer systems, recharge wells have been the main method employed. This is the most difficult and expensive method of recharge enhancement because if source water is not adequately treated, clogging can quickly render the well inoperable. The method can involve both single wells for injection and recovery or individual injection and recovery wells.

Infiltration basins are another method in which water is collected in carefully constructed holding ponds and allowed to infiltrate through the base of the ponds to shallow water table aquifers. Bank filtration is the third method. In this process pumping wells adjacent to the watercourse are used to induce water movement to the groundwater store via the beds and banks of the stream. The method has limited application in SA because of the ephemeral nature of many of our creeks and the shortage of shallow aquifer systems adjacent to those water bodies carrying regular and adequate supplies of water.

In the Adelaide metropolitan area, the redirection of large amounts of stormwater runoff into a shallow aquifer system to limit discharge into the sea can quickly add up and can result in rising water tables and infrastructure damage through water logging. The prime targets for large scale ASR in the metropolitan area are therefore the deeper confined aquifers where increasing pressures will not cause water table elevation. Deep injection wells and filtration equipment can be relatively unobtrusive, and opportunities may exist to use existing infrastructure to distribute the captured runoff.

Within rural catchments, pollution of the aquifer is a major constraint to the successful implementation of an ASR scheme. On-going water sampling and analysis is critical in rural areas where some users rely solely on groundwater for potable use. In both urban and rural situations confined aquifer systems allow the best management of injected water.

Fractured rock aquifers, like the deep, confined sedimentary aquifers, offer good sites for the injection of stormwater. There are sites that have been operating in SA for a number of years, principally using gravity recharge. The storage capacity is relatively small and the fracture networks can be connected over very large distances. Injected water can move over these distances in a very short time also. Remediation of contamination is difficult and injection into fractured rock aquifers should be confined to storm water or creek runoff.

A significant number of ASR schemes are now established or under establishment in Adelaide metropolitan, regional and country areas. Within the next seven years ASR schemes currently under development or investigation will be capturing, storing and reusing in excess of 20 GL of stormwater or treated reclaimed water. Opportunities exist to triple this volume under the management framework outlined in the integrated water strategy currently being developed by DWR.

Recent ASR focus in SA has been on the Bolivar Wastewater Treatment Plant. A consortium involving United Water, SA Water, CSIRO, the Department for Water Resources (DWR) and the Department for Administrative and Information Services (DAIS) are undertaking a joint study into the feasibility of injecting winter-excess treatment water into the highly-stressed confined aquifer beneath the Northern Adelaide Plains region.

Where aquifers are favourable, ASR offers a potentially low-cost method of storing water as an alternative to surface storage. As a potable water supply option, per unit volume of water, it is about half the cost of other water supply alternatives. In country regions, and in arid and semi-arid environments, ASR can compete even more favourably. Expansion of water supply capacity in these locations could be more economic using ASR and utilising surplus pipeline capacities in winter.

The first Australian guidelines on the quality of stormwater and reclaimed water for injection into aquifers, and for subsequent recovery and reuse, were produced in SA in 1996. These were the outcome from a two-year Urban Water Research Association of Australia study and were an international first. The guidelines contained specific recommendations relating to licensing, pre-treatment, monitoring, maximum concentrations of contaminants in the injected water and minimum residence time.

A number of potential issues that will impact on ASR management and technology have now been identified and are discussed in this paper. Other issues relate to use of reclaimed water, licensing of ASR schemes, reporting and monitoring of existing projects, accreditation of operators and installers, mapping of ASR potential, energy cost relationships, aquifer storage capacity evaluation and aquifer rehabilitation.

The paper’s consideration of these issues has lead to recommendations that are in favour of –

- Streamlining the ASR approval process with coordination by the Department for Water Resources within the integrated water strategy framework
- annual monitoring reports by scheme operators and the establishment of a public data base
- The accreditation of ASR installers and operators
- A technical and economic evaluation of potential ASR sites across the State
- A continued public sector role in ASR pilot projects and research which coincides with the objectives of the integrated water strategy
- The early finalisation of technical and administrative guidelines
- A comprehensive education program for ASR owners and operators.

CONTENTS

	Page
Executive Summary	2
Abstract	7
1. INTRODUCTION	8
2. WHAT ARE AQUIFER RECHARGE ENHANCEMENT AND ASR?	10
2.1. Types of recharge enhancement	11
2.1.1. Recharge wells	12
2.1.2. Infiltration basins	13
2.1.3. Bank filtration	14
2.2 ASR applications	14
3. AUSTRALIAN HISTORY OF WATER BANKING	15
3.1. ASR in South Australia	15
3.2. ASR with reclaimed water	20
3.3. Potential for ASR in South Australia	22
4. ASR ISSUES	24
4.1. Issues associated with aquifer types in South Australia	29
4.1.1. Unconfined aquifers	29
4.1.2. Confined aquifers	29
4.1.3. Fractured rock aquifers	30
4.2. Regulatory Issues	31
4.3. Lessons from ASR Failures	32
5. RESEARCH	34
5.1 Outcomes of Australian ASR research	34
5.2 Current research	35
5.3 Future directions for research and applications	36
6. SUMMARY OF COSTS AND BENEFITS TO SOUTH AUSTRALIA	37
7. ASR GUIDELINES AND REGULATIONS	41
7.1. Water quality guidelines for ASR, 1996	41
7.1.1. Specific guidelines	42
7.1.2. Operation of ASR sites	45
7.2. Draft SA guidelines for stormwater ASR	47
7.3. Proposed SA guidelines for domestic scale stormwater ASR in unconfined or semi-confined aquifers	52
8. POTENTIAL ISSUES AND OPPORTUNITIES	55
8.1. Domestic scale rainwater/stormwater ASR	55
8.2. Reclaimed water ASR	55
8.3. Licensing of new ASR projects	55
8.4. Monitoring and reporting of existing projects	56
8.5. Accreditation of ASR installers and operators	56
8.6. Maintenance of Government technical expertise in ASR	56
8.7. Mapping of ASR potential	56
8.8. Energy and water	56
8.9. Storage capacity evaluation	57
8.10. Aquifer rehabilitation	57
8.11. Communications	57

9. RECOMMENDATIONS 58
    9.1. Licensing procedures to be streamlined 58
    9.2. Monitoring and reporting of ASR projects 58
    9.3. Accreditation of ASR installers and operators 58
    9.4. Mapping ASR potential in SA 58
    9.5. Continued public sector investment in innovation in ASR pilot projects 58
    9.6. Guidelines 59
    9.7. Education 59

10. CONCLUSIONS 59

11. ACKNOWLEDGEMENTS 60

12. REFERENCES 61

List of Figures **Page**

Figure 1.	Location of ASR sites around South Australia	9
Figure 2.	Schematic depiction of ASR. Stormwater or reclaimed water is recharged during the wet season and recovered in the dry season.	10
Figure 3.	Types of groundwater recharge enhancement (a) ASR, (b) separate injection and recovery wells, (c) infiltration basins, and (d) bank infiltration.	11
Figure 4.	Bolivar ASR trial site and monitoring well configuration for the confined Tertiary limestone target aquifer (T2).	21
Figure 5.	Twin strategies for managing over-exploited aquifers	31
Figure 6.	Flow chart showing the feasibility of artificial recharge with stormwater and reclaimed water.	47
Figure 7.	Multiple barriers to protect groundwater and recovered water at ASR projects.	50
Figure 8.	Components of a well-configured ASR system showing barriers to pollution.	51

List of Tables

Table 1.	The advantages and disadvantages of using wells for recharge enhancement to aquifer systems.	12
Table 2.	Advantages and disadvantages of using infiltration basins for recharge enhancement to aquifer systems.	13
Table 3.	Applications of ASR for water resource management.	14
Table 4.	Operational ASR sites in South Australia.	17
Table 5.	ASR Investigation sites in South Australia.	19
Table 6.	Groundwater provinces of South Australia and the potential for enhanced recharge.	23
Table 7.	Potential changes in recharge post urbanisation.	25
Table 8.	Issues associated with source water and source water quality.	27
Table 9.	Water Resource and Water Use in South Australia and in Adelaide and the Mount Lofty Ranges	37
Table 10.	Comparison of estimated costs for domestic and municipal scale ASR schemes.	39

Abstract

Aquifer Storage and Recovery (ASR) has the potential to utilise surface water resources, including urban stormwater runoff and treated wastewater that is largely wasted; thereby relieving the pressure on groundwater resources. In the broader sense, opportunities exist to use ASR to rethink our traditional water management and distribution policies, and to provide cost-effective and innovative alternatives to current methods of water supply. In South Australia, an increasing amount of stress is being placed on surface and groundwater resources to meet demands from expanding irrigated horticultural areas and urban populations. ASR can be used to reduce some of the pressure on traditional supplies of water, especially in metropolitan areas. But the sources of water for ASR must be carefully considered especially in rural areas so as not to shift the burden from one water supply source to another. A number of issues surround the use of ASR as a water management solution and these relate principally to water quality and water quantity. In rural areas, for example, the 'harvesting' of water from creeks and streams may result in extra pressure on an already stressed resource by further reducing the amount of water available to the environment. In urban areas the expanse of paved surfaces provides an ideal medium to capture large volumes of stormwater runoff. However, the volumes are often well in excess of any potential local demand. Understanding ASR technology ensures success in almost all situations, whereas failure to understand the unique aspects and complexities of implementing and managing an ASR system will result in failure and lost investment. Over the past decade a significant number of investigations into ASR have been undertaken by the Department for Water Resources in partnership with CSIRO, local councils and industry gaining extensive experience in both the implementation and management of ASR schemes using source waters of varying quality. The main objective behind the investigations into ASR have been to demonstrate that the process is technically feasible and to address the associated management issues that accompany enhanced recharge techniques. The experience gained places South Australia as a world leader in the design and implementation of ASR schemes using low quality waters injected and stored in low transmissivity aquifers. This report reviews the status of ASR in South Australia, describes some of the successes and failures experienced to date, highlights emerging issues and examines the future potential for ASR.

1. INTRODUCTION

The need to conserve, reuse and recycle water is becoming increasingly important for both environmental and economic reasons. Water availability and demand are both subject to seasonal variation, this results generally in a surplus of water availability during peak winter rainfall periods and a shortage during the dry summer months. Throughout the world various methods of recharge enhancement are employed to meet the growing demand for safe potable water supplies.

The Department for Water Resources (DWR) in collaboration with the CSIRO Centre for Groundwater Studies (CGS), and other partner organisations including SA Water, United Water, local councils, catchment water management boards and industry are involved in developing ASR technology in South Australia. ASR has been conducted extensively throughout the world and other parts of Australia, but the practice in these localities is generally restricted to spreading basin recharge to unconfined aquifers.

The current research and development being undertaken by DWR and partner organisations, where low quality water is being stored in deep confined aquifers of low hydraulic conductivity, is world leading in the application of ASR technology.

In recent years, trials have examined stormwater ASR applications in the Adelaide metropolitan area at Andrews Farm, The Paddocks, Greenfields Wetlands, Regent Gardens, Scotch College and Mawson Lakes (Figure 1). Proponents have included developers, local government, and the Major Projects Group from within the SA Department for Administrative and Information Services (DAIS). Different aquifer systems have been targeted including fractured rock, Tertiary limestone and Quaternary sands. Different scales of application, ranging from small schemes to meet localised demands to larger schemes that address more regional groundwater issues, have been undertaken.

Applications being trialed outside the metropolitan area include the McLaren Vale irrigation area, Barossa Valley, Northern Spencer Gulf (Spencer Regions Economic Development Board) and the Clayton Water Supply (SA Water). Trials involving the storage and subsequent recovery of treated wastewater are currently being undertaken at Bolivar on the Northern Adelaide Plains and in the McLaren Vale area (Figure 1).

ASR using treated wastewater presents an exciting opportunity to use the available water resources more efficiently. It has the added advantage of providing a continual supply, unlike stormwater, or harvesting from creeks and streams, which depends upon rainfall.

One of the key drivers to the rapid acceptance of ASR in South Australia has been the distinction by regulatory authorities concerning requirements for maintaining water quality. A second key driver is that, where aquifers are favourable, ASR offers a potentially low cost method of storing water as an alternative to surface storage.

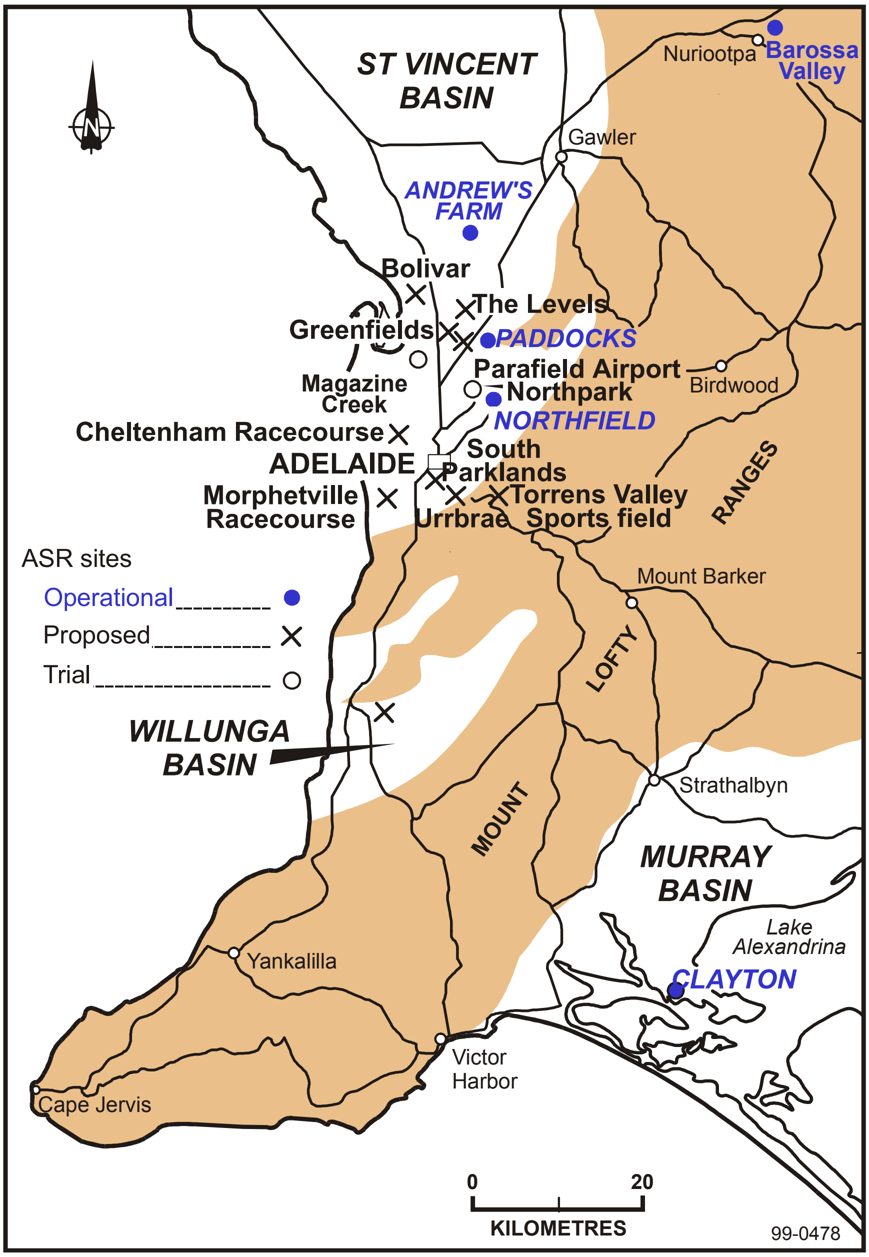


Figure 1. ASR Locations throughout South Australia

2. WHAT ARE AQUIFER RECHARGE ENHANCEMENT AND ASR?

Recharge enhancement is defined by Freeze and Cherry (1979) as "*Any process by which man fosters the transfer of surface water into the groundwater system*". A more detailed definition is given by Asano (1985) *as* "*augmenting the natural movement of surface water into underground formations by some method of construction, surface spreading of water in basins, or artificially changing natural conditions, such as by stream channel modification*." Among the methods for recharge enhancement, is the use of wells to inject water into aquifers.

The term ASR is attributed to Pyne (1995): "*Aquifer Storage and Recovery may be defined as the storage of water in a suitable aquifer through a well during times when water is available, and recovery of the water from the same well during times when it is needed*".

ASR can be used as a resource management tool where water from a source is treated and then stored underground (Figure 2). Large volumes of water may be stored underground thereby reducing the need to construct expensive surface reservoirs. ASR can also have added benefits in aquifers that have experienced long-term declines in water levels as a result of concentrated and heavy pumping. Groundwater levels can be restored if sufficient quantities of water are recharged eg the confined aquifers beneath the Northern Adelaide Plains.

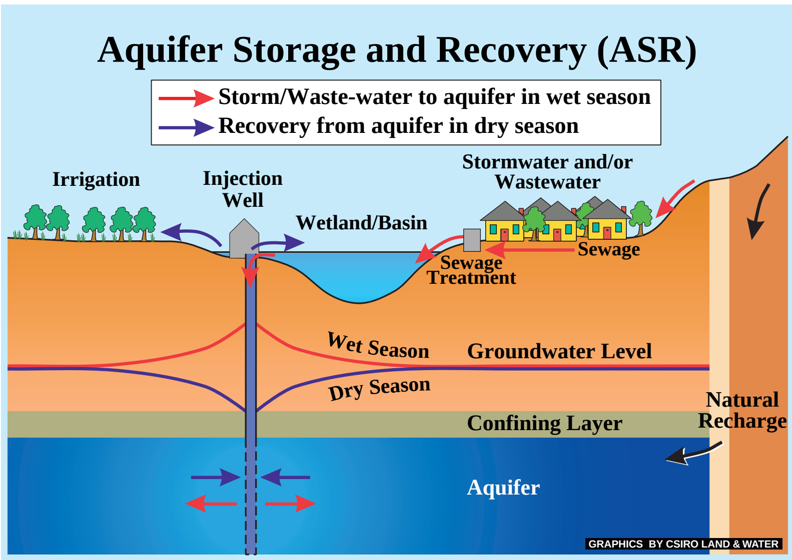


Figure 2. Schematic depiction of ASR. Stormwater or reclaimed water is recharged during the wet season and recovered in the dry season. (after Dillon *et al,* 2000)

2.1. Types of recharge enhancement

There are a number of methods whereby the natural recharge processes can be accelerated and collectively are referred to as recharge enhancement or artificial recharge. ASR relates specifically to enhanced recharge using a well and is typically associated with deeper confined aquifer systems (Figure 3(a)). Individual injection and recovery wells (Figure 3(b)) can be used where groundwater quality is fit for intended use and the distance separating the wells provides opportunities for attenuation of contaminants. Infiltration basins are another method whereby water is collected in carefully constructed holding ponds and allowed to infiltrate through the base of the ponds to shallow water table aquifers (Figure 3(c)). Bank filtration is a third method whereby pumping wells adjacent to a watercourse are used to draw water from a stream into the aquifer (Figure 3(d)).

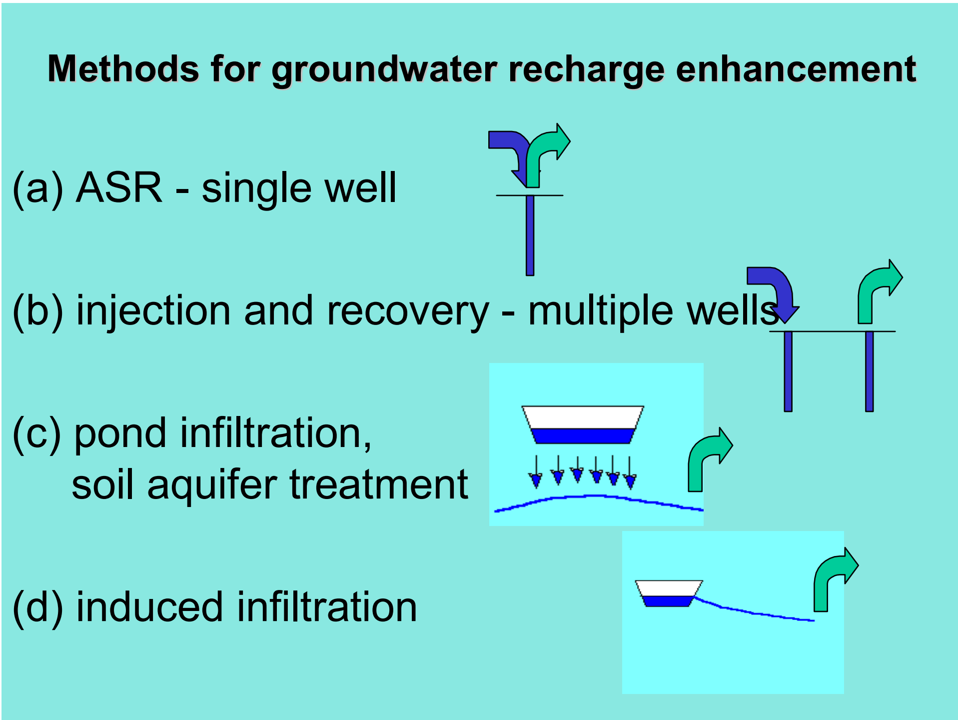


Figure 3. Types of groundwater recharge enhancement (a) ASR, (b) separate injection and recovery wells, (c) infiltration basins, and (d) bank filtration

2.1.1. Recharge wells

Recharge wells are typically the most difficult and expensive method of recharge enhancement because if the source water is not adequately treated clogging will quickly render the well inoperable. Recharge wells are used where the shallow lithology does not possess characteristics suitable for aquifer storage and recovery such as, low transmissivity or where land has such a high value that above ground storage ponds are not economically viable. On-going management and maintenance costs associated with the operation of recharge wells are also the highest of the possible recharge methods. Appropriate well construction coupled with careful management is required to ensure that the maximum life (up to 20 years) can be obtained for the recharge well. If any one of these aspects is ignored and the operator neglects to manage the system appropriately, failure of the ASR scheme will result or alternatively expensive remediation of the injection well will be necessary.

In South Australia, because the most suitable host aquifers for the storage and recovery of large quantities of water are the deep confined Tertiary aquifer systems, recharge wells have been the main method employed. Table 1 presents a summary of some of the advantages and risks of using an injection well as a method of introducing the captured water to the aquifer.

Table 1. T*he advantages and disadvantages of using wells for recharge enhancement to aquifer systems*

Recharge enhancement to deep aquifers using wells	
Advantages	**Disadvantages**
▪ Injection and recovery rates can be mechanically controlled to ensure desired rates are obtained ▪ Relatively small space required for installation of well ▪ Recovery efficiency (the volume of injected water that meets the enduse requirements) is typically greater than 50% on first injection and recovery cycle for sedimentary aquifers ▪ Recovery efficiency improves with successive injection cycles ▪ Treatment works can be some distance from injection wells ▪ Opportunities to use existing infrastructure to redistribute water ▪ Opportunities to use existing infrastructure to deliver treated water to injection sites ▪ In sedimentary aquifers the injected water remains in close proximity around the well making it easy to clean up in the event of contamination. ▪ Variety of methods of treatment for the source water. ▪ Only economic method of accessing confined aquifers.	▪ Clogging of aquifer matrix or screens from either fine particulate matter or from microbiological activity ▪ Large surface storages may be required to capture source water from creeks or stormwater if recharge rates are slow. ▪ Recovery efficiency can be as low as 10% from fractured rocks. ▪ Geochemical interactions between rock and injected water may affect quality of recovered water. ▪ Well collapse through dissolution of aquifer matrix. ▪ Over-pressure may result in failure of the confining bed separating aquifers. ▪ On recovery, continual production of fine aquifer material causing pumps to seize. ▪ Well failure after only a few years of operation requiring new replacement wells to be drilled. ▪ Potential changes in contaminate loads if source water is from urban or rural catchment runoff. ▪ In a fractured rock aquifer little control on direction and distance injected water may travel. ▪ Backwash waters need to be discharged.

2.1.2. Infiltration basins

Infiltration basins are typically used where there is sufficient depth of sediment between the base of the infiltration pond and the underlying watertable and there are no low permeability layers. Infiltration occurs through the base of the pond with the infiltration driving force controlled by the depth of water in the pond. Infiltration basins are employed where the water source to be captured is stormwater runoff and there is sufficient room to establish the basins, often alongside the watercourse. Recovery of the stored water from these systems is generally via shallow collector wells. Table 2 presents some of the advantages and disadvantages of using infiltration basins as a means of recharge enhancement to aquifer systems.

There are limited opportunities to establish large-scale infiltration basins within South Australia generally because there is insufficient depth of sediment between the base of the pond and the shallow water table aquifer or the shallow lithology has low permeability in the case of the Hindmarsh Clay across the Adelaide Plains. There are some small-scale schemes operating in metropolitan Adelaide (eg. Brompton Estate established by the University of South Australia (Argue 1997)). Some opportunities may present themselves in the outback areas of South Australia to augment the supplies of remote Aboriginal communities.

In the outback areas one of the issues that needs to be addressed is the design and maintenance of surface capture structures to withstand the extreme events that typically occur. If the basins are not designed properly they are likely to wash away in the first flood event requiring expensive rebuilding. A second issue that would need to be addressed is that high evaporation rates are likely to result in rapid changes in the quality of the water held in the storage dams unless the dams are covered to reduce the evaporation that will occur while the water infiltrates to the underlying aquifer.

Table 2. *Advantages and disadvantages of using infiltration basins for recharge enhancement to aquifer systems*

Recharge enhancement using infiltration basins	
Advantages	**Disadvantages**
▪ Can be relatively low maintenance ▪ Simple and effective system ▪ Improved water quality ▪ May reduce the need for treatment of recovered water. ▪ Increased hydraulic gradients leading away from beneath the infiltration basin that may result in greater discharge to surface water bodies. ▪ Maximised recharge rates	▪ Requires periodic drying out and scraping to maintain infiltration efficiency ▪ Large areas required for construction of infiltration basins ▪ Water may be subject to reinfection from birds/animals ▪ May require chemical additives to control algae growth ▪ Some loss of supply to evaporation ▪ Expensive to construct above ground storage appropriate for the conditions ▪ If water table not deep enough below ground surface water logging may result ▪ Can increase discharge to surface water bodies

2.1.3. Bank filtration

Bank filtration is the acceleration of the naturally occurring influx of surface water to the groundwater store, via the bed and banks of the surface water body, induced by pumping. This process is often used to obtain a general improvement in water quality. Induced bank filtration schemes are exploited mainly in Europe and USA.

Bank filtration has advantages over surface water extraction allowing -

- Removal of particles, bacteria, viruses and parasites,
- removal of easily biodegradable compounds, including algal toxins,
- reduction of persistent organic contaminants and heavy metals; and
- attenuation of demand and supply concentration peaks.

In addition, bank filtration can provide an effective pre-treatment step through use of natural processes to ensure sustainability of supply and the provision of uniform quality raw feed water to enable treatment process optimisation.

There are limited applications of bank filtration in South Australia because many of the creeks are ephemeral. Very few locations have sufficiently well developed shallow aquifer systems adjacent to large water bodies to enable adequate quantities of water to be drawn into the aquifer system to meet large demands. Many alluvial aquifers, including those adjacent to the River Murray, are saline, preventing bank filtration for potable supplies. Some isolated opportunities may present themselves at Paringa (Dillon et al. 2000) where banks have been flushed.

2.2. ASR applications

ASR has gained acceptance as a water resource management tool because of the wide variety of applications to which it may be applied. ASR may be used to address issues relating to water storage, water quality and environmental and operational needs. These are broken down into the broad categories illustrated in Table 3.

Table 3. *Applications of ASR for water resource management*

Water Storage	Water Quality	Environmental	Operational
Seasonal storage and recovery	Pathogen reduction	Restoration of groundwater levels	Maintenance of distribution system pressure and flow
Long-term storage	Chlorination byproduct removal	Reduce/prevent saline intrusion	Deferment of the expansion of treatment facilities
Emergency storage	Stabilisation of aggressive water	Reduction of land subsidence	Deferment of the development of new water sources
Diurnal storage	Control of contaminant plumes	Enhancement of baseflow to streams	Balancing peak seasonal demands
Reclaimed water for reuse		Reduction of nutrient rich discharge to marine environment	Enhance wellfield production

(adapted from Pyne 1995)

3. AUSTRALIAN HISTORY OF WATER BANKING

The first known and largest Australian water banking projects were established in the 1970's in the Burdekin Delta near Townsville, Queensland. Groundwater levels in the delta were in decline because extraction for irrigation of sugar cane had increased and exceeded the natural replenishment of the aquifers from rainfall recharge and from flows in the Burdekin River. Two main recharge projects divert large quantities of river water into seepage trenches, constructed in sandy deposits with high permeability. Intermittently the ponds are allowed to empty and the accumulated layer of silt and algae are removed.

A similar style of recharge trial but at a much smaller scale was conducted at Geelong in the late 1980's to help store surface water in a semi-confined aquifer. A thin layer of silt several metres below the base of the basin impeded infiltration rates and a trench was dug to perforate this layer and increase recharge to the underlying aquifer. This trial was discontinued presumably because the volume of recharge did not justify the cost of operation.

Another recharge system was established in South Australia in 1979 to ensure continuation of groundwater recharge to the aquifers of the Northern Adelaide Plains from the Little Para River following construction of a water supply dam upstream. Approximately 1800 ML of water is released annually from storage according to a release schedule designed to maintain annual recharge at its mean annual rate. At around this time the Ophir Dam was built in the north west of Western Australia to provide water supplies for mining. Water was released from the dam into infiltration ponds downstream to increase groundwater recharge and protect water from evaporation. It is understood that this system is no longer operating. Attempts to increase recharge from the Lockyer and Callide Valleys in Queensland in the 1970's by constructing weirs to hold surface water longer and raise the driving head in the streambeds were regarded as failures, due to silt accumulation reducing active storage and lowering the streambed hydraulic conductivity and infiltration rate.

For more than a century stormwater has been introduced into aquifers via pits and sumps in Perth, Western Australia and via drainage wells at Mount Gambier in South Australia. Recharge was initially incidental to stormwater disposal for flood control but consequences on groundwater quality have been taken into account from the 1970's as appreciation of the potential for pollution has increased. In the Angas-Bremer area of the southern Mount Lofty Ranges in South Australia the first intentional recharge via wells commenced in the 1980's. An expansion of viticulture and deteriorating groundwater quality and yields in irrigation wells resulted in some farmers diverting fresh winter stream flow into their wells to improve yields and reduce salinity in the following summer.

3.1. ASR in South Australia

In South Australia, surface and groundwater resources are increasingly being stressed to meet the demands of expanding irrigated horticulture and urban populations. The availability of adequate water supplies is crucial to the future development of most regions in South Australia.

In many areas of the State, reticulation systems are operating at or near full capacity during peak demand periods. A continued sole reliance on current sources would raise the prospect of an expensive duplication or augmentation of supply capacity to meet growing demand. Potential alternative sources of second class water supplies such as urban stormwater runoff and reclaimed water (from sewerage treatment plants or industrial effluent) are largely ignored in many areas and could be used to reduce current demands on potable supplies from external sources.

- Since the early 1990's Aquifer Storage and Recovery (ASR) has been increasingly used in South Australia to address specific surface or groundwater problems that have needed innovative solutions.
- The schemes implemented range from harvesting catchment runoff in urban areas to providing safe potable rural water supplies.
- Many of the schemes thus far implemented cover a variety of scales from mitigating catchment runoff in urban areas and provision of safe potable water supplies, to meeting the demands of large irrigation schemes.

In metropolitan Adelaide annually around 200 000 ML (ML) of stormwater runoff from paved surfaces is discharged via a network of drains. Up until recently around 100 000 ML of secondary treated wastewater was discharged annually to the sea from the various wastewater treatment plants.

In recent years, trials by the Department for Water Resources, in cooperation with local councils (notably Salisbury), CSIRO, and other partners have examined, ASR applications at a number of sites throughout the metropolitan area. These sites include The Paddocks, Andrews Farm, Greenfields Wetlands, Regent Gardens and Kaurna Park which collectively capture and store (when last evaluated) around 680 ML of stormwater runoff per year (Table 4). This figure is reported to have increased to 1000 ML per year (*pers. com.* C Pitman, City of Salisbury). Treatment prior to storage in the aquifer is typically via wetlands.

The potential performance of wetlands as key components of an ASR scheme for urban water was first investigated at The Paddocks (Thomlinson et al, 1993). The first ASR schemes specifically designed to capture urban stormwater from specially constructed wetlands were established at Andrews Farm and Regency Gardens. These systems have been closely monitored and reported on in several publications. They are listed with other national and international references on similar schemes in Pavelic and Dillon 1997.

The Urban Water Resources Centre based at the University of South Australia has focussed on the development of trench systems to undertake a similar role to that of wetlands in pollution reduction, flood mitigation and water capture. Schemes have been established and monitored at Brompton Housing Estate and Parfitt Gardens (Argue, 1997).

Table 4. *Operational ASR sites in South Australia*

SITE (year commenced)	AQUIFER	SOURCE WATER	TYPICAL RECHARGE (ML per year)
Mt Gambier (late 1800's)	Tertiary Limestone	Stormwater	2,800
Angus Bremer (mid 1970's)	Tertiary Limestone	Bremer River	1,000
Scotch College (1989)	Fractured rock	Brownhill Creek	40
Regent Gardens	Tertiary Limestone	Urban runoff	60
Andrew's Farm (1993)	Tertiary Limestone	Urban runoff Wetland prefilter	150
The Paddocks (1995)	Tertiary Limestone	Urban runoff Wetland prefilter	120
Willunga Basin (various)	Tertiary Limestone	Creek stormwater flow	Approx 70
Greenfields (1995)	Tertiary Limestone	Stormwater Wetland prefilter	100
Kaurna Park	Tertiary Limestone	Stormwater Wetland prefilter	100
Northgate (2001)	Tertiary Limestone	Urban runoff	110
	TOTAL	**Adelaide Metro** **State**	**680** **4000***

Note:
* Assumes only 500 ML per year is currently stored in the aquifer via enhanced recharge in Angus Bremer region.

Increasing numbers of ASR schemes are now being established in Adelaide and other urban areas. The success of all the schemes indicates that the technique has wide application in many different hydrogeologic regimes in South Australia. A further eleven sites are currently under investigation within the metropolitan area with an additional 12 proposed investigation sites. Collectively, these additional sites could capture and store up to an additional 3000 ML of stormwater runoff (*pers. com.* C Pitman, City of Salisbury) (Table 5). A summary of the aims for each of the ASR sites follows

- *Mount Gambier:* Mount Gambier, a city of 23,000 people in the south-east of the State, disposes of all stormwater via a network of drainage wells into an underlying karstic aquifer. This water is subsequently withdrawn for use as a potable water supply.

- *Scotch College:* A small ASR scheme harvesting approximately 10 ML of water from an adjacent creek, and recharging a fractured hardrock aquifer is in use at the College. The stored water is used to irrigate adjacent ovals during the summer months.

- *Andrews Farm:* Andrews Farm, on the Northern Adelaide Plains, was a project undertaken in conjunction with a private housing developer and local government to manage urban stormwater. Flood detention ponds are used to provide temporary storage of the urban runoff and to filter the water prior to injection into the confined aquifer. Results indicate that the aquifer is capable of storing injected water and the brackish native groundwater has been significantly freshened to a level suitable for irrigation. Quantities recharged between 1993 and 1996 ranged from 18 to 100 ML depending on winter rainfall.

- *Regent Gardens:* At Regent Gardens, ASR was designed and constructed as part of a medium density urban infill development. The capacity of the existing stormwater system necessitated the inclusion of a flood control basin within the development to attenuate peak flows. Stormwater is retained in a system of wetland detention basins and recharge is via gravity infiltration through a 150mm diameter, 80m deep well completed in a saline, fractured hardrock aquifer. Annual recharge volumes are in the order of 40 ML per year from winter flows and the site has been operational since 1994.

- *Clayton:* At Clayton, on the western shore of Lake Alexandrina, the town water supply has been traditionally pumped from the lake. In recent summers this supply has been under threat from toxic algal blooms caused by high nutrient loads in the River Murray. An ASR project was undertaken to inject high quality potable water, when available, from the lake into an unconfined, high salinity (>40,000 mg/L) limestone aquifer. This unique situation required the development of a lens of potable water within a buffer zone of mixed saline and fresh injected water. Testing confirmed that a lens of potable water was successfully established creating a safe potable town water supply. This scheme is now in its fourth year of operation.

- *The Paddocks:* The Salisbury Council wetland site known as The Paddocks was developed with the long term goal of conjunctive wetland treatment and ASR of stormwater using a confined limestone aquifer. Injection at this site was under pressure due to the low hydraulic conductivities. Some 75 ML of stormwater were injected during the winter of 1996, and a recovery trial produced an equivalent amount of irrigation quality water. The site has been operational since that time and routinely stores between 75 and 100 ML of water from an urban catchment runoff with wetlands pre-treatment to reduce nutrient and pollution loads prior to injection.

- *Willunga Basin:* In the Willunga basin, aquifer injection testing has been undertaken as a result of interest shown in ASR by local irrigators and local government. ASR is to be incorporated as part of the integrated catchment water resources management of the basin. Three sites have been established to harvest excess catchment runoff for injection and subsequent reuse for irrigation of vines.

- *Mawson Lakes:* This is an infill urban development encompassing some 610 hectares and catering for a community of approximately 10,000 people. DWR carried out preliminary investigations into the feasibility of using ASR techniques to manage stormwater and treated wastewater from the development. Further development of this scheme is awaiting the outcomes of the Bolivar Trial.

- *Greenfields Wetlands:* This involves opportunistic harvesting of excess water for irrigation and industrial uses from the wetlands and storage using ASR.

- *Kaurna Park*: A laser-levelled wetland was constructed at Kaurna Park and receives stormwater for gravity or pressure injection into a Tertiary limestone aquifer on the Northern Adelaide Plains.

- *Clare Valley:* The Clare Valley ASR project is assessing the feasibility of harvesting excess streamflow and storing the water in a fractured hardrock aquifer. The aim is to provide additional water supplies for the viticulture industry.

- *Morambo Creek:* At Morambo Creek the aim is to use ASR techniques to store water in an aquifer that is under stress as a result of irrigation demands. Excess winter flows will be captured and stored. An additional benefit is that this scheme will also provide flood mitigation for land downstream that is subject to inundation during severe flood events.

Table 5. *ASR Investigation sites in South Australia*

SITE (year commenced)	AQUIFER	SOURCE WATER	TYPICAL RECHARGE (ML per year)
Clare Valley	Fracture Rock	Creeks	approx 50
Bolivar	Tertiary Limestone	Reclaimed water	approx 10,000
Urrbrae	Unconsolidated sands	Urban runoff Wetland prefilter plus rapid sand prefiltration	30
Parafield Airport	Tertiary Limestone	Urban runoff Wetland prefilter	1,500
Mawson Lakes	Tertiary Limestone	Urban runoff & treated wastewater	approx 600
Morphettville Racecourse	Tertiary Limestone	Urban runoff Wetlands prefilter	approx 150
Willunga Basin	Tertiary Limestone	Reclaimed water	approx 4,000

Other projects where ASR has been employed as a water resources management tool include the Angas Bremer region.

New projects featuring ASR technologies applied in an urban area include; Coopers Brewery, Parafield Airport, Cheltenham Racecourse, Morphettville Racecourse, Tea Tree Gully, South Parklands and the reuse of reclaimed water from the Glenelg Wastewater Treatment Plant.

3.2. ASR with reclaimed water

More recently the focus of ASR in South Australia has shifted to using treated wastewater from the major treatment plants as this provides a constant source and quality of water all year round. The storage of treated effluent in aquifers by direct injection via bores has not been practiced widely. Where it has been trialed the level of pre-treatment has been to near potable quality (Pavelic and Dillon, 1997).

The Bolivar Wastewater Treatment Plant (WWTP) produces approximately 50 000 ML of treated wastewater per year. Significant long term environmental impacts on the mangrove forest and on sea grass beds have been observed as a consequence of discharging secondary treated sewage effluent and stormwater to the marine and estuarine environments along the South Australian coastline (Martin, 1998).

At the same time the horticultural industry in the nearby Virginia triangle is lacking sufficient irrigation water to fully meet its needs.

A consortium comprising United Water, SA Water, CSIRO, DWR and Department of Administration and Information Services (DAIS) have combined to undertake a joint study into the feasibility of injecting the winter surplus of reclaimed water into the confined aquifer beneath the Northern Adelaide Plains. A four year, $3 million research project is currently underway to determine the technical feasibility, environmental sustainability and economic viability of ASR using treated water from the Bolivar WWTP. The project will demonstrate that any potential health risks associated with the practice can be controlled effectively by a strict quality regulation and monitoring regime.

It has been proposed that reclaimed water from Bolivar WWTP be used for irrigation purposes in the Virginia/Two Wells region. However, the Bolivar WWTP produces wastewater all the year around at a constant rate. With increased irrigation development on suitable soils, the Virginia Pipeline Scheme (VPS) will account for much of the summer flow, but a demand is needed for the winter production. Injection of the reclaimed water into the highly stressed confined aquifer of the region provides that opportunity.

The benefits to follow from the injection of water into the confined aquifer (Figure 4) are that there will be an increase in groundwater hydraulic pressure. This increased pressure in the aquifer will result in an improvement in the groundwater level throughout most of the aquifer.

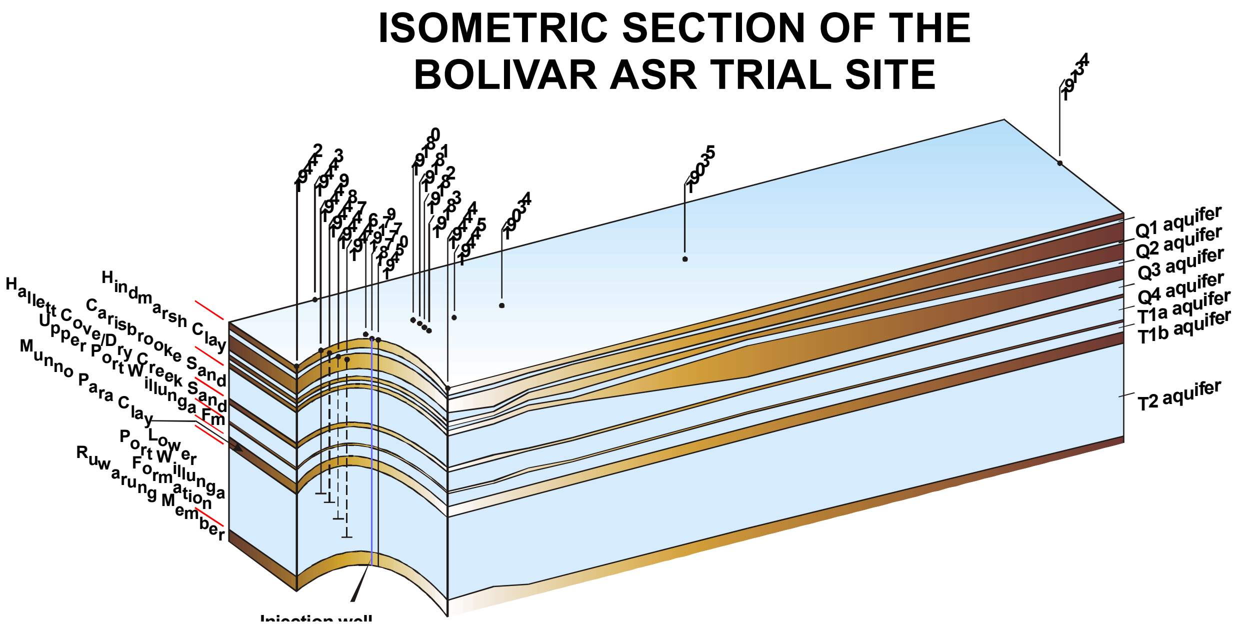


Figure 4. Bolivar ASR trial site and monitoring well configuration for the confined Tertiary limestone (T2) target aquifer (after Martin 2000)

The unique aspect and new technology associated with this project is that the water is treated to a level that is suitable for unrestricted irrigation use and subsequent ASR. This is unlike other localities where treatment is to a much higher standard prior to ASR.

The project is structured to address the issue of a water quality less than drinking standard that confronts the proponents when considering injection of this water. It is recognised that reclaimed water differs significantly from stormwater in its nutrient and microbiological content. Issues associated with reclaimed water - well bore clogging, fate of pathogens and microbiota, interaction of chemical species with aquifer matrix material and aquifer hydraulics - need to be evaluated.

In addition, the potential impacts of ASR on adjacent aquifers and on the pressures and quality in wells of other groundwater users in the area, need careful assessment. This work is currently being undertaken.

Aquifer storage and recovery is a key element in balancing seasonal supply and demand for the treated water with outcomes from the project that are likely to include-

- additional water being available for the development of horticulture throughout the region,
- the availability of more water for irrigation with the potential to double the current farm gate value of produce from $100 million to over $200 million,
- maintenance of pressures within the aquifer system to maintain groundwater levels and ensure that this resource does not become un-useable as a result of intrusion from surrounding saline groundwaters and the sea,

- transfer of the information gained at this site to other similar sites such as McLaren Vale where treated water from the Christies Beach WWTP is being used.

As the required level and cost of pre-treatment rises, the target area for sale of the recycled effluent must shift towards urban users. They can substitute recycled effluent for potable water for those uses requiring good quality water - but at a quality and price less than that of potable water.

Table 4 presents a summary of the operational ASR sites within South Australia and the quantities of water that are harvested annually. All of these sites have been implemented by DWR in cooperation with either local councils or the private sector. The current volumes captured, stored and reused are relatively small (approx 1 GL), in comparison to the total amount of water that discharges to the Gulf St Vincent as stormwater runoff (estimated to be 390 GL/year (State Water Plan 2000)), it should be remembered that most of the operational constraints to undertaking ASR using low quality surface waters injected into low hydraulic conductivity aquifers have only been resolved in the past five years as a result of the Andrews Farm trial site. If all of the current ASR investigation sites shown in Table 5 (inclusive of those using reclaimed wastewater) are fully implemented, the quantities of water captured for storage and subsequent reuse will approximate 20 GL within the next 10 years. Rather than allowing ASR to develop independently by interested groups or individuals, ASR forms the basis of the integrated water strategy framework for South Australia, currently being developed by DWR. Under this framework ASR could potentially increase the quantities of water available for reuse within the next 7 to 10 years by two fold over the projected 20 GL.

Trials are progressing at McLaren Vale using the reclaimed water from Christies Beach WWTP. There is a requirement to undertake trials in this locality also because the treatment processes used at Christies Beach treatment plant are significantly different. The quality of water is considered to be Class C suitable only for application by drip irrigation. The different treatment processes means that the water product from Christies beach has a higher level of suspended particulate matter which has required pre-filtration to prevent clogging and thus well failure. A number of different filtration methods have been trialed to provide water of a suitable quality for injection.

3.3. Potential for ASR in South Australia

Table 6 identifies the major groundwater areas across South Australia and presents an indicative summary of the potential of these regions to incorporate ASR as a resource management tool based on the known aquifer types and the availability of source water. As factors affecting the viability of ASR are site specific, it is recommended that more detailed evaluation be undertaken accounting for geology, aquifer suitability, source water quality and demands for water.

Table 6. *Groundwater provinces of South Australia and the potential for enhanced recharge.*

Region	Aquifer	Type	Potential
Officer Basin	Quaternary & Fractured rock	Unconfined	Minor potential and sustainability of schemes may be questionable as rainfall duration and intensity highly variable. Only likely to occur on small scale given limited number of users.
		Confined	Limited opportunities
Great Artesian Basin	Quaternary	Unconfined	Minor potential and sustainability of schemes may be questionable as rainfall duration and intensity highly variable. Only likely to occur on small scale given limited number of users.
	Tertiary aquifers	Confined	Occurs adjacent to WMC wellfield A to sustain aquifer pressures near mound springs
Eucla Basin	Quaternary	Unconfined	Minor potential but sustainability of schemes may be questionable as rainfall duration and intensity highly variable. Only likely to occur on small scale given limited number of users.
Torrens Basin	Tertiary aquifers	Confined	Limited opportunities
Pirie Basin	Tertiary aquifers	Confined	Potential exists around some of the urban centres however, underlying aquifers highly saline. Some potential from offpeak mains and treated wastewater. Further investigation warranted. Possibilities may also occur in outwash alluvium along base of Flinders Ranges
Eyre Peninsula	Quaternary	Unconfined	Limited potential for capturing surface water and limited potential for storage of large quantities of treated wastewater near major urban centre of Port Lincoln
Yorke Peninsula	Quaternary	Unconfined	Potential in a few locations where stormwater / surface pipeline water is available.
Adelaide Geosyncline	Fractured Rock		High potential although recovery efficiencies likely to be low. Potential risk of reactivating dormant springs.
▪ **NAP** ▪ **Metro Adelaide** ▪ **Barossa** ▪ **Willunga**	Tertiary aquifers Shallow aquifers & Tertiary aquifers Gravel aquifers Tertiary aquifers	Confined & unconfined sub-aquifer systems	High potential throughout the various St Vincent sub-basins in both the confined and unconfined aquifers. Water sources available include stream catchment runoff (<15GL), treated wastewater (approx 17GL) and urban catchment runoff (approx 280GL)
Murray Basin			Contains a variety of suitable aquifers and may be an option for some of the larger communities to treat and store wastewater.
Olary Arc			Limited potential
Otway Basin			Potential for treated wastewater and from some of the creeks. Review of the stormwater discharge around Mt Gambier required.

4. ASR ISSUES

The main issues facing any proponent of ASR relate to source water quality and the technical feasibility at the selected location. ASR systems will be feasible where three key areas are adequately addressed:

i) hydrogeological and technical system design and operation to achieve benefits that exceed costs.
ii) system compliance with regulations, within a progressive regulatory regime
iii) establishment of suitable consultative mechanisms to allow satisfactory stakeholder negotiations.

A feasible system must work within the constraints of -

- availability of surface water of sufficient quantity and quality,
- suitable lands for surface works required for surface water capture, temporary storage, treatment, transfer to the ASR site, ASR headworks and reticulation to the demand location,
- a suitable aquifer for long term storage, additional quality modification and transmission (as may be required),
- a capital funding source for establishing the system and;
- a contracted demand for the water product, adequate to ensure the ongoing profitability of the system.

Issues associated with ASR in an urban setting generally revolve around constraints on available storage or, if the water is of low quality, the need for additional infrastructure to deliver the water to the demand centres.

One emerging issue relates to the mixed messages that the public is receiving concerning the management of stormwater runoff. In a particular catchment area for example, if a few individuals are redirecting their roof runoff into a shallow aquifer system then there is likely to be a good outcome. However, as more people in the catchment take up this practice to limit the amount of stormwater that is discharged to the marine environment, the incremental volumes quickly add up to a significant amount of water being directed to shallow aquifer systems resulting in rising water tables and damage to existing infrastructure through waterlogging.

The problem is further compounded by the misconception that recharge rates to natural groundwater systems under urban areas are substantially reduced as a result of the increase in impervious surfaces. In actual fact, because of the importation of reticulated water, and the practice of summer irrigation, the net recharge to groundwater has increased under urbanisation (Martin, 1997; Learner, 1996).

Table 7 shows the potential impacts on the shallow aquifer system in both pre and post urbanisation situations assuming recharge under natural vegetation conditions (that is prior to urbanisation) may have been up to 5% of the total annual rainfall. Redirection of stormwater roof runoff, and other sources, to the shallow aquifer system, coupled with the summer irrigation from imported water, may have the capacity to increase recharge up to five times that which occurred under pre-urban conditions. In addition, urbanisation has altered the natural drainage courses that in the past would have facilitated discharge from the shallow aquifers.

Table 7. *Potential changes in recharge post urbanisation*

	Assumptions	Pre- Urbanisation	Urbanisation
Area	100 sq km		
Rainfall	800 mm		
Recharge under natural vegetation	5% of precipitation	4000 ML	0 ML
Recharge under urbanisation (1)	8% of precipitation		6400 ML
Summer recharge (2)	1% of irrigation (estimate 300 mm urban)	0 ML	300 ML
Enhanced recharge using ASR (3)	20% of precipitation	0 ML	16 000 ML
TOTAL		4000 ML	22 700 ML

Note: Theoretical values used for the purpose of illustration

1. Recharge under urbanisation increased as a result of removal of vegetation cover
2. Recharge increased during summer as a result of irrigation
3. Assumes capture and storage of only 20% of available runoff

There are a number of sites across metropolitan Adelaide where waterlogging and flooding of cellars is becoming more prevalent especially if above average rainfall occurs during winter. Consequently, the primary targets for large scale ASR in the metropolitan area are the deeper confined aquifers where increasing pressures do not affect water table elevation.

Provided a balance is maintained between the water that is captured and stored and subsequently withdrawn to meet a sustained demand, many of the above issues can be managed. ASR within an urban environment can clearly play a significant role in re-using water that otherwise may be lost as discharge to the marine environment. It can also reduce demands on existing supplies.

ASR schemes situated in either urban or rural areas have the capacity to capture large quantities of surface water because the dams can be filled and emptied multiple times during a season. This has potential to shift pressure from groundwater resources onto surface water resources, thus reducing flows required to sustain environmental needs.

Pollution of the aquifer is also one of the major constraints to the successful implementation of an ASR scheme within a rural catchment. Proponents should be aware of the on-going management costs and risks associated with the practice.

1) On-going water sampling and analysis will be required up to three or four times per year at each location. The types of analyses required could cost in excess of $1200 per sample and depend on a risk assessment based on pesticide use within the catchment and on the nature of other contaminants and nutrients that could impair water quality.

On-going sampling is critical in rural areas where there are users who rely solely on the groundwater for potable use. Another reason for very regular sampling is that landuse within a catchment can change very rapidly resulting in changes in the types and concentrations of pesticides/herbicides and other potential contaminants being applied across the catchment. Different concentration levels of pesticides and herbicides may be mobilised from within the catchment depending on rainfall duration and intensity.

In urban areas contaminants also include organic compounds that may be extremely difficult to remove from an aquifer. Consequently, the sampling suite is considerably more diverse and more expensive.

2) Water recovered after injection needs to be assessed to determine its suitability for its intended use.

Water rich in oxygen, coming into contact with various minerals in the aquifer matrix may result in deterioration as well as improvements in its quality. It is therefore advisable to undertake detailed mineral analysis of the aquifer matrix material before undertaking ASR and even then there are no certainties as the sample analysed is only representative of a very small section of the entire aquifer. As an example, release of arsenic or production of hydrogen sulphide can occur.

3) Careful management may be required to ensure the well will continue to accept the same quantity of water each year or during each subsequent injection cycle. Clogging or partial well collapse can cause reduced injection rates.

Inadequate filtration of the source water, incorrect completion of the well and a number of other factors will result in the well failing. A monitoring well will assist to evaluate clogging and the effectiveness of unclogging methods.

Like a filter, the well will also require some periodic backwashing throughout the injection phase and a good practice is to do this every three to five days during injection for an hour or two at the maximum pumping capacity. The water recovered from the well can be discharged back into the storage dam and allowed to settle out any solids before reinjection.

In some areas despite all the best intentions and the adoption of best practice for ASR, replacement injection wells may be required every five to ten years. In most cases however, injection wells should last longer than ten years if optimum operating practices are adopted.

Table 8 summarises some of the considerations that must be addressed in relation to possible impacts of source water quality on the successful implementation of ASR. The setting, either urban or rural, may also pose some constraints on the successful implementation of ASR.

Table 8. *Issues associated with source water and source water quality*

Water Source / Issues	Creeks & rivers	Urban stormwater	Reclaimed water
Contaminants	▪ Large range of contaminants ▪ Diffuse sources ▪ Rapid changes in types of contaminant associated with rapid landuse changes in catchment ▪ Typically rural source waters may have elevated nitrogen, phosphorus and ammonia compared to groundwaters	▪ Large range of contaminants ▪ Diffuse sources ▪ Organic contaminants may not attenuate in aquifer	▪ High nutrient levels ▪ Potentially a large number of contaminants (depends on level of pretreatment and pretreatment process) ▪ Organic contaminants may not attenuate in aquifer ▪ Contamination with pharmaceutically active chemicals (PACHs) (Bowen, 1996) ▪ Consistent water quality
Availability	▪ Ephemeral creeks & streams ▪ Stream flows are typically of short duration ▪ Large variation in quantities of water available ▪ Large variation in water quality ▪ Impacts on dependent ecosystems ▪ Geochemical reactions between aquifer matrix and source water may render water unsuitable for intended enduse	▪ Ephemeral creeks & streams ▪ Stream flows are typically of short duration ▪ Large variation in quantities of water available ▪ Large variation in water quality ▪ Geochemical reactions between aquifer matrix and source water may render water unsuitable for intended enduse	▪ Constant supply at known rates ▪ Small variation in total flow ▪ Geochemical reactions between aquifer matrix and source water may render water unsuitable for intended enduse
Filtration	▪ Filtration required to remove suspended sediments ▪ Treatment may be necessary to control iron bacteria around injection.	▪ Filtration required to remove suspended sediments ▪ Wetlands can provide filtration treatment adding to aesthetic value of site	▪ High levels of filtration required ▪ Filtration infrastructure may be very expensive
Demand	▪ Typically to meet irrigation demands ▪ Freshen up native groundwater	▪ Typically to meet irrigation or industrial demands ▪ Freshen up native groundwater	▪ Can be treated to a level for beneficial enduse
Microbiological	▪ Open storage may be subject to infection eg cryptosporidium or giardia ▪ Treatment for faecal coliforms ▪ Impacts of injected water on groundwater ecosystems unknown	▪ Open storage may be subject to infection eg cryptosporidium or giardia ▪ Treatment for faecal coliforms ▪ Impacts of injected water on groundwater ecosystems unknown	▪ cryptosporidium or giardia may enter the system ▪ Treatment for faecal coliforms ▪ Impacts of injected water that is nutrient rich on groundwater ecosystems unknown

	Creeks & rivers	Urban stormwater	Reclaimed water
Disinfection byproducts (DBP)	▪ If chlorination is overused this may occur although some evidence indicates that DBP quickly attenuate in aquifer. Concern is mainly about trihalomethanes (THMs) & halo-acetic acids (HAAs)	▪ If chlorination is overused this may occur although some evidence indicates that DBP quickly attenuate in aquifer. Concern is mainly about trihalomethanes (THMs) & halo-acetic acids (HAAs)	▪ If chlorination is overused this may occur although some evidence indicates that DBP quickly attenuate in aquifer. Concern is mainly about trihalomethanes (THMs) & halo-acetic acids (HAAs)
Clogging	▪ Results from inadequate filtration ▪ Inadequate monitoring of source waters ▪ Inadequate treatment and incorrect operation of injection wells	▪ Results from inadequate filtration ▪ Inadequate monitoring of source waters ▪ Inadequate treatment and incorrect operation of injection wells	▪ Results from inadequate filtration ▪ Inadequate monitoring of source waters ▪ Inadequate treatment and incorrect operation of injection wells
Infrastructure	▪ For small schemes can be fairly simple and cost effective	▪ For small schemes can be fairly simple and cost effective	▪ Must be suitable for large schemes where large volumes of water require filtration
Confining bed integrity	▪ If gravity recharge generally no problems ▪ Pressure recharge needs to be carefully managed to prevent failure of confining beds	▪ If gravity recharge generally no problems ▪ Pressure recharge needs to be carefully managed to prevent failure of confining beds	▪ If gravity recharge generally no problems ▪ Pressure recharge needs to be carefully managed to prevent failure of confining beds
Failure rate	▪ In rural areas individual small schemes failure rate is high ▪ Geochemical reactions between aquifer matrix and injected water may result in failure	▪ Unless adequately monitored failure rate will be high ▪ Geochemical reactions between aquifer matrix and injected water may result in failure	▪ Capital investment is high therefore ongoing maintenance is high if systems are to have an operating life beyond 10 years ▪ Geochemical reactions between aquifer matrix and injected water may result in failure
Operational	▪ Small schemes low maintenance	▪ Small schemes low maintenance	▪ Large schemes high maintenance
Ongoing costs	▪ Approximately $3-5000 per year depending on number of samples that must be taken to comply with regulations	▪ Approximately $3-5000 per year depending on number of samples that must be taken to comply with regulations	▪ Could be up to $100000 per year depending upon the scale and complexity of the system
Space for capture	▪ Rural setting has ample space to establish capture dams	▪ Urban setting limited space for capture dams/wetlands ▪ Opportunities to provide attractive water features within urban environment	▪ Associated with treatment plant and types of treatment processes

4.1. Issues associated with aquifer types in South Australia

4.1.1. Unconfined aquifers

Implementing ASR within an established urban setting presents its own set of unique challenges. Some of the issues that need to be addressed include:

- Potential damage to existing infrastructure through soil salinisation resulting from rising water tables and also differential swelling of soils
- Increased saline groundwater ingress into sewers.
- Costs associated with retrofitting and redesigning existing established infrastructure
- Many of the technologies employed or newer construction materials available today which can facilitate enhanced recharge are unfortunately more costly than traditional materials which makes it difficult for these newer materials to be universally accepted as a viable alternative.
- In some instances the volumes of water that can be captured are far in excess of local consumptive use which can result in waterlogging and other undesirable outcomes.
- Soil sodicity in many localities as a result of evaporative fluxes or historically low lying coastal swamps and tidal estuaries groundwater being very saline. Through increased recharge resulting in rising groundwater levels the saline water reacts with the soil chemistry. Reducing the salinity of sodic soils can reduce the soil permeability.
- Inability to ensure protection of groundwater quality from pollution by contamination from surficial infiltration.

4.1.2 Confined aquifers

Within an urban setting, deep confined aquifers offer the capacity to store large volumes of water without the associated disadvantages of shallow aquifer systems. Deep injection wells can be relatively unobtrusive and the filtration equipment can be disguised in many clever ways. If treated wastewater is likely to be the source for injection and subsequent reuse, opportunities may exist to use existing infrastructure to distribute the water to the various demand centres.

Confined aquifer systems offer the best scope to manage the injected water as it tends to stay within close proximity of the injection well allowing easy recovery. Consequently, recovery efficiencies tend to be higher than for unconfined or fractured rock aquifers.

The majority of successful ASR schemes within South Australia operate in deep, confined, Tertiary Limestone (calcarenite) aquifers. While these aquifers typically exhibit low to moderate hydraulic conductivity allowing for injection rates of a maximum of around 26L/sec, they have some advantages that facilitate easy management of ASR schemes. The sandy limestone is sufficiently well consolidated to facilitate open-hole completion as part of the design strategy. This method of completion provides a number of alternatives for well rehabilitation in the event that clogging occurs. Dissolution of the aquifer matrix material (Tertiary limestone) by the injected water helps to maintain steady rates of injection and delays the loss of injection efficiency from clogging.

Injection wells that are screened have been less successful as the screens usually become blocked with fine particulate matter and cease to be efficient. Clogging of the screens can be minimised by increasing the degree of prefiltration prior to injection.

However, in the majority of cases where clogging of the well screen has occurred, the source water has generally been from creeks containing fine suspended solids and the operators were unwilling to pay for additional filtration. Consequently, the injection wells failed within a few months of operation.

Limited success has also been achieved in very fine sand aquifers in South Australia. Wells completed in such formations require gravel packs and screens with small apertures. For example, at Urrbrae, lignitic material in the aquifer clogged the well screen on recovery. To eliminate this problem at the Urrbrae site, injection and recovery was carried out at low velocities to avoid mobilisation of the lignitic material. The well ultimately clogged due to algal matter that had passed through the pre-filter (rapid sand filter) and become entrapped on the inside of the screen within the well. The algal mass facilitated biofilm growth within the gravel pack surrounding the screen. Failure of the ASR well often results from clogging but more typically it is a result of inappropriate well construction. Construction and well completion is one of the key factors to undertaking a successful ASR project and the method of construction employed is dependent on the target aquifer formation type. More often than not a specifically constructed well for the purpose of ASR will be required rather than injecting down an existing well.

A number of small ASR schemes have failed as a result of trying to force the water into the well at a rate faster than the aquifer can accept. This typically results in large pressure uild-ups within the bore that ultimately fracture the formation around the well causing the well to collapse. The majority of successful ASR sites within South Australia use gravity injection.

4.1.3 Fractured rock aquifers

Fractured rock aquifers like confined deep sedimentary aquifers also offer good sites for injection of captured stormwater. There are sites that have been operating in South Australia for a number of years principally using gravity recharge. One drawback to undertaking ASR in a fractured rock aquifer is that injection rates are very slow. The consolidated material allows for open-hole construction of wells but the crystalline nature of the rock limit the options for well remediation in the event of clogging.

Because the water is contained within the fractures, the available storage capacity is relatively small. The fracture networks can be connected over very large distances consequently, the injected water may travel large distances from the injection well within a very short timeframe. The ability for the water to travel large distances also impacts on the recovery efficiency of the injected water which may be as low as 15% (Harrington et al, 2001). This also has impacts on nearby users especially if the injected water is of a low quality potential. Remediation is likely to be very difficult in the event of contamination and consequently, at this stage injection into fractured rock aquifers should be confined to captured stormwater or creek runoff.

One advantage of the fractured rock aquifer is that the crystalline rocks can withstand greater hydraulic loadings which means that injection under pressure can be undertaken without risk of the formation failing. In addition, if the fracture openings are of a sufficient aperture they may allow for slightly more turbid water to be injected. In turn this will allow economies in the level and type of pre-filtration. Conversely, the fracture aperture may be such that clogging occurs almost instantaneously.

Additionally, attenuation of any pollutants (herbicides or pesticides) is likely to be different within a fractured rock aquifer system than a sedimentary aquifer system.

A further risk associated with fractured rock aquifers is that previously inactive springs may be reactivated as a result of the enhanced recharge, potentially causing localised problems.

4.2. Regulatory issues

Care is needed in applying ASR as a solution where aquifers are over-exploited. It should never be seen as an alternative to increased water use efficiency, or relaxation of quotas or their policing. However with good resource management, ASR can be a support for demand management (Figure 5). For example, the community can perceive setting prices or increasing prices of groundwater as yet another tax. However a two handed approach, where the additional revenue raised is invested in establishing ASR for a depleted aquifer, gives a defensible reason for increasing the price of water. A sufficient price increase will assist the community of groundwater users to value the resource and improve water use efficiency, and thereby reduce demand. The increase in recharge provided by ASR can mitigate the magnitude of the required reductions in demand to achieve a sustainable water balance. ASR can also be targeted to locations within a regional aquifer where pressures are most affected, or where environmental consequences of pressure reductions would be most severe, such as where saline intrusion could be induced. It would be very difficult to equitably reduce demand on the regional aquifer to gain the same level of protection for the aquifer.

Local Solutions

- Reduce Demand
- Expand the Water Resource

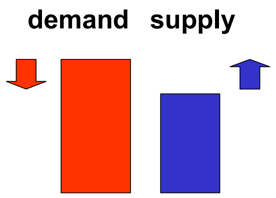


Figure 5. Twin strategies for managing over-exploited aquifers

Clearly for successful implementation of such policies there is a need to establish suitable consultative mechanisms to allow satisfactory stakeholder negotiations. Without the success of existing ASR projects and the sound research base on which they are founded it would not be possible to recommend to communities that investments be made in recharge enhancement. This is a management tool that has been developed by DWR and its collaborators and enables much more flexibility than counterparts in other states currently enjoy. It is important that ASR therefore be part of an integrated water solution, and is not treated as a band-aid measure to fix local problems that are otherwise intractable. In this way SA will continue to lead the field in innovative groundwater management.

4.3. Lessons from ASR failures

Six known failures have occurred in ASR pilot projects in SA, from more than 40 site investigations. The first failure was at a well where a market gardener on the Northern Adelaide Plains attempted to inject water from one production well into another. The injection well and injection system was not appropriately designed for this purpose and it is likely that air was introduced into the well and blocked the pores of the aquifer at the well face. As no data was recorded it is not known whether there were other causes for the unsatisfactory rate of injection. The exercise was abandoned and caused unnecessary loss of local confidence for several years in the potential for ASR, in spite of other successful preliminary trials in the same area.

The second failure was at a location where the most suitable formation for water storage at a site appeared to be a thick bed of dry sand above a deep watertable. The area was on a plain with a low slope and after a period of injection, groundwater started to discharge at the ground surface in the gardens of private residences down-slope of the injection site. Evidently the target 'aquifer' was dry because the water table position reflected equilibrium between natural recharge and discharge. The unconfined aquifer was sufficiently transmissive that a storage volume could not accumulate without conspicuously increasing discharge to the land surface. Clearly, knowledge of the groundwater system is essential, particularly for unconfined aquifers, to avoid damages that could significantly exceed the value of the water stored and recovered.

A third failure occurred when a domestic-scale ASR well was installed in a private property in Malvern. Roof runoff was used to recharge a well completed in a Quaternary alluvial aquifer. The large roof area and low injection rate meant that a very large surface water detention storage was required if a significant fraction of roof runoff was to be recharged. The detention storage overflowed onto soil and when the water subsequently returned to the well it was dirty, contributing to clogging. The well was freshened sufficiently for groundwater to be blended with mains water for garden irrigation, but its use as an ASR well was abandoned.

A fourth failure occurred where a large diameter well was drilled to a thin alluvial gravel aquifer for gravity drainage of stormwater. The well was completed as a concrete caisson to the depth of the aquifer at about 17m and grouted on the outer perimeter. Trials using mains pressure water revealed that the grouting was not effective. After a short period of pressure injection into the well, the ground around the well became waterlogged. Clearly water was migrating upwards through the alluvial mixture of clays, sands and gravels assisted by unintended preferential pathways adjacent the caisson. Acceptance rates were sufficiently low, such that injection would need to be via gravity however the quantities of stormwater to be captured required the establishment of a huge number of injection wells and large surface storage areas for ASR to be viable at this site.

The fifth failure was in the Willunga Basin where water from an ephemeral stream was pumped into a well. Recharge occurred without sufficient detention time to allow suspended solids to settle or without adequate pre-filtration resulting in muddy water entering and blocking the well. In addition the operator attempted to inject at rates well in excess of the capacity of the aquifer to accept the water causing a pressure head to build within the well resulting in ultimate fracturing of the formation and well collapse. Better control on the quality and rate of injection would have circumvented these problems.

Finally, in the sixth case Plio-Pleistocene fine-grained unconsolidated sand between 60 and 80 m below ground was chosen as the target aquifer at the Urrbrae wetland. The well was rotary-drilled using mud, so formation physical properties could only be determined from mud samples and geophysical logs. The samples showed the presence of coarse sands and also some lignitic bands. The screened intervals and apertures (0.5 and 1mm) were set on the basis of the geophysical logs (gamma and resistivity) and particle size distributions inferred from washed mud samples. Development of the well took several days indicating that the proportion of fine materials present was greater than anticipated, and had been disguised by the drilling mud. Recognising the potential for injection to disrupt the gravel pack that had been developed, tests were performed to inject water at different rates, and determine the length of time after which recovered water was clear. Injection rates were restricted to only about half the injection rate that could be achieved in order to maintain the gravel pack effectiveness.

Unfortunately, at this site the injection system was activated approximately a month before the recovery pump was installed in the injection well. During this period the stormwater was rich in algae, and it was subsequently found that while the rapid sand filtration system broke up the algal matter, it did not reduce the turbidity, organic carbon or nutrient loadings entering the well. There was also at least one input of engine oil from the stormwater catchment and evidence that traces of oil had got through the sand filter and into the well. Although a monitoring well had been included in the design of the ASR operation, it had not been constructed due to budgetary constraints, so the reasons for the decline in flow rate could only be guessed. By the time the pump was installed, the capacity of the well for injection and recovery had been reduced to one sixth its initial rates.

Attempts to restore the well included; repetitive surge pumping, injection of chlorine disinfectant and dispersant, and bailing to recover sand that was found to cover the third of the three slotted intervals. Video monitoring of the well showed that sand was entering the well from a small gap between the top screen and the casing, possibly vandalised from a star dropper (metal fence post) that had been dropped in the well (also dislodging the pump shroud), or damaged through the bailing process that had been complicated by the buried shroud. Down-hole velocity flow metering confirmed that the loss of third screen interval was not the cause of the substantial decline in injection rate. It is concluded that the injection system is not adequate for this aquifer and that the absence of a monitoring well prevents a much clearer description of the requirements for sustainable operation of this site. As a result of this experience fine-grained unconsolidated aquifers are regarded as unfruitful targets for operational ASR systems in the Adelaide metropolitan area until further research on such systems is undertaken, and appropriate procedures for flushing and topping up gravel packs are incorporated into well design.

In summary, lessons from these experiences are that it is necessary to obtain good samples of aquifer materials, to know the quality of the injectant, to have a nearby monitoring well, to defer injection until a recovery system is in place, to understand the groundwater system and potential environmental consequences of ASR, to monitor flows, heads and quality intensively during the first phases of an ASR operation in order to understand the performance characteristics of the well and to determine appropriate redevelopment and well maintenance strategies, and to have contingency plans in place to deal with issues such as turbid water, pollution, clogging, and adverse effects on groundwater. A staged approach to ASR development minimises investment risks, and most of these failures could have been averted with a more systematic and comprehensive approach. Further details are given in Dillon and Pavelic (1996), Dillon et al (2000) and EWRI/ASCE (2001).

5. RESEARCH

5.1. Outcomes of Australian ASR research

The Australian research on ASR commenced in 1992 with a project to assess the potential for ASR in the upper Quaternary aquifer beneath the Adelaide metropolitan area (Pavelic et al, 1992). This was followed with a field experiment at Andrews Farm, supported by CSIRO, Department for Mines and Energy, Hickinbotham Homes and the Urban Water Research Association of Australia (Dillon et al, 1997). An injection well was constructed in Tertiary limestone near a stormwater detention pond, and following storm events over the next four winters, water was pumped into the well from a pump mounted on a pontoon moored in the detention pond. Groundwater was initially brackish having a salinity of more than 2,000 mg/L. The injected water was fresh (<200 mg/L TDS) but turbid, and in the winter when most water was injected (100 ML) its suspended sediment concentration averaged more than 150 mg/L. It was considered quite extraordinary that the well would accept that quality of water given that ASR operators in the Netherlands, England and USA regard source water turbidity more than 2-5 NTU as unacceptable. Furthermore, unlike conventional practice in USA the water was not chlorinated prior to injection. Even in the newly released standard guidelines for Artificial Recharge of Groundwater (EWRI/ASCE, 2001), it is recommended that injectant is disinfected to prevent bioclogging of the well. It became obvious through further research that there were processes occurring in the aquifer that counteracted the effects physical clogging by suspended solids and bioclogging by micro-organisms.

Although initial efforts at ASR were successful, in retrospect they seem primitive in comparison with best practice that has subsequently emerged from ongoing research. At the Andrews Farm pilot project, there was a detention storage, not a wetland. The pond sides were too steep, and ASR operations gave a range in water levels that was too large for reeds to establish. Consequently, any new storm or windy day resulted in wave action on the un-vegetated clay banks resuspending clays. Furthermore, it was found that drying of the clay liner of the pond had resulted in cracks that were infilled by coarser solids during stormwater inflows, and consequently the pond leaked severely. Calculations showed that over the four years of stormwater injection, as much water seeped through the pond bed to the unconfined aquifer as was injected into the underlying confined aquifer (250ML). Wetland designs have improved, and for the same volume of cut and fill much better passive improvement in water quality can occur, and as much active storage can be produced, even when restricting this to 100mm for maintenance of aquatic and riparian vegetation. Engineered water management improvements have also grown from a coarse screen to prevent diatoms clogging the well during blooms in the wetland in spring and autumn, to parallel rapid sand filters, and control systems that can shut down injection if turbidity or electrical conductivity lie outside specified tolerances, and trigger redevelopments to prevent well clogging.

Examples of how these may be achieved for a stormwater ASR project are shown later in Figure 7. Stormwater can be sourced selectively. Figure 8 shows this as a capability to divert water from a stream or drain into an off-stream wetland based on the quality (eg turbidity) of the flow. This could also occur for example by selecting only roof catchments and not collecting runoff once it had reached the ground. Selecting an aquifer that is brackish gives much more room for flexibility on the quality of injectant than targeting an aquifer that is already of potable quality, where injectant would need to be consistent with drinking water uses. Maintenance of equipment, such as recalibration of sensors and checks on control systems are needed and contingency plans need to be formulated and communicated so that all know how to deal with for example polluted water entering the injection system or aquifer.

An important consideration that has developed from this work is that proponents of ASR projects need to ensure that proper account is taken of the monitoring and management costs of the project when evaluating the costs and benefits and deciding whether to proceed. In this way there is a clear economic incentive for the operator of viable projects to proceed. It would be very unfortunate to have operators cut corners, as when this occurs, not only are projects likely to fail (eg via clogging), but there is also insufficient data to determine the exact cause of failure and whether and how it could be fixed. An international literature review, together with the Andrews Farm data led to Australian guidelines for the quality of water for injection and recovery into aquifers being published (Dillon and Pavelic, 1996). These are not part of the National Water Quality Management Strategy series of documents, but rely on the principles of the Strategy, and went through review by state government natural resource and environment regulators in all states.

Aquifers that have been demonstrated in Australia as suitable for ASR are limestone and fractured rock. Open-hole completions are the easiest form of well completion for ASR well maintenance. However there is still insufficient research on wells in unconsolidated or unstable media requiring a screen and gravel pack to provide definitive advice on well maintenance. American experience with use of disinfected potable-quality injectant in such wells indicates these can be very successful (Pyne, 1995).

Other outcomes of ASR research, besides the operational stormwater ASR sites and the guidelines, are maps of ASR potential for some regions and the adoption of ASR as part of state water plan for South Australia (SA Department for Water Resources, 2000). It has also resulted in the development of new techniques; to monitor pathogen survival in aquifers, to measure the ability of low-grade waters to clog aquifers, to measure hydraulic conductivity in 3D at in-situ stresses, and has advanced knowledge of physical and biological clogging processes (2 PhDs) geochemistry of ASR in limestone aquifers, and mixing processes and prediction of recovery efficiency in heterogeneous aquifers.

5.2. Current research

Current research is examining subsurface processes where reclaimed water is injected into aquifers with a view to determine criteria for sustainability of such systems. The Bolivar reclaimed water ASR research project has injected 250ML reclaimed water into a limestone aquifer and has numerous observation wells, and an intensive sampling and logging schedule with various specific experiments overlayed. The aims and outline of that project with the results of the first stage (prior to injection) have been reported elsewhere (Section 3.2 and Dillon et al, 1999).

Another major piece of research is a project to assess water quality improvements during ASR for the American Water Works Association Research Foundation, with a focus on potable water supplies. Water quality parameters of most interest are pathogens (particularly viruses), disinfection byproducts (notably trihalo-methanes), endocrine disruptors (five indicators are being tested), and natural organic carbon components that may be important as precursors for formation of disinfection byproducts. The research embraces five sites in USA, four in Australia (Bolivar, Andrews Farm, Clayton and Jandakot, WA) and one in the Netherlands, and includes researchers from Australia, the Netherlands, France and USA. A brief summary of early progress is about to be published in accessible form (Toze et al, 2001) and indicates that ASR offers some scope for improvement in all these aspects of water quality.

In addition sites at Warruwi (NT) and Jandakot are in demonstration phase to evaluate operational performance with a view towards including these sites within their routine water supply systems when there is sufficient proof on their reliability to produce adequate quantities of water of suitable quality. A number of other sites are undergoing similar investigations, such as Willunga reclaimed water and Parafield stormwater ASR projects in South Australia, as detailed in section 3.1.

5.3. Future directions for research and application

Cases such as stormwater ASR into limestone aquifers for non-potable reuse have clearly moved beyond the research phase, and are now in routine use within the consulting profession and with some client groups, such as local government. However there are still aquifer types, notably unconsolidated or unconfined aquifers, water types, notably mains water and reclaimed water, and reuses, notably potable supplies, that are still in the research phase or where research has not yet commenced for ASR. Transitions from single well systems to separate injection and recovery wells for higher valued reuses are likely and have not yet been explored. Use of reservoir spill to assist with opportunistic flushing of brackish or saline aquifers has not yet started. Conjunctive storage of energy and water has not yet begun in Australia. These new water management tools open possibilities for better environmental and commercial outcomes in the future. With these extensions to existing knowledge the scope for ASR to add value to water management in South Australia and elsewhere will expand considerably. This is likely to have the effect of trebling the potential for ASR, increasing the benefits to the state, improving the efficiency of operation, reducing risks of failure and lowering capital and establishment costs. For these benefits to be realised however, there also needs to be maintenance and enhancement of current expertise within state government, in order to manage this expanded uptake of ASR. This is best obtained by continuing involvement in research projects with research partners such as CSIRO.

On the way there is still much to be learned about disturbed aquifer ecosystems, virus survival and transport, fate of colloids and organic carbon introduced to aquifers, and biogeochemical processes in the subsurface. Regulators and proponents will need to have information more conveniently packaged in the form of ASR water quality risk assessment models, clogging simulators, and predictors of recovery efficiency and storage capacity in heterogeneous aquifers. These in turn will lead to refinements in guidelines and codes of practice and reduce risks and costs for investors. Such research would need to be well linked with the proposed new national water reuse research program. Information from operational sites will also need to be harvested, for environmental protection and water resources management purposes, and be accessible to researchers so that continuous improvements to ASR technology can proceed. Other forms of water banking in Australia also have substantial latent opportunities, and the ASR research base provides a very convenient and efficient launching pad.

6. SUMMARY OF COSTS AND BENEFITS TO SA

South Australia uses 1240GL/yr of its average available resource of 2610GL/yr (Table 9). However this apparently large buffer of surplus capacity is largely illusory. The largest component, approximately 1000 GL/yr of groundwater, cannot be exploited without serious impacts on wetlands and riparian vegetation (including some pasture and forests) in the South East of South Australia. Further exploitation of the River Murray would be contrary to the aim of all the states through which it passes to maintain or increase environmental flows in this depleted stream. Other surface water resources also have environmental flow considerations, or the cost of dams in relation to yield would be extravagant. Hence it is apparent that South Australia needs to conserve, recycle and reuse water, and to harvest urban rainfall and stormwater which until the last decade was a minimally tapped resource. Management of urban flooding using wetlands and detention storages has triggered stormwater harvesting and a diversity of innovative approaches have been developed. The one having the largest impact is ASR.

Table 9. Water Resource and Water Use in South Australia and in Adelaide and the Mount Lofty Ranges *(from DWR, 2000)*

Water Resource	State Use Limit (GL/yr)	State Use (GL/yr)	Metro Adel Use Limit (GL/yr)	Metro Adel Use (GL/yr)
River Murray	700	600	130	110
Other surface water	220	140	84	130
Groundwater	1440	460	74	61
Stormwater runoff	130	20	110	21
Treated effluent	120	20	79	17
Total	2610	1240	477	339

To date ASR has focussed on stormwater runoff in the Adelaide metropolitan area, and current research is exploring the potential for expansion of use of reclaimed water (treated effluent). These are the two smallest sources of water in South Australia but are significant sources for the metropolitan area. More will be said on this later.

Research proposed in section 5, would expand ASR to storing potable quality water derived from surface waters including from the river Murray near the termini of pipelines, so that peak demands can be satisfied without pipeline duplication. Deferring, possibly indefinitely, the capital costs of new pipelines would produce significant savings. ASR projects could be established incrementally as demand increases, and before pipelines reach full capacity, so that this is a viable proven option available for expansion of regional mains water supplies. It is expected that areas such as the northern Spencer Gulf, and Yorke Peninsula would be regions where such benefits would be significant. The costs of ASR could be compared in the first instance with the costs of covered terminal storages of the order of 1000ML capacity, where capital costs would be one to two orders of magnitude more expensive than subsurface storage. Costs would be recovered at the potable water price. According to regional development boards in these areas, limitations on water resources are considered a limit to growth in these areas. Again, as in the case of over exploited aquifers, prudent water management suggests that ASR would be instituted hand in hand with programs to encourage water use efficiency.

In arid and semi-arid environments, the cost of alternative sources of supply is high so ASR can compete more easily with traditional sources of water. For example, in some country towns of SA, annualised unit costs of SA water supplies may be considerably higher than in Adelaide due to long pipelines and relatively low water consumption. In the northern region, for example, these range from $3.50 to $4.70/KL and on Eyre Peninsula $5.50 to $7.20/KL (Van der Wel and McIntosh, 1996). Expansion of water supply capacity in these locations could be by development of ASR, to make use of surplus pipeline capacity in winter.

Table 9 hides the additional surface water resources that are intermittently available in years when reservoirs spill. Prior to and during spill events mains water from these reservoirs could be banked in aquifers to build drought and emergency supplies. Adelaide's traditional reliance on the River Murray has resulted in it having the smallest surface storage to annual demand ratio of any major Australian city. For Adelaide this ratio is 1.0. In Perth (which depends on significant aquifers), the ratio is 2.6, whereas in Sydney (4.0), Melbourne (4.1), Brisbane (7.3) and Canberra (3.4), the ratio is higher even though their water supply catchments have comparatively higher rainfall and less variability than Adelaide's Mount Lofty Ranges catchments (Dillon, 1996). If we had prolonged blue-green algal problems in the River Murray or concurrent problems in the Mount Lofty Ranges storages, Adelaide would be very vulnerable. ASR provides a very low-cost strategy to provide short-term emergency supplies. For this to be an option some consideration should be given to allocating aquifers to potable water ASR. Stormwater ASR need not preclude this option, and could help to reduce the salinity of ambient groundwater to provide a buffer zone in which potable water is stored. This would help to keep recovery efficiencies high, which may be important if there is internal charging for water to be banked. Clearly there would need to be protections given to water utilities that bank water in aquifers to ensure that they can access the water at times when withdrawals are required.

Concerning the now 'traditional' stormwater source for ASR in Adelaide, currently the cost to users varies between 20 and 50c/KL depending on local conditions, such as scale of operation, availability of water, and suitability of the aquifer. At first sight it would be much cheaper to buy River Murray water licences (say 10c/KL) and pay for pumping costs (say 2c/KL) but this does not take into account the lost return from agricultural production (eg typically 20 to 40c/KL) depending on the irrigated crop and water use efficiency. With loss of production there are flow on effects to incomes and jobs in rural communities. There are also different environmental consequences, and use of ASR retains environmental flows in the River Murray and reduces discharge into the Gulf of St Vincent of stormwater contaminants (retained and in part attenuated in wetlands). Therefore, although for individual users the economics of transferring water rather than developing new water resources may seem superior, from a State perspective, the reverse is true. The state should therefore give consideration to setting policies that internalise current externalities and encourage the development of water resources where these will be of most benefit to the State.

Typical costs for domestic and municipal scales of ASR schemes are summarised in Table 10. These assume that maintenance, monitoring, and depreciation costs are fixed annual costs, and that the only variable costs are for energy for pressure injection (at 5c/KL/pump) and for recovery, at the municipal scale. In reality the quantity of runoff may restrict the amount of recharge. Costs will vary from site to site, depending on the depth of the target aquifer, drilling conditions, the extent of pre-treatment and surface storage costs, and investigations required as part of the environment management plan (Dillon and Pavelic,1996). These do not take into account the costs of surface detention storage, which normally would be covered as a flood mitigation capital works cost, nor do they account for changes in future costs such as energy and water.

Table 10. Comparison of estimated costs for domestic and municipal scale ASR schemes

Costs		Domestic (500 KL)	Municipal (100 ML)
Initial costs		$2 400	$200 000
Annual cost	- fixed	$200	$10 000
	- variable	$25	$10 000
Total annualised cost (15yrs, 7% discount rate)		$489	$42,000
Cost per kilolitre ($/KL)		0.98	0.42
'Break even' time c/f. mainswater @ 90 c/KL (years)		-	3.3

(after Dillon, 1996)

These typical figures indicate that the break-even time for municipal scale facilities using a single-well capable of supplying 1 to 2 ML/day continuously over summer is less than 4 years. The expected lifetime of an appropriately constructed and managed ASR facility is greater than 15 years. If larger annual water volumes can be banked for the same capital costs the unit price of water can be reduced. If warranted by surface supplies or peak demand, a series of wells can be constructed, and some economies of scale may be possible. Domestic scale facilities at the scale shown in Table 10, are not economic compared with mains water supplies. Possibly this is fortunate from the point of view of aquifer protection, sustainability and equity of access to the resource (as discussed later). Domestic rainwater tanks are more expensive per KL of water supplied than ASR, however the capital cost is significantly lower, and this may be a preferred option for improved domestic rainwater management.

From a water utility perspective ASR can be viewed as a means of expanding supply capacity during peak demand. Unit costs for ASR facilities in the United States generally range from about AUS$100,000 to AUS$300,000 per megalitre per day (ML/d) of peak demand capacity *(Pyne et al 1996*). These apply to supplies of hundreds to thousands of ML/yr. Many of the schemes implemented thus far in South Australia deal with smaller volumes of around 80 to 150 ML/year and the principal enduse is irrigation. Consequently, costs are lower because the systems generally do not require expensive infrastructure such as advanced filtration and disinfection. Installation costs typically range from around AUS$50,000 to AUS$200,000 for 1 ML/d supply capacity during the peak demand season. On-going operational costs are typically 5c to 10c/KL for simple ASR schemes where wetlands are used as the filtration method and recharge is by gravity. Setup costs obviously increase when advanced filtration pre-treatments are required to ensure that source water meets the criteria for aquifer storage and recovery.

Incorporating ASR as one of the tools for resource management can reduce user reliance on imported water by -

- improving groundwater quality locally for irrigation and industrial use,
- creating low salinity lenses for domestic water supply within saline aquifers,

- reducing outflow of stormwater to the marine environment,
- reducing the dependence of urban and rural users on the River Murray and;
- maintaining groundwater systems for current/future development.

ASR offers a potentially low cost method of storing water as an alternative to surface storage where aquifers are favourable. Some of the factors that must be considered to achieve successful ASR are:

- a contracted demand for the water product, adequate to ensure the ongoing profitability of the scheme
- surface water availability of sufficient quantity and quality,
- a suitable aquifer for long term storage, additional quality modification and transmission (as may be required),
- suitable land for surface works involved in surface water capture, temporary storage, treatment, transfer to the ASR site, ASR headworks and reticulation to the demand location,
- pre-treatment of water as necessary to reduce suspended solids concentrations, whether by wellhead filtration or by movement through surficial sandy soils, and,
- a capital funding source for establishing the system

7. ASR GUIDELINES AND REGULATIONS

7.1. Water quality guidelines for ASR, 1996

The first issue to be addressed in ASR is the protection of groundwater quality. Until 1996, a major barrier to the storage of surface waters in aquifers via injection wells was a lack of scientifically based guidelines on the quality of water to be injected. The first Australian guidelines on the quality of stormwater and reclaimed waters for injection into aquifers for recovery and reuse (Dillon and Pavelic, 1996) addressed that gap. This superseded previous documents on artificial recharge of reclaimed waters (AWRC 1982, and NRC 1994) and was a first attempt (internationally) to provide a sound basis for the injection of non-potable waters into aquifers for a range of beneficial uses.

These guidelines were an outcome of a two-year Urban Water Research Association of Australia study that reviewed international practice and guidelines for artificial recharge of waters by injection. The study also reviewed literature and data on the quality of stormwater and treated sewage effluent; effectiveness of pre-treatment methods including constructed wetlands; basins and engineered treatments; clogging and redevelopment of injection wells; and attenuation of chemical and microbial contaminants in aquifers. The Andrews Farm experimental ASR site was used as a case study to demonstrate the viability and sustainability of injecting urban stormwater that received only passive treatment in flood detention ponds, into a brackish aquifer. The recovery was as an irrigation resource.

The principles, objectives, and guideline values for maximum contaminant levels in water for a range of beneficial uses (environmental values) were founded on Australia's National Water Quality Management Strategy (NWQMS). The guidelines were distributed for comment to water resource managers and environment protection agencies in all states and territories of Australia, the Australian Health

Commission, the NWQMS chairman, and water companies. Eighteen sets of comments were received and considered in finalising the guidelines.

While the guidelines adhere to internationally accepted principles they are quite different from those currently used to regulate ASR sites in other parts of the world for two reasons. They do not presume potability as an essential and sole objective, and they allow for demonstrated sustainable attenuation of contaminants by natural processes in aquifers. Currently there are pressures within the USA to adopt the principles embodied in these Australian guidelines, particularly in arid areas where alternative sources of supply are possible. The American Water Works Association Research Foundation currently supports a project (#2618) 'Water quality improvements during ASR' aimed at gaining a better definition of attenuation of contaminants of interest to water supply companies involved with US drinking water quality standards. This project is led by CSIRO Land and Water and involves the Department for Water Resources, SA Water and United Water.

The guidelines covered licensing, pre-treatment, monitoring, guidance for maximum contaminant concentrations in injectant, residence time prior to recovery and management of ASR operations.

The report also made recommendations on revising the guidelines as identified knowledge gaps are addressed; concentrating research at selected sites; and establishing a national ASR research program to coordinate and conduct ASR research; collating all monitoring data and reports from Australian ASR sites; and producing a design manual for ASR. Knowledge gaps were also identified to help focus research and enable the guidelines to be improved.

7.1.1. Specific guidelines

The guidelines contained specific recommendations concerning licensing, pre-treatment, monitoring, maximum concentrations of contaminants in injectant, and minimum residence time. A condensed summary follows.

Licensing

There should be two types of licences. Proposed new ASR sites should be subject to a *demonstration licence* for a specified trial period, typically three years, to enable demonstration of achievement of the three objectives; protection of groundwater quality, ensuring that the quality of recovered water is fit for its intended beneficial use, and that clogging is managed effectively. The demonstration licence would be based on an environmental management plan to account for all environmental impacts and associated risks. The plan would include appropriate monitoring and reporting to demonstrate performance with respect to objectives, operational and contingency plans to manage risks, and projections of performance over the longer term. Appropriate opportunity for public comment should be allowed. Issue of a longer-term operating license, and its conditions, would be subject to a performance review of the demonstration period.

Pretreatment

The overarching principle should be to remove or reduce whatever contaminants can be viably attenuated at the surface before injection, in particular those contaminants that are resistant to degradation in the aquifer.

The minimum level of pretreatment required for a demonstration licence is that which results in predicted achievement of water quality criteria (eg. NWQMS 1992a, 1994b) relevant to all pre-existing potential beneficial uses for the aquifer. Where the beneficial uses of recovered water are different from those of the ambient groundwater, pre-treatment combined with aquifer treatment should meet the relevant criteria at the point of extraction. This will determine whether disinfection or any other pretreatment is required during the period of the demonstration licence. Pretreatment methods may include passive and engineered systems, or a combination of these. There will be at the discretion of the proponents as part of their environmental management plan.

Where any relevant water quality criterion is not initially met by the ambient groundwater, excluding the effects of anthropogenic pollution, the injected water only needs to have a concentration less than that of the ambient groundwater - at least for the period of the demonstration licence.

Detention storage as part of pretreatment is desirable in reducing the variability of the quality of injectant. This has the advantage of increasing confidence in the results of monitoring for any given level of monitoring effort.

Monitoring

At least one observation well is required at each ASR site, and where reliance is placed on water treatment within the aquifer to meet water quality objectives at least three (3) observation wells in addition to the injection well are recommended. In fractured or heterogeneous aquifers more wells may be needed. Extraction wells may be used as observation wells, if sited appropriately. In areas where existing drainage wells or ASR operations are prolific, and have a history of use, a rationalised monitoring program designed on risk management principles may be adopted in the environmental management plan.

For new operations at least one observation well should be located down-gradient on the flow path through the injection well. This is to monitor breakthrough of injectant within the period of the demonstration licence. The other wells are required to establish the direction of ambient flow at the site.

The parameters to be measured are those appearing in the water quality criteria for the potential beneficial uses (NWQMS 1992b; 1994b), prior to, and following establishment of the ASR site. Exclusions may be granted by the regulating authority on the basis that certain contaminants are known not to be present in the source water.

There is a need to be able to track the injectant in the aquifer, and determine the proportion of injectant in recovered water. If there are no obvious contrasts between injectant and groundwater, use of ‘natural’ isotopes or CFC’s as tracers is recommended. Measurement of the mass of contaminants and solutes injected into aquifers (and recovered) will be a valuable aid for total catchment management.

The monitoring frequencies for a wide suite and a surrogate (smaller) suite of water quality parameters should be determined on a site-by-site basis, and from a risk management perspective, by the regulatory authority. This would take into account the source of the water for injection and its quality, proposed pretreatment methods, aquifer characteristics, groundwater quality, existing and proposed uses of groundwater and sampling locations.

If, during the demonstration licence period, monitoring shows that the water quality objectives are not met (ie. predicted rates of treatment above and below ground are not achieved), pretreatment should be upgraded accordingly, and if necessary, contingency plans put into action to ensure that adverse effects do not persist.

Sites proven by monitoring to achieve their water quality objectives during the demonstration licence period, should be granted a full licence for a period to be nominated by the regulatory authority, with appropriate terms and conditions.

Guidance for maximum concentrations of contaminants in injectant

Guideline values for individual parameters should be determined by water quality objectives and by the capacity for treatment within the aquifer. The following information is provided as a general guide on several parameters that are commonly regarded as constraints to ASR with reclaimed waters.

Suspended sediments - Where bore redevelopment is required more frequently than daily, the suspended sediment concentration of injectant should be reduced. Values of 30 mg/L have been acceptable in a variably cemented limestone aquifer. Finer grained aquifers with no macroporosity will require considerably lower suspended solids.

Total dissolved solids - A maximum of 500 mg/L is recommended for potable reuse and 1000 mg/L is desirable for non-potable reuse, although higher values may be used where these are locally acceptable for environmentally sustainable irrigation systems or other beneficial uses, provided these do not exceed the TDS of ambient groundwater. These figures assume that TDS is approximately conservative. Where wastewater is more saline it may need to be blended with surface water to reach these values prior to injection.

Faecal coliforms - A maximum of 10,000 colony-forming units per 100 mL is recommended. Allowing for 1 log cycle removal per 10 days (which is conservative), faecal coliforms would be depleted to the irrigation water quality guideline after 10 days and to near potable standards after 50 days residence in the aquifer.

Nitrogen - For potable reuse a maximum of 10 mg/L is recommended, subject to ammonia concentrations being less than 0.5 mg/L. Denitrification within the aquifer should not be relied upon to attenuate nitrate concentrations as this may cause gas binding. For irrigation reuse the nitrogen concentration in recovered water should be sufficiently low (typically less than 10 mg/L) that the nitrate concentration in irrigation leachate is environmentally sustainable. Where groundwater containing injectant discharges into surface waters or estuaries, the receiving water concentrations should remain below 0.1 mg/L.

Minimum residence time

A minimum residence time of 50 days for undisinfected injectant is recommended to provide an acceptable degree of health protection when recovered water is used for recreation or irrigation. Shorter residence times may be allowed if source water quality and exposure paths provide an equivalent level of public health protection. Protozoa and viruses may have longer survival times in aquifers, and recovered water should not be used for water supplies unless there is either a field-based assessment of the potential for breakthrough of these species, or the injected or recovered water is suitably treated.

7.1.2. Operation of ASR sites

The 1996 guidelines also recommended a series of measures to assist in achievement of the licensing objectives. These recognised that injection of water bypasses the natural protection afforded confined aquifers by their confining beds. The high costs of remediating contaminated groundwater, injectors of reclaimed water have an obligation to establish that their operations meet the three licensing objectives. The need to provide this assurance, together with the current uncertainties in our knowledge of contaminant attenuation, requires that an environmental management plan include the following features:

- sites that are initially treated as pilot or research operations until the regulatory authority is assured that the objectives have been met in a way which can be sustained,

- impacts on groundwater quality and the fate of contaminants in aquifers are monitored,

- effects of the operation on piezometric pressures, aquifer leakage rates, groundwater-dependent ecosystems, groundwater discharge rates and groundwater quality are monitored and changes predicted,

- number, location, and design of observation wells, the frequency of sampling of these and of injectant and recovered water, and the analyses required should be determined for local conditions and be based on an assessment of the risk of contamination,

- safeguards are in place to prevent injection of unacceptable water,

- contingency plans are produced to provide for the recovery of any polluted groundwater, and if the site is to be continued, contingency plans are prepared for the establishment of appropriate pretreatment to enable objectives to be met,

- plans for well redevelopment (or other methods for unclogging injection wells), means of disposal of recovered water and sediments have been considered and are acceptable,

- consequences of changes in source water quality and supply, and changes in the demand for recovered water are considered, the effects understood, and the management response plan acceptable,

- results of monitoring are reported (and related to predictions) at agreed periods

- proponents of new or expanded ASR facilities lodge, with the relevant state government authority, a report containing - geological logs; groundwater quality and source water analyses; design of system; estimated annual volume of source water available, and target volumes for recharge and recovery; injectant water quality targets based on sustainability objectives and accounting for contaminant attenuation in the aquifer(s); plans for pretreatment of injectant; operational, monitoring, and contingency plans; and projections of the effects of the operation. Relevant scientists, including an experienced hydrogeologist, to determine its technical merit should review the report.

A well considered environmental management plan presents the opportunity to trade-off sustainable treatment in the aquifer against pretreatment of injectant, providing all objectives can be met. Aquifer treatment effects on recovered water may be increased for some contaminants by lengthening the flow path and residence time in the aquifer. This can be achieved by the suitable placement of injection and recovery wells. The increase in knowledge of the sustainable attenuation capacity of aquifers as a result of information collected at these sites will allow improved design of matching pre-treatment systems, and allow costs to be contained. This will apply particularly to non-potable uses of recovered waters from aquifers that are initially non-potable.

The guidelines also noted a very strong linkage between environmental sustainability and economic feasibility for proposed ASR sites. For example (Figure 6) a flow chart to assist potential ASR operators determine economic viability, shows the impacts on treatment costs of an inability to meet environmental objectives. Operations that are marginally economic may be unable to meet the required costs of monitoring, and the level of operational management may be compromised. It is important therefore that the ASR facility is economically viable, taking account of monitoring costs.

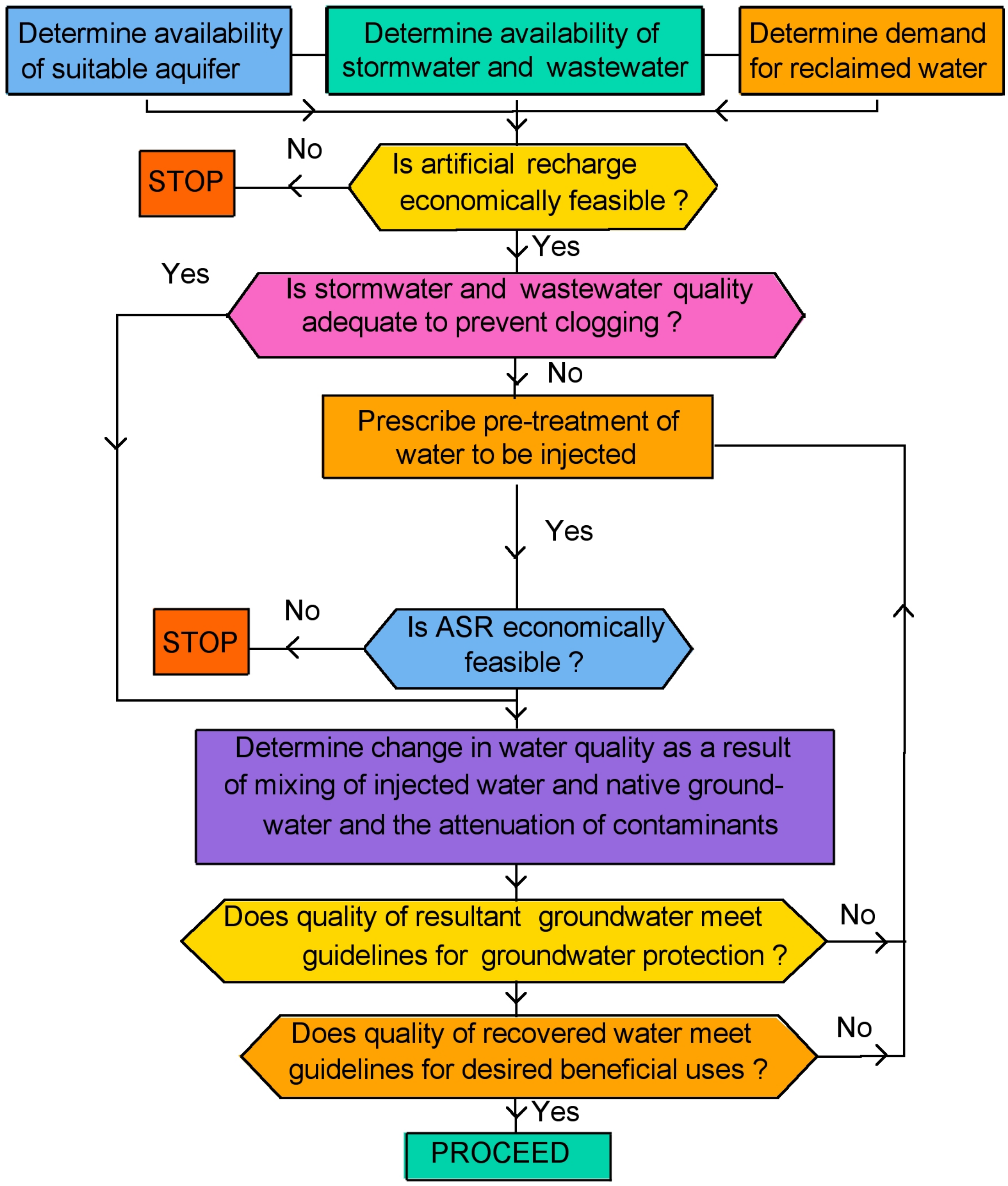


Figure 6. Flow chart showing the feasibility of artificial recharge with stormwater and reclaimed water (from Dillon and Pavelic, 1996)

7.2. Draft SA guidelines for stormwater ASR

With the impending commencement of the SA Environmental Protection Policy (Water Quality) it became clear that the 1996 ASR guidelines did not cover the range of issues in the broader catchment management context that need to be considered in issuing licences for ASR operations. For example, competing uses of stormwater and environmental flows within a catchment were not addressed. Furthermore, impacts of upstream developments on surface water quality and quantity could also have an impact on the viability of an approved ASR project, and the potential constraints an ASR operation may impose on such developments needed to be addressed.

It was also suggested that there was a need to move towards a code of practice for ASR operators, which, if adhered to, would indemnify operators from prosecution under the Environment Protection Act. Concurrently, there was a view that the state should set objectives and leave it to operators to determine how to achieve these. A consensus was reached among members of the SA Artificial Recharge Coordinating Committee, that the state should also provide advisory information, which if followed ought to lead to a satisfactory outcome. Operators would, however, be at liberty to use other methods, which would be just as acceptable if they achieved the required outcome.

Drafting of this guideline/code of practice commenced in October 1998 and at October 1999 agreement was reached on the technical content of the document. This covered the guiding principles to achieve best practice, a discussion of the factors that affect the success of ASR projects, and some examples of successful ASR operations. The latest draft of the guidelines (draft 6) was produced in April 2000 (Dillon et al, 2000).

However, the guidelines/codes of practice were also to contain advice on the approvals and permits required as part of the ASR establishment process. This component of the report became entangled and was still unresolved in August 2001. The reasons for this are set out below.

However at a meeting called by the EPA on 25 June 2001, it was agreed to split the new guidelines into two separate documents. The technical component is to be produced as a stand-alone guideline that will not reference administrative procedures. This can then be used as a national (or international) reference and be subject to national peer review prior to release. The second document will outline the licenses required and the procedures and sequence through which they may be currently acquired in South Australia. This document will reference the technical document, but not repeat its content.

The complexity of the licensing of an ASR project stems from the fact that ASR, while included within the State Water Plan (Department for Water Resources, 2000) as having a significant contribution to the development and more efficient use of state water resources, is subject to three pieces of legislation:

- The Environment Protection Act 1993, which is concerned with the quality of water stored and recovered ,
- The Water Resources Act 1997 , which controls the construction of wells throughout South Australia and the recovery component in prescribed areas ,
- The Development Act , which may require approval before the Environmental Protection Authority (EPA) can issue a licence and may require local government approval for some components of an ASR scheme eg, storage dams with a wall height in excess of 3m.

The licensing conditions are related to the components of the ASR scheme, the size of the scheme, and it's location. The approval process and licence conditions are detailed in Appendix A of Dillon *et al* (2000), and are in essence:

- a well construction permit is required for all wells (Water Resources Act);

- any water-affecting activity within a catchment water management board boundary will require permitting from that board (Water Resources Act);
- EPA licensing is required for discharge to aquifers from areas greater than 1Ha in the city of Mt Gambier and in the Adelaide metropolitan area (Environment Protection Act 1993, Section 4 (2) of schedule 1 and Section 36);

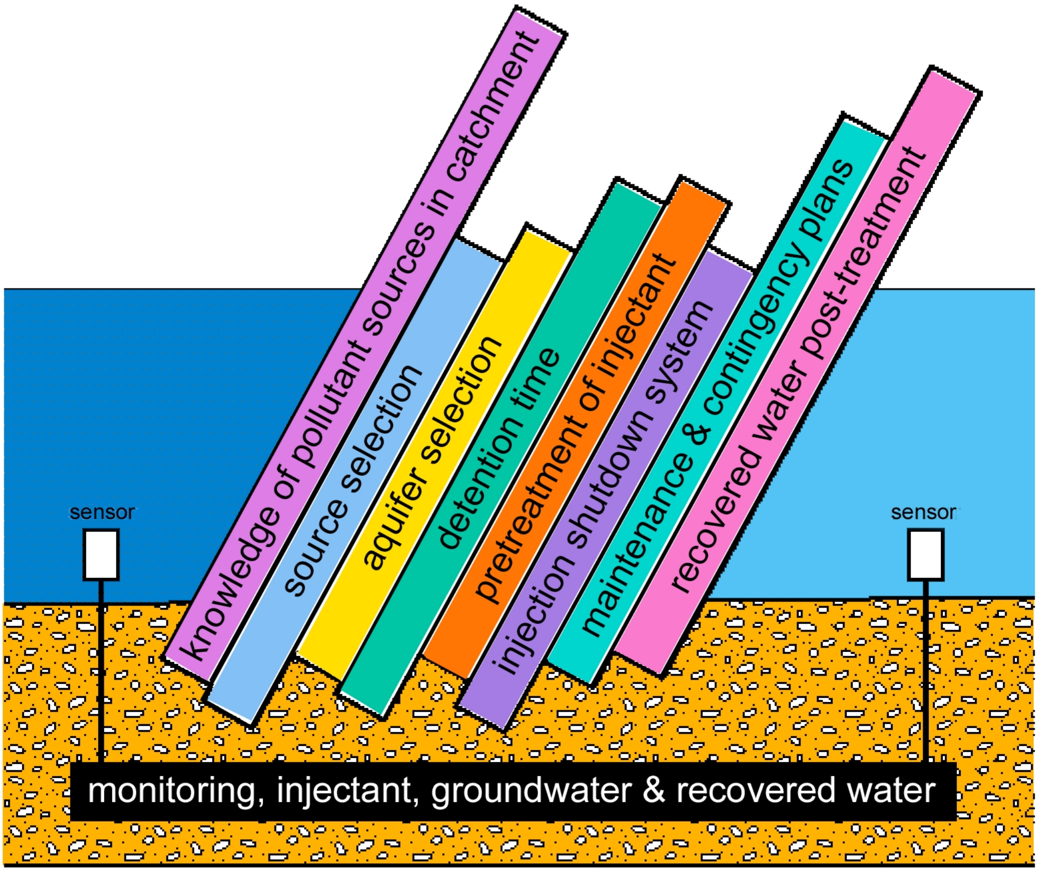
The EPA may issue an interim ASR licence, which allows the proponent an opportunity to demonstrate effective ASR operational skills. On satisfactory completion of all conditions by the proponent, the EPA may grant a full licence, to which will be attached operational and reporting requirements. An example demonstration licence is given in Appendix 2 of Dillon and Pavelic (1996). Development approval is however required before the EPA can issue this Licence (Development Act).

- In prescribed well areas, a licence to take water is required (Water Resources Act)

Currently it is difficult to provide a “one stop shop,” given the need in some instances, to seek approvals under three different pieces of legislation. DWR has an ASR licence application form on its web page, and has produced several brochures to explain ASR and assist potential proponents to consider the factors that could affect viability before submitting applications.

The 2000 draft guidelines refer to ASR operations using stormwater at a scale larger than household level. This leaves two major gaps:- 1) Domestic stormwater ASR which brings a range of issues discussed at length in section 6.3 of this report, and 2) ASR with reclaimed water. This is currently in the research phase and it is considered premature to attempt to make enduring statements on requirements for such ASR operations.

As an example of the advances in the concepts and practice of groundwater quality protection at ASR sites, Figures 6 and 7 show how multiple barriers can be incorporated in the design and operation to improve confidence in effective operation.



Multiple barriers to protect groundwater and recovered water at ASR projects

Figure 7. Multiple barriers to protect groundwater and recovered water at ASR projects (after Dillon *et al*, 2000)

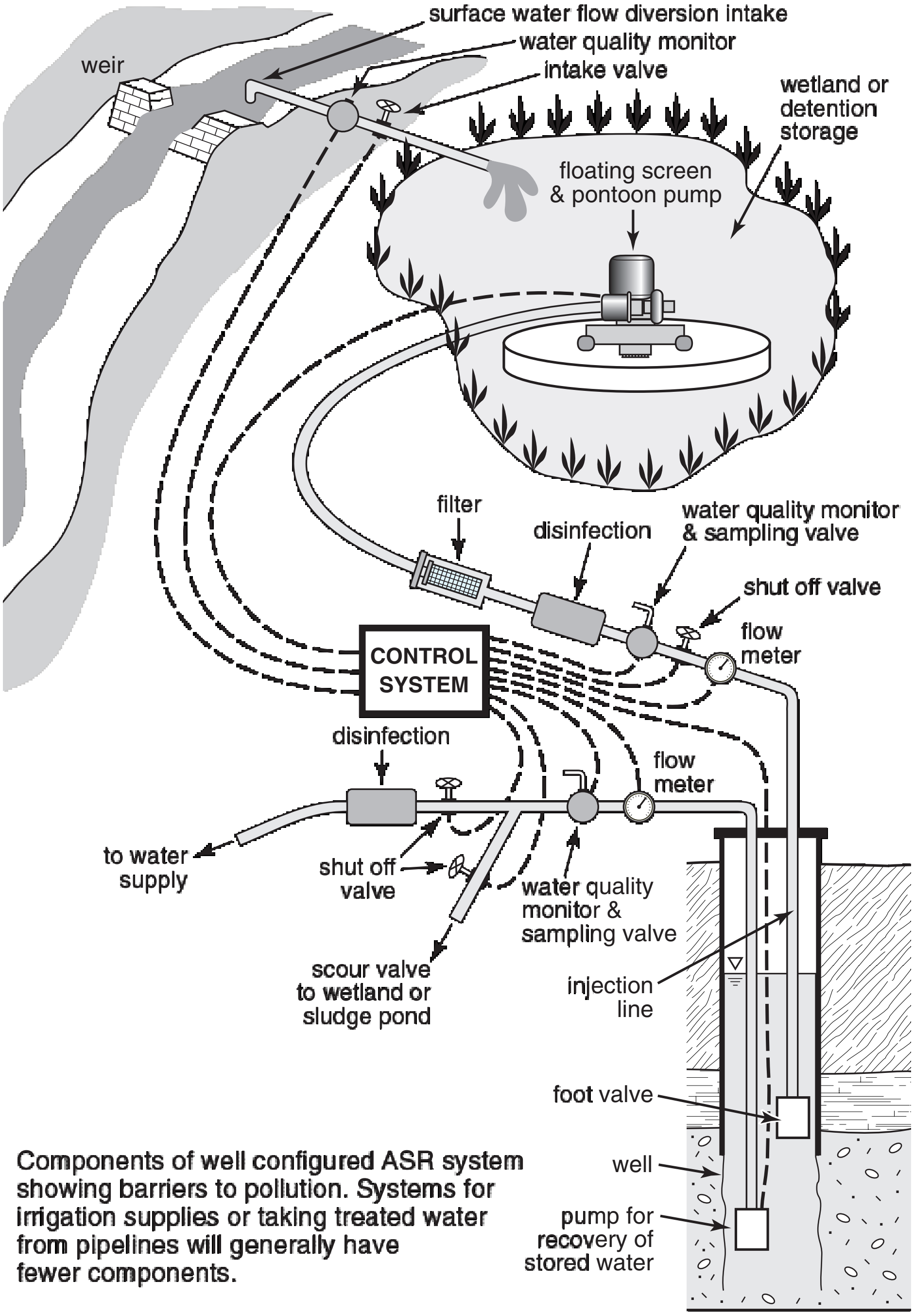


Figure 8. Components of a well-configured ASR system showing barriers to pollution (after Dillon *et al* 2000)

7.3. Proposed SA guidelines for domestic scale stormwater ASR in unconfined or semi-confined aquifers

Draft guidelines for domestic-scale stormwater ASR are currently under consideration by the SA Artificial Recharge Coordinating Committee.

The benefits of stormwater ASR at domestic scale include; more efficient water management (it is easier to deal with stormwater at its source than downstream); potentially high quality injectant if only roof runoff and rainwater tank overflow is used; use of an otherwise wasted resource; reduced demand on mains water supplies; slightly reduced urban runoff into the sea or receiving waters; and, in some cases, potential for reduced domestic water costs. In general, recharge and recovery of small volumes of water are economic only if capital costs are very low. At domestic scale, this will restrict the depth and types of wells and the types of treatments that can be provided. It will also restrict monitoring costs. Expert management cannot be assumed and provision needs to be made for ownership succession.

As the economic attractiveness of ASR is scale-dependent, it is likely that large users of water will be first to want to do ASR and in many cases the amount of their roof runoff will be less than the volume of water they wish to recover (Dillon, 1996). While ASR would reduce net withdrawals from the aquifer, this form of operation is not encouraged, as groundwater would then become a resource available only to those who could afford to subsidise high water usage.

In sandy locations such as on the LeFevre Peninsula dune (west of Adelaide), tube wells can be jetted in inexpensively and here there should also be an attempt to balance groundwater discharge with recharge to avert the threat of saline intrusion if aquifer water levels decline (Martin, 1996). On the highly permeable sands of the Swan Coastal Plain, roof stormwater down-pipes are directed into sumps that allow water to percolate to the aquifer, and garden water is recovered through separate wells.

Higher groundwater levels could cause havoc. They could increase the entry of saline groundwater to sewers: cause salt damp, movement and cracking in houses; damage to roads and pavements; salinisation and damage to water-sensitive vegetation; and submergence of underground utility services. Conversely, if the groundwater levels were dropped by a recharge/discharge imbalance, the results could include a reduction or cessation of base flows in urban streams; reduce yields of wells; also cause settlement of building footings; and may, in coastal areas induce salt water intrusion. ASR also increases opportunities for the shallow aquifer to become polluted and increases the possibility of human contact with polluted groundwater.

Given that there are limitations on the investment in failsafe control systems to prevent these potentially significant problems, it is necessary to have a guide for ASR in shallow systems that are practical and robust. Good design can reduce the amount of management required by ASR well owners, but this cannot be limited entirely, and all proponents of ASR wells will need to be aware of their ongoing responsibilities if ASR is to produce benefits with no adverse side effects. Hence there will be a need for education programs for ASR well owners.

Principles and practices that will lead to sustainable operations and that are embodied in the draft guidelines

It is recommended that ASR in shallow aquifers not be undertaken in locations where water tables are already shallow (less than 5m), in areas where saline groundwater ingress to sewers occurs, where water tables could rise to within 5m of the soil surface as a result of ASR, where expansive clay soils occur, or where other structures such as cellars or basements could be adversely impacted by rising water tables. For the Adelaide metropolitan area, maps of depth to water table, salinity, yield and hydraulic gradient are shown in Pavelic et al (1992), and sewer invert levels in relation to groundwater levels are shown in Bramley et al (2000). All Australian cities are included in state groundwater databases where similar information is available.

The water recharged should only be at the highest possible quality and equivalent to roof runoff after first flush bypass. This would be provided by overflow from a rainwater tank, and it should be filtered to prevent entry of leaves, pine needles, and other gross contaminants into the well.

No runoff from paving should be admitted, unless this has first passed through a sand filter. (This will also help to avert clogging of the well.) If cars, motorbikes or other machines containing petrol, oil, or other hydrocarbons parked on a paved area which is part of the well's catchment, an oil-grease trap is required in addition to a sand filter.

An inventory should be made of other potential pollutants in the catchment for the well and strategies devised to ensure these are excluded from the well, or are treated and removed before water enters the well. Existing groundwater quality in the shallowest aquifer is summarised for three western suburbs in the Adelaide metropolitan area in Dillon et al (1995).

The aquifer pressure should at all times be below ground level. To achieve this, injection should be by gravity drainage into the well, rather than using a pressurised injection system, and there should be an overflow facility. This, for example, could be to a garden area, where excess water does not cause nuisance to neighbours, or an urban stormwater drainage system.

At least the uppermost 2 metres on the outside of the well casing should be cement grouted to prevent upward leakage outside the casing and waterlogging in the vicinity of the well.

The ASR scheme should include provision for measuring water entering the well and water discharged from the well, with a view to keeping these approximately in balance. Ideally, two water meters would be used, and annual records of recharge and discharge maintained.

In areas where groundwater levels are deep or falling, there may be a requirement to ensure that groundwater recharge exceeds extraction over a given period of several years.

Where groundwater is naturally saline, care will be needed that the salinity of recovered water is acceptable for irrigating salt-tolerant species, especially towards the end of summer. During the first few years of operation, withdrawal should be less than recharge to improve the salinity of subsequently recovered water.

The well should have provision for groundwater level measurements, such as a tube within the well through which a water level monitoring probe can pass. The owner should have access to a water level monitoring probe, and an electrical conductivity meter. He or she should be provided with hands-on training in how to use these.

Water level and salinity should be recorded at least each six months, at the end of winter (Sept/Oct) and the end of summer (March/April). Without meters, there should be at least an additional two water level measurements recorded annually in Dec/Jan and June/July.

If water tables rise or fall by more than two metres at the same time of year over a course of five years (when neither recharge or discharge is occurring), meters should be installed and bore owners should aim to increase either net discharge or net recharge respectively so as to re-establish a local groundwater balance.

The well needs to have a permanently equipped pump that can be activated intermittently in winter to purge suspended solids that accumulate in the well during injection. This water should be discharged to lawns or gardens and not be allowed to enter street stormwater drains or sewers.

Where a property containing an ASR well is sold, the new owner is to be alerted to the management requirements. If they are unwilling to adopt these, the well should be backfilled with bentonite pellets, or concrete, by an appropriately qualified contractor, the state government's well-licensing group notified, and stormwater diverted.

Where several neighbours combine to establish a single ASR well, a legal agreement needs to be in place setting out the obligations on each of the parties. It should cover costs of maintenance, supply of stormwater, maintenance of the well catchment, ownership of recovered water, the keeping of records, and the consequences of changes to property ownership.

It is recommended that catchment water management boards provide the first point of contact for landowners seeking to establish stormwater ASR wells or inheriting an ASR well through purchase of a property. The boards should provide brochures on design and operation of ASR projects; give advice on management of ASR systems; hold template agreements for joint ASR projects; lending and give training in water level and salinity monitoring equipment to landholders; provide access to DWR records on well depths, yields, groundwater levels and salinities in their catchment; and lists of contractors accredited to install and decommission ASR systems.

Successful implementation of any proposed scheme must involve consideration of:

- Site feasibility and conceptual design, including
  - water supply,
  - recharge water quality,
  - water demand,
  - hydrogeology,
  - recharge processes,
  - site characterisation.
- Regulatory and water rights issues
- Impacts on existing users
- Institutional constraints
- Economic considerations
- Legal and regulatory issues
- Environmental impacts

Implementation of ASR must be undertaken in a coordinated and integrated manner involving:

- Regulators
- Planners
- Practitioners
- Politicians and
- The community

8. POTENTIAL ISSUES AND OPPORTUNITIES

8.1. Domestic scale rainwater/stormwater ASR

A major issue arising from what has been outlined previously, is that the proposed management requirements are strict, and enforcement is possibly unrealistic. The costs of enforcement would possibly exceed the benefits to SA of the total volume of water savings, unless this can be streamlined or outsourced. It's a case of weighing up the risks and benefits.

A minority of enlightened citizens, in locations where domestic stormwater ASR is viable and with good intentions that would be backed up by good practice, could find the above guidelines too restrictive or onerous to contemplate establishing a project. In essence such guidelines could inhibit what, in some cases, would be best practice in water management. However the damage that could be caused by inappropriate operations may be many times the water benefits achieved.

It is recommended that demonstration and research domestic ASR sites need to be established and monitored to indicate impacts on groundwater levels and quality, and effects on the environment and structures. These sites would also demonstrate achievable volumes of recharge and facilitate testing of robust control technologies.

8.2. Reclaimed water ASR

While it is premature to provide guidelines on ASR with reclaimed water, early indications suggest that the management regime required for sustainable operation will require operators to have expertise in water quality management. This, in turn, suggests that water utilities rather than individuals like irrigators would be the most likely holders of ASR licences.

Further information from the Bolivar and Willunga projects will be available in 2002 to enable clearer guidance for operations in limestone aquifers.

8.3. Licensing of new ASR projects

There is an urgent need to coordinate licensing of new ASR projects. Currently this is a time-consuming, tortuous, and not necessarily thorough process. It is recommended that a one-stop shop be established and the communication channels between departments, catchment water management boards and local government be streamlined so that applications can make use of appropriate technical expertise and local knowledge and be processed expeditiously. It would be helpful to have a single agency with the responsibility to lead and coordinate, and as a conspicuous point of contact for the community. DWR is the only department with the appropriate experience to do this, but needs to be given the mandate by all other organisations.

8.4. Monitoring and reporting of existing projects

Feedback on existing projects is currently uncoordinated and generally deficient. There is no follow up process to chase monitoring reports nor to evaluate these and modify the terms of licences. It is recommended that this be made a responsibility of the coordinator of the licensing body, with a view to feeding this information back into the licensing process. Information provided by proponents should be tabulated as public data and accessible to researchers in a convenient form - possibly as a web site. This would be of national and international interest. Furthermore annual or biennial reports should be produced to summarise developments over the first six to eight years at least, in order to report state-wide statistics and to draw conclusions on issues that may affect sustainability of ASR operations and the achievement of licensing objectives.

8.5. Accreditation of ASR installers and operators

Recognising that a wide range of skills are required for planning, designing, constructing, commissioning and operating a successful ASR project, it is suggested that consideration be given to the accreditation of ASR installers and operators. This could recognise attendance at accredited training programs, such as those offered by Centre for Groundwater Studies (with staff of DWR, CSIRO and Flinders University), and be reinforced by audits on the performance and compliance of projects with respect to the guidelines.

8.6. Maintenance of Government technical expertise in ASR

There will be an ongoing need for maintenance of ASR technical expertise in government, in order to overview ASR licensing and to assist with trouble-shooting when problems occur. It is therefore appropriate for DWR to play a role in future ASR projects of a novel nature, - including those in different aquifer types or using different water types. An ongoing role for DWR in partnership with CSIRO in the operation of innovative ASR projects, is recommended. This can also be justified in terms of widening the scope of projects that could be approved, thereby progressing opportunities identified in the State Water Plan and under the Integrated Water Strategy.

8.7. Mapping of ASR potential

Apart from the Adelaide metropolitan area, there has been limited mapping of areas in this State that are potentially suitable for ASR (Gerges, 1996-Tertiary; Pavelic *et al* 1992- upper Quaternary). Priorities deduced from the State Water Plan and this report can indicate the most prospective areas for the augmentation of water resources. The preparation of strip maps along regional supply pipelines, together with maps of water-short areas near towns, mines and irrigation areas, would allow a strategic approach to be developed for investments in schemes aimed at enhancing emergency water resources and drought proofing water supplies across the State.

8.8. Energy and water

As the cost of energy increases the price of water, it will be important to assess the energy efficiency of ASR projects from a Greenhouse Gas perspective, and to ensure that proponents take this into account in their plans and designs.

There is also the prospect of geothermal energy being tapped by ASR-type projects, for example for space heating and cooling in large buildings with heat exchangers. Consideration will need to be given to conjunctive management of aquifers for energy and water. This may require overlaying geothermal information in future mapping exercises where ASR water storage opportunities require assessment, particularly in cities and towns, and near intensive livestock industries.

8.9. Storage capacity evaluation

As yet the storage capacities of aquifers in the Adelaide metropolitan area are still unknown. Ultimately, as stormwater harvesting becomes more efficient and reclaimed water ASR becomes established, ASR will no longer be limited by the available surface water source but will instead be capped by the storage capacity of the aquifer system. Projects will then compete for the remaining capacity. Decisions will be required in allocating parts of aquifers for the storage of different qualities of water, such as mains-quality water (for emergency potable supplies), stormwater and reclaimed water. The costs and value of each of these, and the degree to which these are mutually exclusive, or sequential uses, have yet to be determined. Hence it is recommended that, from a strategic perspective, an evaluation of storage capacity for ASR systems in the aquifers in the St Vincent Basin is warranted.

8.10. Aquifer rehabilitation

Ultimately ASR involving stormwater can flush brackish urban aquifers and present the opportunity to upgrade the beneficial use status of those aquifers. While it is not proposed that water recovered from an injection well would meet potable standards, it is highly likely that groundwater drawn from separate recovery wells could be potable. Such value-adding may be substantial and could result in the development of strategies for flushing extensive contiguous segments within aquifers. It is therefore recommended that additional research be undertaken involving several stormwater ASR sites, to assess the potability of groundwater with respect to the distribution of salinity and stormwater contaminants in the region around the ASR sites. This would be done with a view to developing an aquifer rehabilitation strategy. It is anticipated that the value of a potable supply will be at least double the value of an irrigation supply, and will expand options for water management in SA.

8.11. Communications

ASR has been the cause of a continuous stream of visitors to South Australia. Already there have been two national short courses on ASR in Adelaide, in October 1996 and October 1999. The 4th International Symposium on Artificial Recharge will be held in Adelaide 22-26 September 2002, and was secured largely on the basis of the innovative and scientifically-founded ASR undertaken in and near Adelaide. Co-located with this will be a UNESCO/IAEA short course on uses of isotopes to evaluate recharge enhancement in arid and semi arid areas. (20-21Sept 2002). ISAR4 will also provide the 3rd meeting of IAH-MAR the International Association of Hydrogeologists Working Group on Management of Aquifer Recharge (soon to become a Commission). There will also be a meeting of the AWWARF project group that is based in four countries. These present opportunities to consolidate and convey Australian research findings, to demonstrate our experience, and to share these in a national and international audience. It also gives us exposure to the developments occurring overseas, for example a new 200 ML/day recharge enhancement project in California, the advances in bank filtration being made in Europe, and to learn from the cream of international researchers on subsurface processes affecting the utility of recharge enhancement. Allocation of some staff time to preparing communication materials would reap instant rewards and save staff time later in dealing with enquiries that the conference is bound to generate.

With these materials and some training of multi-lingual staff of local eco-tourism bureaux, the stream of future visitors could generate tourism revenue, create kudos for the state and have minimal impact on DWR staff time.

9. RECOMMENDATIONS

9.1. Licensing procedures to be streamlined

It is recommended that a streamlined ASR approval process be established with a single point of contact and that there be close coordination between departments, boards and councils involved in decision making.

It is further recommended that the Department for Water Resources takes responsibility for this coordination.

9.2. Monitoring and reporting of ASR projects

It is recommended that the Department for Water Resources establish a public data base, ideally on the web, for receipt of (annual) monitoring reports in accordance with licence conditions. The Department is to be responsible for evaluating reports, and consequently for recommending changes to licence conditions, and the accreditation status of installers and operators of ASR sites.

9.3. Accreditation of ASR installers and operators

It is recommended that the Department establish an accreditation program for ASR installers and operators, based on attendance at training programs and on feedback from monitoring sites established or operated by them.

9.4. Mapping ASR potential in SA

It is recommended that the Department for Water Resources performs a technical and economic evaluation of the potential for ASR across the state, in accordance with needs for increased supplies, improved quality of water and increased security of supply. This work should be done in sufficient detail to produce a list of potential projects to assist regional development initiatives. The potential projects are to clearly indicate expected benefits and costs.

9.5. Continued public sector investment in innovation in ASR pilot projects

It is recommended that further investigations be undertaken in a number of key strategic areas of ASR. These investigations should include determining the ASR storage capacity for the Adelaide metropolitan area, developing aquifer rehabilitation strategies, establishing demonstration projects for domestic scale stormwater ASR, continuing the development of reclaimed water ASR, advancing mains water ASR where appropriate, evaluating opportunities for use of aquifers for energy and water (conjunctively), extending the types of aquifers (to unconsolidated sedimentary systems), wells (screened wells with jets in gravel packs), waters (various pre-treatments and mains water), and applications (saline intrusion barriers, land subsidence mitigation, wetland protection).

It is recommended that further research necessary to underpin policies that lead to continuous improvement in ASR practices be undertaken. It is recommended that such research interfaces with integrated water management research and embraces the novel aspects of innovative projects.

9.6. Guidelines

It is recommended that technical and administrative guidelines for ASR with stormwater be finalised as soon as possible and that the technical guidelines are submitted to national and international review with a view to standardising Australian practice. Further guidelines on reclaimed water ASR and domestic scale ASR should be prepared as soon as adequate information is available.

9.7. Education

It is recommended that an education program be established (web page, brochures, training events, open days) for ASR owners and operators and for CMWB's and local government on domestic rainwater, large scale stormwater, and reclaimed water projects. The Department may also consider contributing to eco-tours of ASR projects and other innovative water management projects in SA involving schools and community, national and international delegations. These may also serve as marketing opportunities for SA expertise in water management.

10. CONCLUSIONS

ASR is practiced in many countries throughout the world and generally to address issues associated with potable water supplies. Consequently, the water that is stored in the aquifer systems is treated to potable standards before injection. As reduced quality places more pressure on Adelaide's traditional water supply sources such as the River Murray and the Mount Lofty Ranges, one of the risks faced in continuing to inject low quality waters into our existing aquifers is that it limits future opportunities to use groundwater as a least cost option to augment existing potable water supplies.

South Australians are becoming increasingly aware of the need to conserve and reuse our available water resources more effectively in order to maintain a balance between environmental needs, social well being and economic needs.

In South Australia, an increasing amount of stress is being placed on surface and groundwater resources by expanding urban populations, and expanding irrigated horticultural areas. The impacts of this demand on groundwater are showing in the long-term downward trends of water levels in major aquifers and the decrease in groundwater quality. ASR has the potential to capture largely unused surface water resources, including urban stormwater runoff, and relieve the pressure on groundwater resources. There is little doubt now that the conjunctive use of surface and underground water resources is critical to the optimal development of rural and urban populations. In many cases, serious consideration is being given to the need to reuse our available water resources more than once before summarily treating and discharging them into the coastal marine waters. In the broader sense, the opportunity exists to use ASR to rethink our traditional water management and distribution policies, and to provide cost-effective and innovative alternatives to current methods.

The current state of groundwater recharge enhancement in South Australia has been presented together with a series of issues and recommendations, which provide a basis through which to:

- protect and enhance our water resources, and thereby fulfil the State Water Plan,
- streamline and better integrate water administrative procedures,
- appropriately monitor and report on existing and new ASR operations,
- encourage appropriate investment in innovative water management,
- map the potential for ASR in places where it has most strategic potential,
- evaluate the storage capacity of Adelaide's aquifers for ASR,
- ensure technical competencies are retained in state government,
- enable the range of aquifers and water types used for ASR to expand according to need,
- facilitate continuous improvement of ASR technology, where SA is currently a world leader,
- encourage the industry forwards with an accreditation program and,
- capitalise on the leadership developed in SA for national and international markets.

11. ACKNOWLEDGEMENTS

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