CASE STUDY:

RECYCLING OF SURFACE WATER IN ADELAIDE AND NORTHERN ADELAIDE PLAINS

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by
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INTRODUCTION

South Australia is known as the driest state in the driest continent, and the lack of water is a constraint to state development. Traditionally most of the water supply is piped directly from the River Murray or from groundwater resources.

It is estimated that 390,000 ML of storm water/effluent is generated in South Australia annually. Most is discharged, less than 5% being reused. In recent times attitudes have changed and the resource potential of this water is being recognised, particularly in situations where a potable standard is not required.

The combined stormwater discharge of the Adelaide metropolitan area exceeds 60 gigalitre per annum, and when compared to the dependency on the River Murray (average of 80 gigalitres/annum), there is considerable opportunity for the conjunctive use of stormwater, through Aquifer Storage and Recovery technology (ASR), to relieve the demand for imported water.

ASR has been conducted extensively throughout the world including Australia, where ASR practice is mainly restricted to surface spreading basin recharge to unconfined aquifers.

South Australia currently leads the nation in experimenting and implementing a policy of reuse, especially for irrigation. This involves aquifer storage and recovery (ASR), a management tool which enables conjunctive surface water and groundwater resource management as an alternative to the traditional methods such as licensing and quota restrictions.

The research and development which has been underway in South Australia over the past few years has been unique in that it has focussed on the injection, storage and recovery of storm water and treated domestic water into shallow unconfined and deep confined aquifer systems. Different aquifer environments have been targeted including fractured rock, Tertiary limestones and Quaternary sands.

WHAT IS AQUIFER STORAGE AND RECOVERY (ASR).

ASR is a modification of natural processes which have been occurring for millions of years.

Artificial recharge is achieved by injection of surface water, by gravity or pump, through a purpose-built well, directly into the aquifer, where it is stored for later re-use. Aquifers can store large quantities of water without losses from evaporation and with reduced risk of contamination, both of which are problems associated with surface storage systems, such as reservoirs.

Surface water is often of lower salinity than the native groundwater and, when placed in an aquifer, forms a lens or “bubble” of fresh water around the injection well Because lateral movement of groundwater is low, and generally only in the order of a few metres per year, the “bubble” will generally be retained around the injection well. Aquifers therefore generally provide a stable and predictable environment for storage.

ASR OBJECTIVES IN SOUTH AUSTRALIA

- Developing aquifer storage and recovery technology for use in South Australia and identifying where this technique can be used to enhance the States’ water resources.
- Development of a key future water resource management tool which will help maintain groundwater systems for current and future development.
- Reducing the reliance of urban users on imported (River Murray) water and the associated high infrastructure costs related to storage and distribution. Also to reduce the usage of mains water which is treated to drinking water standards for irrigation.

- Reducing costs of flood mitigation infrastructure and the outflow of storm waters to the marine environment.
- Reducing the high infrastructure costs associated with mains water supply, especially to country towns, and the development of economically viable alternatives where traditional water supply is impractical or unavailable.
- Using aquifers as a water treatment medium.

ASR BENEFITS

There are many benefits from the use of ASR as a water management tool. The main benefits relate to improved water management such as:

- Restoring groundwater levels and pressures
- Improving groundwater quality
- Storing and treating potable water
- Preventing salt water intrusion
- Increasing groundwater allocations.
- Controlling contaminant plumes
- Reducing subsidence caused by extensive extraction.
- Restoration of aquifer pressure regionally (eg. Northern Adelaide Plains): Injection into elastic storage of an aquifer results in instantaneous pressure transmittal regionally (eg. Angas – Bremer irrigation area)
- Protection of low salinity aquifers from saline groundwater / sea water intrusion (eg. California)
- Reduction in the salinity of native groundwater where traditionally the groundwater has been unsuitable for irrigation (eg. Andrews Farm urban development)
- Creation of low salinity lenses / bubbles within saline aquifers for town water supply (eg. Clayton)]
- Reducing high infrastructure costs associated with mains water supply, especially to country towns (eg. Clayton)
- Development of economically viable alternatives if traditional water supply or storage impractical / unavailable (eg. Clayton)
- Reduced cost of water storage / treatment to towns along major pipelines (eg. the Morgan – Whyalla pipeline)
- Reduced cost of flood mitigation infrastructure and reduced outflow to the marine environment (eg. Northfield irrigation of parks in an urban development) Reduction in the use of main water for recreation park irrigation (eg. The Paddocks, Scotch College)
- Storage of water underground to minimise evaporation and contamination (eg. NAP area).
- Development of water storage's where topography unfavourable for surface storage development (eg. Clayton town water supply)
- "Purification" of injected waters (eg. Clayton town water supply)
- Alternative to the limiting options of licensing / quota systems promoted by the managers (Northern Plain Area).

METHODS OF ASR

- **Spreading Basins**
- **Trenches**
- **Deep Well Injection**
- **Inter Aquifer Flow Via Deep Wells**

Spreading Basins

Advantages

- Infiltration to shallow unconfined and dry aquifers
- The basin acts as a wetland, water is purified in the unsaturated zone
- Unsaturated zone will act as a filter for bacteria and viruses as water infiltrates
- Clogging issue is easy to deal with by removing silt from the bottom of the basin
- Passive system, energy requirements are minimal, no pumps are required for injection.

Disadvantages

- Not suitable for confined aquifers
- Infiltrated water forms a thin layer or lens which may be difficult to recover from
- If the native groundwater is very saline upconing may be a problem during recovery
- Environmental issues, eg. Holland
- Potential for land salinisation
- Susceptible to high evaporation and evapotranspiration
- Requires commitment of large areas of land which may have a high cost
- Must be built into the existing topography, otherwise excavation costs will be prohibitive
- Infiltration relies on vertical hydraulic conductivity which is probably several fold less than the horizontal hydraulic use by the injection well
- The practical driving head in the basis is very much less than those in injections well and cannot be manipulated.

Trenches

Similar to spreading basins.

Advantages

- Require less land and useful in urban areas if can be sited so will not affect foundations
- Can harvest, "purify" and store water if gravel filled (eg. Brompton)
- Provide easy access to shallow unconfined aquifers.

Disadvantages

- Require a stable formation to prevent collapse of the trench
- Foundation problems if located near buildings.

Deep Well Injection

Deep well injection involves drilling and completing wells into either shallow unconfined or deep confined aquifers. Some recorded injection wells reach depths of hundreds of metres. Generally in South Australia, it is expected that wells would not exceed a depth of 200m.

Advantages

- Injection into unconfined aquifers which may underlay an impermeable layer (do not confuse with confined aquifer)
- Direct injection into deep confined aquifers bypassing the confining bed
- Can inject mine dewatering water into a deep aquifer
- Line of injection wells can create hydraulic barrier against saline groundwater / seawater intrusion (eg. California)
- Can inject water which has been harvested at a distant site
- The driving head can be readily manipulated

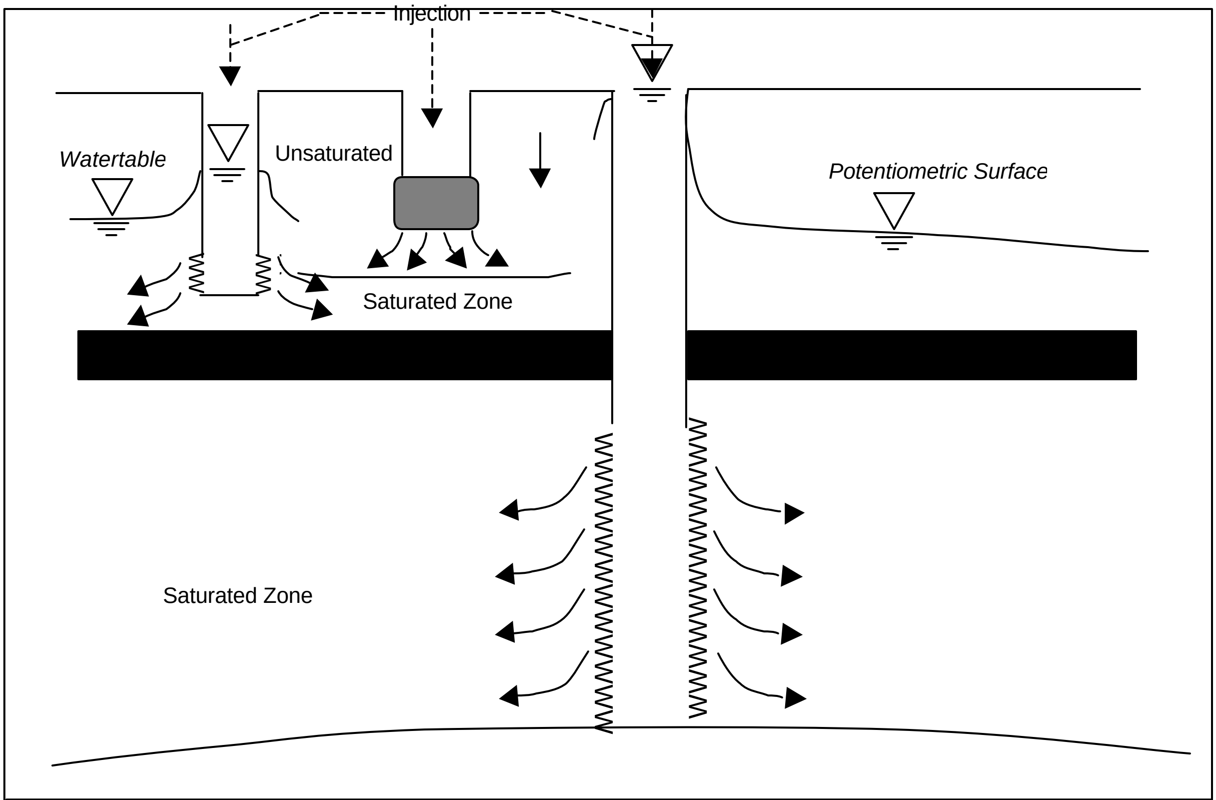
- Allows the rapid injection of a large volume of water in a short period of time utilising minimal surface area.

Disadvantages
- Clogging is the most severe problem encountered caused by suspended solids, gasses, temperature etc.
- May require a wetland / detention basin if stormwater to be injected.

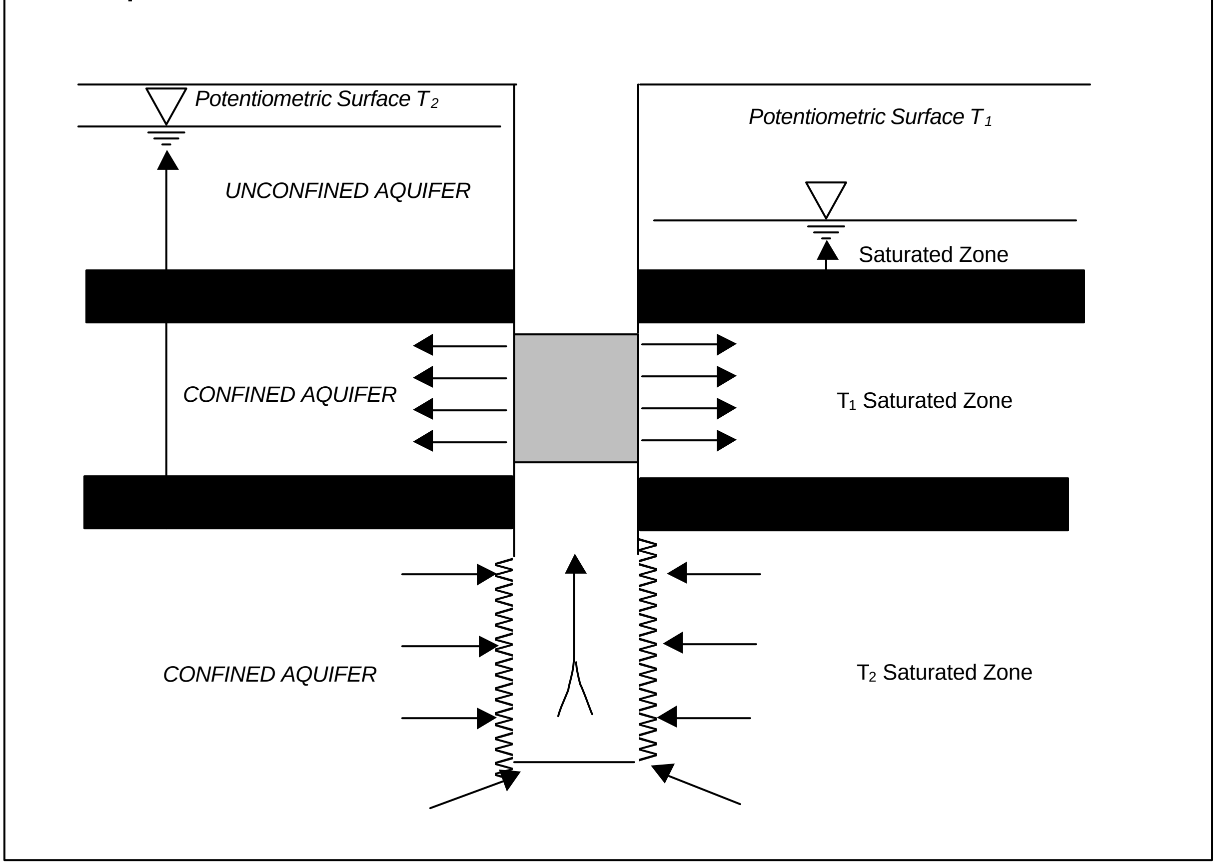
SOUTH AUSTRALIA INVOLVEMENT WITH TECHNOLOGY AND PRACTICES

- Developing a matrix for analysing and demonstrating the potential for ASR (eg Northern Adelaide Plains). As a result an extensive series of plans have been produced.
- Developing different types of well construction to maximise injection efficiency in the Northern Adelaide Plains. Wells using different well construction have been completed at the ASR sites at Andrews Farm, Greenfields, The Paddocks, and the Strathalbyn site.
- Developing techniques to maximise the potential for injecting into low permeability aquifers.
- Introducing acidisation to increasing well efficiency, this technique was used at The Paddocks ASR site.
- Implementing the vacuuming methods, this technique was used at Andrews Farm and Glengowrie School.
- Advancing ideas on the use of large diameter wells for injection (South Parklands).
- Implementing an in-ground sandfilter to reduce suspended solids concentration of injecting waters (Greenfields).
- The development of the concept of taking treated effluent from Bolivar, injecting it underground at strategic locations, and using pressure transmittal to reduce the stress in aquifer from which most irrigation water is extracted in the Northern Adelaide Plains.
- The development of the concept to mine hyper-saline water from deep aquifer for salt production by Penrice Soda, this idea is now being trialed. At the conclusion of the mining operation, the aquifer can be used for ASR purpose,
- The development of the concept of injecting water from the Roxby Downs well field near Mound Springs (to guard against depleting the resource as a result of mining development and associated pumping) to reactivate the flow. The concept was discussed with to a consultant with the idea being taken up and subsequently implemented.
- South Australia pioneering the research and development of ASR technique particularly in the St Vincent basin acting on a vision for its future application. The complexity of ASR is illustrated by:
  - The uses of injection well techniques.
  - Injection in saline aquifers.
  - Injection into karst aquifers.
  - Injection into low permeability aquifers.
  - Increasing well efficiency by acidisation.
  - Defining and solving clogging mechanisms.
  - The ability of the aquifer to purify injected water.

Deep Well



Inter-aquifer



SUMMARY OF GEOLOGY AND HYDROGEOLOGY OF ADELAIDE METROPOLITAN AREA AND NORTHERN ADELAIDE PLAIN AREA

The Adelaide Embayment, is a section of the St Vincent Basin and underlain by a thick sequence of sedimentary deposits of Quaternary and Tertiary age, which in turn overlays Precambrian basement. It contains five to six Quaternary aquifers and also three to four, almost flat lying, Tertiary aquifers. The first and second Tertiary aquifers are the thickest and the most productive, with relatively low salinity. The greatest proportion of abstracted groundwater for industrial and recreational use comes from the first Tertiary aquifer.

Quaternary Aquifers

The main lithology of the Quaternary sediments is mottled clay and silt with interbedded sand, gravel and thin sandstone. The sands, gravels and sandstones represent aquifers. Up to six thin aquifer zones can be recognised over most of the region from drill log and geophysical log interpretation. These are designated Q1 to Q6 in order of increasing depth.
The majority of the Quaternary aquifers are thin and insignificant and are not usually used for commercial irrigation because of low yields and high salinities

Tertiary Aquifers

The Tertiary sediments contain several aquifer systems, each of which may comprise various sub-aquifers.

Groundwater occurs mainly in four, mostly confined aquifers, designated T1, T2, T3 and T4 in order of increasing depth.

The First Tertiary aquifer

The First Tertiary aquifer (T1 aquifer) generally lies 40-100 m below ground. This aquifer has a water salinity ranging between 600 to 3000 mg/L. Standing water level ranges between 12-20 m below ground. Supply averages 1500 m^3/day/well (17 l/s).

The aquifer consists mainly of two subaquifers: Hallett Cove Sandstone/Dry Creek Sand (Subaquifer T1A) and the Upper Port Willunga Limestone (subaquifer T1B).

The Second Tertiary Aquifer

The Second Tertiary aquifer lies at a depth of some 60 - 200 m below ground with salinity ranging between 600 to 4500 mg/L. Standing water level is varies between 2 and 60 m below ground.

The Third / Fourth Tertiary

The Third / Fourth Tertiary aquifer lies at approximately 500 m below ground and contains groundwater of high salinity (over 70,000 mg/L).

EXAMPLES OF ASR IN SOUTH AUSTRALIA

Currently, over 20 ASR projects are being developed in Adelaide Metropolitan area and Northern Adelaide Plain area with the intention in most cases of using stormwater for irrigation, and these includes:

- Andrews Farm - irrigation supply in confined limestone saline aquifer.

- Greenfields - irrigation supply in confined limestone saline aquifer.
- The Paddocks - irrigation supply in confined limestone saline aquifer.
- Regent Gardens - irrigation supply in confined fractured rock saline aquifer.
- Clayton Township - town water supply in unconfined limestone highly saline aquifer.
- Strathalbyn - town water supply in unconfined limestone saline aquifer.
- South Parklands - irrigation supply in complex confined aquifer.
- Morphettville Racecourse - irrigation supply in confined limestone saline aquifer.
- Heynes Nursery - irrigation supply in confined limestone saline aquifer.
- Salisbury development - irrigation supply in confined limestone saline aquifer.
- The Pines—irrigation supply in confined limestone aquifer.
- Northfield development—irrigation Fracture rock aquifer.
- Parafit Square housing state, irrigation supply unconfined aquifer.
- Brompton housing state irrigation supply unconfined Quaternary aquifer.
- Scotch College- Irrigation supply, unconfined fractured rock aquifer.
- Numerous research and development sites, such as Glengowrie, Marine Land. In addition. Responsible for conceptualising and initiating the injection of 10,000 ML/y [1]of treated effluent from Bolivar pipeline during winter in to the Limestone aquifer in NAP.
- Parafield air port ASR project capable of suppling 1000 ML/year.
- Cheltenham Racecourse ASR project.

Reuse of effluent on land is becoming a common way to reduce nutrient discharges to coastal and surface water bodies. However, storage of effluent is needed in the wet or winter season to protect both coastal or surface waters and groundwater from contamination and supply irrigation in the dry season. Surface water dams are normally expensive. If the effluent is given appropriate treatment a injection and extraction wells can be used to restore saline and brackish aquifers. This concept combines water that would otherwise be wasted with an unproductive aquifer to add value to both. In South Australia at a site near Bolivar, Adelaide's, a multi-disciplinary research project is underway to assess technical viability, environmental sustainability, and commercial/economic feasibility of ASR. The project team seeks to extend this work to other sites and expand the range of applications and scientific knowledge of aquifer processes.

SELECTED EXAMPLES OF ASR PROJECTS IN SOUTH AUSTRALIA

Among the numerous investigation sites the two most complex sites are at The Paddocks, Salisbury and Andrews Farm in the northern Adelaide Plains and at Clayton adjacent to Lake Alexandrina. All sites required investigation of a nature previously not undertaken by any other organisation in Australia. In particular the Clayton project is the first investigation of its kind on an international basis and the outcome of the work will have wide application in similar coastal aquifers throughout Australia. Other sites have been summarised for reference.

A). ANDREWS FARM

The Northern Adelaide Plains, a market gardening area, 40 km north of Adelaide is underlain by confined Tertiary limestone. Irrigators have depended entirely on groundwater from the second Tertiary aquifer over the last 25 years which has resulted in depletion of elastic storage and the development of a large cone of depression (75 m deep in the centre). Urbanisation of the surrounding area has resulted in increasing stormwater runoff. A trial project assessing the potential of the second Tertiary aquifer system to support ASR has been successful.

An injection well was drilled to a total depth of 180 m and three deep observation wells were drilled and completed in the second Tertiary aquifer. The injection well was completed open hole from 107 –

[1] 1L =1000 m^3 =1000,000 litres

125 m producing a yield of 20 L/s with a salinity of 2,200 mg/L and depth to water of 20 m below ground.

During testing the response of the injection well and the 25 m observation well were almost identical in time and magnitude indicating a high degree of connection between both wells. Inter-connection is believed to be due to the removal of sand from the naturally occurring limestone aquifer fractures as a result of well development.

Several gravity injection tests with storm water (salinity 250 - 350 mg/L) were conducted at rates of 20 L/s. Some clogging of the well and near aquifer material was observed but it is believed that major clogging due to aquatic microfauna can be avoided by filtering.

The work undertaken at this site indicates that this limestone aquifers are capable of storing and restraining (confirmed by monitoring movement of injected 260 ML over 3 years) the movement of injected waters while improving the salinity of the native groundwater locally.

B) GREENFIELDS

The Greenfields wetland site 10 km north of Adelaide was developed with the long-term goal of conjunctive wetland treatment/aquifer storage of storm water. DWR is investigating the potential for ASR using the confined first Tertiary aquifer.

An investigation/injection well was drilled to a depth of 148 m, cased to 102 m, and completed open hole through the shell bed and the limestone. A final standing water level of 14 m, an airlift yield of 9 L/s and a salinity of 2,050 mg/L were measured. Instability in the shell bed required airlift development to be carried out intermittently for several weeks during which 30 to 50 tonnes of sand and shells were removed from the well. A further injection well was drilled and completed with a screen from 102 - 111 m in the shell bed, and open hole from 120 - 145 m. Preliminary pressure injection testing at a rate of 13 L/s into the well completed with screen and open hole resulted in a head of 50 m. This well's inefficiency is believed to be due to development problems over the screened interval. The well-completed open hole only is expected to operate satisfactorily under gravity injection.

C) THE PADDOCKS

The Paddocks wetland site 10 km northeast of Adelaide was developed with the long term goal of conjunctive wetland treatment/aquifer storage of storm water]

An investigation/injection well was drilled and completed open hole from 134 - 164 m in a silty sandy green grey limestone. A final standing water level of 10 m, a salinity of 1,850 mg/L and an airlift yield of 10 L/s were recorded. The well was injection tested using both wetland and mains water. Data analysis indicated that with respect to the discharging well that injection with wetland water was 50% as efficient as discharge, and injection with mains water was 70% as efficient as discharge. It was apparent that there was a water compatibility problem at this site. Controlled acidisation was conducted using 5,000 L of acid. Hydraulic testing was then conducted indicating a 30% increase in efficiency.

D) CLAYTON

Clayton (80-km south east of Adelaide) draws its water supply from the River Murray, which in summer months is suffering pollution from toxic algal blooms. Work was carried out to investigate using ASR to develop a summer water supply of 20 ML. Water will be injected into the underlying aquifer during the winter months, when toxic algal counts are low, and this water extracted during the summer.

An investigation/injection well was drilled to a depth of 115 m, cased to 22 m and completed open hole within unconfined fossiliferous sandy limestone. A final SWL of 14 m, a salinity of 37,000 mg/L and an airlift yield of 25 L/s were recorded.

Injection testing indicated that the well was readily able to accept injection of lake water, but was 40% less efficient than when the well was discharging. It was apparent that there was a water compatibility problem, although this was not considered to be a problem at this site which may be capable of accepting up to 50 L/s without pressurising the well. A lens 10 m thick and with a salinity of 4,500 mg/L developed during the injection and mixed with ambient groundwater over a period of 105 days resulting in a salinity of 6,900 mg/L.

The results are encouraging considering the unconfined nature of the limestone, the high aquifer transmissivity and the high groundwater salinity. A volume of approximately 500 ML was gravity injected in early 1996 at a rate of 50 L/s, it is expected that a lens of drinking water quality can be developed. Information gathered from this site will have a wide application in similar coastal aquifers throughout Australia.

E) REGENT GARDENS

At Regent Gardens housing estate in Adelaide an ASR scheme was developed to reduce storm water outflow and provide an irrigation water supply for parklands. This scheme involves piping storm water to a wetland detention basin. After treatment it is gravity injected into a saline fractured rock aquifer. Water is then extracted during the summer for irrigation of the surrounding parks and gardens. This scheme became operational in 1994 during which 10 ML was injected, followed by 40 ML in 1995.

Hydrogeological investigations were conducted by drilling an 80 m investigation/injection well. The well was completed open hole in the confined fractured rock aquifer intersected at 44 m (slate). A highly fractured quartzite was intersected at 68 m. The native groundwater had a salinity of 2,700 mg/L, depth to water was 14 m. Several hydraulic tests and injection tests using mains water (salinity 360 mg/L at 22 L/s, total volume 5 ML) resulted in a transmissivity of 70 m^2/day, calculation of the yield as 24 L/s and the gravity drainage rate as 13 L/s. Following the injection of the small volume of 10 ML of storm water during 1994 some extraction occurred. During repeated pumping periods of 6 hours water quality initially started at values between 500 and 800 mg/L and rose to 1,000 - 1,100 mg/L. This trend suggested that low salinity water was initially being withdrawn from the major fracture system, and after some time additional water was being withdrawn from minor fractures and the primary porosity which yields more saline groundwater. This problem is expected to be reduced when much larger volumes of storm water are injected.

CONCLUSION

Although limited experience with ASR exists within Australia, South Australia has recently developed the expertise of aquifer injection in various hydrogeological environments. This has been demonstrated at various other sites. Experimental injection into the shallow coastal highly saline aquifers will have wide implication throughout Australia and possibly South - East Asia.

ASR has the potential to enhance the State’s water resources and relieve the pressure on traditional sources. 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 and stormwater management. In irrigation areas, surplus winter runoff can be harvested for summer re-use, and assist in reducing the stress on groundwater basins.

ASR has the greatest potential in those regions, which are approaching full development of the water resource, have degraded or low quality groundwater, and have a surplus of suitable quality alternative water resources, such as stormwater.

ASR offers opportunities for both government and the private sector to increase management options for greater use of the State's water resources.

The obvious application is temporary storage of stormwater, which would normally flow to waste. Other options could include the use of existing pipelines to take advantage of "off-peak" opportunities to store quality water at a re-use location. It can also enhance degraded aquifers and assist in improving or maintaining existing irrigation developments.

Research and development work undertaken in South Australia indicates that ASR will be a key conjunctive surface and groundwater resource management tool in the near future. Well construction is critical to the success of injection, in particular where water compatibility problems exist and clogging may occur. Wells completed in sedimentary aquifers are more susceptible to clogging than fractured rock aquifers. Controlled acidisation experiments in carbonate aquifers demonstrate the effectiveness of this method for enhancing well performance.

The results of using ASR in South Australia will be restoration of aquifer pressures, localised reduction in salinity of groundwater where traditionally groundwater was unsuitable for irrigation and the creation of low salinity lenses/bubbles within saline aquifers for town water supply. Consequently infrastructure costs associated with mains water supply will be reduced, in particular to country towns, and there will be less reliance on imported water.