Smart Water Fund

Developing Aquifer Storage and Recovery (ASR) Opportunities in Melbourne

Technical Guidance for ASR

March 2006

Prepared with the support of:

Smart Water Fund

CSIRO

City West Water
Melbourne Water
South East Water
Yarra Valley Water
Department of Sustainability and Environment

Our Water Our Future

Victoria The Place To Be

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CSIRO Land and Water Science Report 4/06

February 2006

ISSN 1833-4563

Foreword

This document provides technical guidance for aquifer storage and recovery (ASR), and is released as a Technical Report by the Victorian Government's Smart Water Fund. The Fund, which is encouraging innovation in water conservation and recycling to help secure the State's water future, recognises that ASR has a role to play in sustainable management of water resources and the environment.

Under Action 5.42 of the Victorian Government's Our Water Our Future White Paper, EPA Victoria, in partnership with the Department of Human Services is reviewing the public health and environmental framework supporting alternative urban water supplies. Subsequently White Paper Action 5.43 relates to the development of a suite of guidance for alternative water supplies including aquifer storage and recovery. Hence the technical guidance provided within this document is expected to assist in the development of a more formal code of practice.

It is intended that the guidance provided by this document is read by proponents of managed aquifer recharge projects, water utilities, consultants, catchment management authorities, and municipal councils and used to assist them to acquire the information necessary to develop project proposals or to consider the merit of such proposals. The technical guidance provided, covers a complex subject, and although it is intended to be a practical guide, it cannot cover all situations that may need to be considered at a specific site, and proponents are encouraged to seek professional advice.

Acknowledgements

This document was developed with the financial support of the Victorian Smart Water Fund and CSIRO's Water for a Healthy Country Flagship Program. Input was also provided through members of the project Steering Committee and other staff from the organisations represented on the committee. Specific acknowledgement of the following people is made for their edits and comments made to earlier drafts of this document: Michael Rehfisch, Wesley Douglass, Suzie Sarkis, Deborah Cownley, Richard Clarke, Terry Flynn and Declan Page.

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1. Introduction

1.1 Scope

The Technical Guidance specifically covers aquifer storage and recovery (ASR) and aquifer storage transfer and recovery (ASTR) with, stormwater, recycled water and groundwater (Figure 1). It does not address injection or infiltration of waters into aquifers for waste disposal. Most aspects of this Technical Guidance may be applied to other forms of recharge enhancement, that is those not involving wells, and proponents of projects should ensure that the most appropriate form of recharge enhancement is adopted (eg see Dillon, 2005). An ASR project which is well-sited, -designed and -managed will be very unlikely to pose an unacceptable risk to the environment.

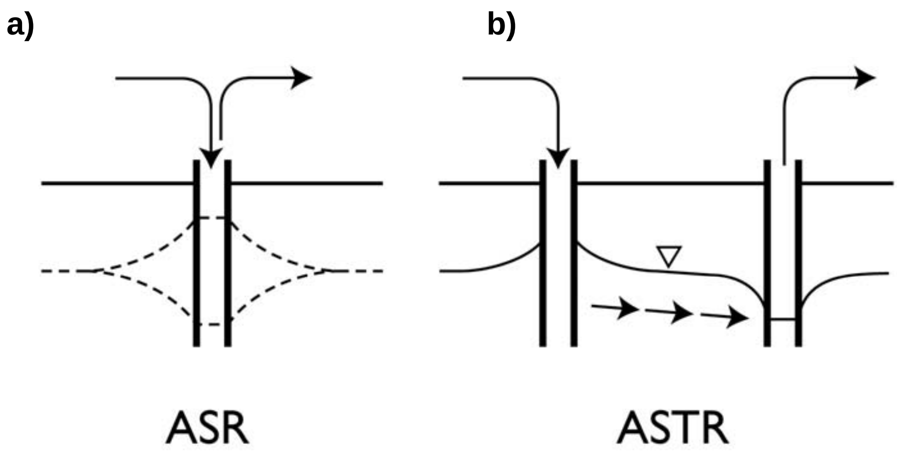

Figure 1. Cross-section diagram of ASR and ASTR (a) ASR by stormwater injection in winter, recovery in summer (b) ASTR where the recovered water has had a guaranteed residence time within the aquifer giving further water quality improvements

1.2 Objectives

This Technical Guidance has four objectives:

1. To ensure all new aquifer recharge enhancement projects protect public health, are environmentally sustainable, socially acceptable and the economics of required operation, maintenance, monitoring and reporting have been taken into account in establishing economic viability.
2. To foster innovation and enable improved practices while managing risks within an appropriate strategy to meet the first objective.
3. To facilitate an integrated framework for effective management that takes into account the resource management objectives of surface water systems, groundwater systems, water supplies, and planning, in order to create opportunities that otherwise would be foregone for developing and improving water resources.
4. To make use of aquifer recharge experience so that future projects will be sited, designed and operated in such a way as to maximise the benefit to the community of the aquifer system and the water available in the catchment for subsurface storage, while protecting or improving the environment.

Specific aims within the primary objective are to:

- Protect or improve groundwater quality wherever ASR and ASTR is practiced
- Ensure that the quality of recovered water is fit for its intended use
- Protect the aquifer and aquitard from being damaged by depletion or over-pressurisation
- Prevent problems such as clogging and excessive recovery of aquifer material
- Ensure that the impacts on surface waters, downstream of ASR and ASTR operations, are acceptable and are taken into account in catchment water management
- Ensure that an appropriate public and environmental health risk assessment and management strategy is in place to deal with potential variations in water quality of injectant
- Ensure that appropriate investigations are performed to site, design and operate the project in an environmentally responsible way
- Ensure that an environmental management system is in place and monitoring and reporting requirements are an integral part of ASR and ASTR operations
- Ensure that data are available for assessing the performance of the project, and to assist in defining the potential of the aquifer and catchment for project expansion or further projects

2. Guiding Principles for Best Practice

There are nine guiding principles set out below that need to be considered for achieving best practice for an ASR or ASTR project

1. Adopting a risk management approach

A preventive risk management approach should be adopted to minimise any potential for contaminants (such as microbial pathogens, inorganic and organic chemicals) in the source water to impact on human health and the environment.

With all aquifer systems, not all relevant characteristics can be defined completely before a project commences, and the same is true for variations in the quality and quantity of source waters in a catchment. Furthermore land uses and management may change within the catchment over the operating life of an ASR project. Hence a risk-based management approach must be adopted. This involves strategies to allow learning about the system while preventing irreparable damage, taking an informed precautionary approach in a structured and documented way, relying on multiple barriers for water quality protection, and being proactive in determining how the aquifer behaves. This follows principles laid out in the NRMMC/EP&HC Draft Guidelines for Water Recycling (2005). A commonly utilised risk-based management system is Hazard Analysis and Critical Control Points (HACCP) plan, which was initially developed to ensure safe food production, and is now widely used to manage risks associated with occupational health and safety (OH&S) and environmental management.

2. Preventing irreparable damage

It is recognised that all of the information required to predict the performance of an ASR project may not be available until a site is operating and can be monitored. Hence proponents should seek approval to proceed subject to demonstrating that the project will not cause irreversible harm (eg over-pressurisation of an aquifer puncturing an aquitard, polluted water reaching water supply wells, or impacts on ecological health of any receiving waters). This involves:

- Identifying all the reasonably foreseeable modes of failure and taking preventative action to ensure with a high degree of certainty that these do not occur. This includes a risk-based management plan for water quality protection in the source waters and in the recovered water.
- Identifying contingency plans to prevent irreparable damage in the event that failures or unforseen conditions are encountered.

3. Demonstrations and continuous learning

Recognising the value of information from complex systems to better inform about system states and processes, monitoring of operations will be an important part of the management of ASR projects. This is especially so in the first few years of an operation, particularly in a new aquifer type or with a different quality of source water or for a new ASR operator. Basic assessment of quantity of injectant and recovered water is essential for all operations. This needs to be supplemented with analysis of samples of injectant and recovered water, and where possible additional samples from observation wells. Monitoring data need to be documented and reported periodically to give the proponent and the regulator a chance to assess any chronic long term issues associated with the project. Analytes and their frequency of sampling would be selected on the basis of potential hazards and estimated risk. Initially sampling frequency will be sufficient to evaluate the temporal variation and factors influencing concentrations, and the frequency of sampling and selected number of analytes subsequently reduced in accordance with the revised level of risk, informed by the collected data.

4. Adopting a precautionary approach

Taking account of the principles above, the frequency of sampling for each selected analyte and use of continuous monitoring of relevant surrogate variables should be undertaken to enable potential problems to be ruled out or verified by data. Until ruled out, all potential problems must be considered possible. However the set of potential hazards should first be constrained or enlarged based on existing knowledge of the system derived from investigations, data from related sites and scientific literature. A rational hierarchy of problems should be addressed using a risk-based management approach, in order to allow projects to proceed with treatment and monitoring budgets in keeping with the risks.

5. Establishing water quality requirements

The quality of water that can be injected into an aquifer will be determined by the designated environmental values (beneficial uses) of native groundwater in the aquifer. Designated beneficial uses, such as raw water for drinking, stock, and irrigation supplies and ecosystem support, are determined by reference to state policies and historical practice. Recharge enhancement should extend or at least maintain environmental values of native groundwater. Baseline groundwater quality and environmental values need to be established before an ASR project commences to serve as a future reference.

Furthermore a rapidly growing knowledge of sustainable water treatment processes in aquifers (Dillon and Toze, 2005) may allow reliance on these processes for groundwater quality protection beyond an identified area of attenuation surrounding the injection well, and within the area of attenuation beyond a specified time period, and for the quality of recovered water to meet requirements of its beneficial uses. This approach is particularly valuable for brackish aquifers used to store fresh water to be recovered for irrigation or industrial use. The efficiency and rate of attenuation depends on the specific biogeochemistry of the target aquifer. Reliance on an area of attenuation warrants investigations of attenuation rates for new aquifer types and the placement of a monitoring well on the perimeter of the area of attenuation in the down-gradient direction to assess the effectiveness of attenuation and allow revision of estimated rates.

6. Rights of water bankers and recoverable volume

As a guiding principle there needs to be provision that water stored in an aquifer is available to the operator of the ASR project for an assured proportion of injected water, over a specified time horizon, typically 10 to 30 years. This requires protections that other well permits will not be issued, nor rights to extract for existing wells, within a proximity that would threaten those rights.

For over-exploited aquifers, ASR can be a means of enhancing net recharge by allowing the operator to recover a proportion, say only 80%, of the volume injected. Where aquifers are in hydraulic equilibrium, the entitlement may be 100% of the water injected, although in brackish aquifers this figure is unlikely to be achieved as recovery efficiency will be diminished by the amount of water required for buffering the ambient groundwater.

7. Finite storage capacity of aquifers and interference effects between sites

The elastic storage capacity of confined aquifers is relatively small and the hydraulic head effects during injection and pumping can extend for kilometres from the ASR well. Hence, while there is a very large capacity to store water in the aquifer, displacement of native groundwater invokes large changes of hydraulic head (piezometric head). Aquitards have a finite capacity to withstand hydraulic gradients (especially when flow is upwards) without rupturing. Injecting against high artesian pressures also creates an excessive energy demand for injection. Therefore each new ASR operation reduces the amount of available storage within the same aquifer. If sites were located close together, significant hydraulic interference effects might occur with each operator affecting the injection rates, energy costs and recovery efficiencies of the other. Hence as a guiding principle, sites should not be located in close proximity unless they are managed by a common operator.

8. Community and other stakeholder consultation

Proponents of an ASR operation should establish open communication with the local community and inform Local Government of their intentions, in order to take account of local knowledge and needs, and to enable scrutiny of the risk-based management plan, and ensure that all relevant factors are taken into account.

9. Highest valued use of resources

Where possible, to maximise net benefit to the community and the environment, water recovered from ASR should have high value uses, including substitution for potable water supplies.

3. Information Required Before Commencing ASR

Before commencing an ASR or ASTR project proponents should

- Establish the use of the water and magnitude of the demand they intend to meet.
- Contact the organisation responsible for groundwater management to determine; if there are suitable aquifers in the intended area of the proposed project, the environmental values of such aquifers, and the potential for storage.
- Contact the organisation responsible for catchment management to ensure that there is sufficient surface water or recycled water available to allocate.

If the demand for water and potential for recharge enhancement appears suitable, and ASR appears to be a viable option, the next step is to undertake a hydrogeological assessment and risk assessment to determine the technical feasibility and ensure the protection of human health and the environment. These investigations will assist in seeking approval from the relevant authorities.

A logical approach is for regulatory authorities to offer limited licences or demonstration licences that enable the proponents the opportunity to acquire the necessary data on project performance and give confidence that hydrogeological conditions and source water quality are as expected, and that the operator is capable of operating the system including monitoring and reporting (part of licence conditions). This also allows the opportunity to revise monitoring and reporting conditions based on site experience, for example frequency of sampling and number of analytes as assessed risks are revised.

The following checklist provides a guide to the information that will need to be supplied by the proponent as the basis for a licence or permit application:

- Volumes of water proposed to be injected and recovered, along with indicative use of recovered water.
- Map showing the location of the scheme, the groundwater basin, surface water catchment, supply point of stormwater or recycled water, topographic features and other relevant characteristics such as land use.
- Hydrogeological cross-section diagram, showing target aquifer with any aquitards.
- Map showing piezometric heads (indicating direction and magnitude of gradient) and all neighbouring wells in the area likely to be affected by the operation, and location of neighbours.
- Estimates of hydraulic properties of aquifer, hydraulic head changes and the extent of injectant migration within the aquifer
- Table of water quality analyses of ambient groundwater in the target aquifer as near as possible to the site, and for at least several samples of the water source for ASR to represent the likely range of conditions. Identify environmental values of aquifer to be protected
- Summary of source water, native groundwater geochemistry and aquifer mineralogy and their interactions, including potential for adverse effects on groundwater quality. This will impact on the design and operation of the ASR scheme (eg consideration of clogging issues and quality of recovered water).

- If relying on aquifer treatment, estimates of rates of attenuation of key pathogens and contaminants of concern (identified from risk-assessment) in the target aquifer, and identification of extent of the area of attenuation
- Drawings with dimensions and capacities of equipment, pipes and storage facilities, and details of pre-injection water treatment.
- A preliminary risk-based management plan and barriers that will be used to protect the environmental values of groundwater and ensure the quality of recovered water is fit for purpose.
- Details of monitoring programs.
- Contingency plans for potential problems (eg polluted source water).
- Site security (eg fencing).
- Amount, quality and fate of any wastewater discharge (eg well purging).
- Maintenance and operation plan for the proposal.
- Noise levels of associated equipment (need to comply with EPA requirements).

Each ASR project falls within a surface water catchment and will also impact on a groundwater system (Figure 2). The quantity and quality of water available for recharge will be determined by the upstream surface water catchment, and the way it is managed. The need to protect water rights, including environmental flow allocations in the down stream catchment, may also constrain the quantity of water that can be recharged. The groundwater system has a finite storage capacity, and existing groundwater use allocations and groundwater quality need to be protected. Therefore an understanding of the water catchment and the groundwater system, and how these are managed, is important in assembling the information needed in the application.

The preliminary risk assessment will consider potential sources of contaminants in the aquifer that may impinge on the environmental values of the target aquifer and on uses of recovered water. This may include a survey of industries, activities and infrastructure within the catchment, an assessment of the risk of a hazard occurring and the means of managing such risks.

This approach goes beyond the EWRI/ASCE (2001) standardised guidance for investigation methods to enable design of large scale recharge projects USA, in response to a quite different regulatory environment without reference to adaptation according to assessed risk.

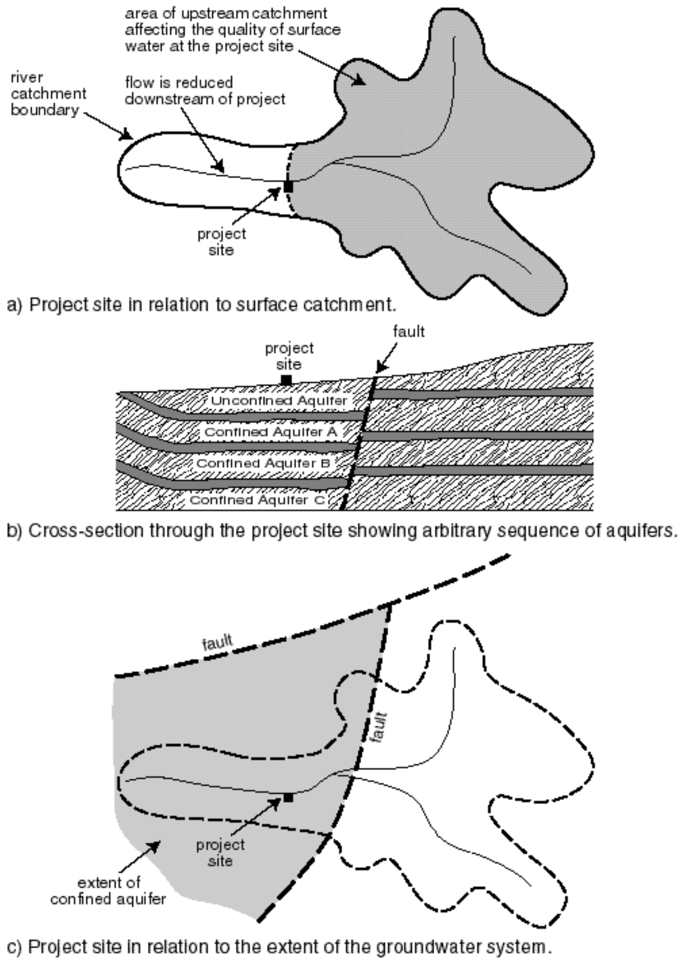

Figure 2. ASR project site in relation to the surface catchment and the groundwater system (from CSIRO Land and Water)

4. Components of an ASR System

An ASR scheme may contain the following structural elements (see Figure 3):

- Diversion structure from a stream, drain, recycled water source, etc…
- Control unit to stop diversion of flow when it is outside the acceptable range of flows or quality.
- Wetland, detention pond, dam or tank (which may also be used as a buffer storage during recovery and reuse).
- Spill structure incorporated in wetland or detention storage.
- Some form of water treatment prior to injection where required to protect beneficial uses of the aquifer.
- Equipped well(s) to inject and recover water from the aquifer (including for periodic purging). In an ASR well the pump needs to be protected from reverse flows, and well design may differ from conventional water supply wells, especially in unconsolidated media.
- A monitoring well near the injection well if clogging is likely to be an issue, and at the down-gradient margin of the area of attenuation, if this is relied on for groundwater quality protection in an aquifer where attenuation characteristics have not been monitored.
- A valve or anti-cavitation device on injection line.
- Systems to monitor (measure and record) standing water level, volumes injected and extracted.
- Systems to monitor (measure and record) the quality of injectant, groundwater and recovered water.
- Sampling ports on injection and recovery lines.
- A control system to shut down recharge in the event of unfavourable conditions.
- Provision for control, or treatment and recycling of the discharge of water purged from the injection well(s).
- Provision for a treatment system for recovered water, if needed.

The area required for ASR project infrastructure will depend on detention storage requirements. If clay-lined and reed bed fringed wetlands are used, a rule of thumb is to allow an active storage depth interval of about 100mm for ASR in addition to flood detention active storage, in order to prevent drying and cracking of the clay liner, and to have no adverse effects on reed bed health. With research this could be enhanced. This gives an active storage of 1ML/ha per fill of the active storage with possibly some additional recharge following storms while pond level exceeds the cease to flow level of the outfall if unsettled water quality is adequate. Shelter and power will be required for the monitoring units, and if possible these should be located together at a control centre for the operation. Siting should avoid flood-prone land. If aquifers are sufficiently saline that density affected flow may occur during storage, packer arrangements may be required to recover water only from the upper part of the aquifer.

For recycled water ASR and mains water ASR operations, the supply side is simpler as it is harnessed directly from a pipe in the water reticulation network, with the benefit of the pressure in the pipe to enhance rate of recharge. A purge sump may be required to hold purge water from well-backflushing which is a standard operating practice for ASR wells, particularly in unconsolidated formations or when using water that contains colloids or nutrients. It is recommended that a monitoring well be constructed close to the injection well to assist in real time operation of the ASR well for recycled water operations. Hydraulic gradients and well injection rates can be used to trigger backflushing and hence prevent filtercake compression.

For domestic scale ASR, with reduced and variable management inputs, only roof runoff is considered a suitable water source for recharge. The system components are simpler with a screen to prevent leaves entering a rainwater tank which is used as a balancing storage, and a filter in the gravity feed line from the tank to the ASR well.

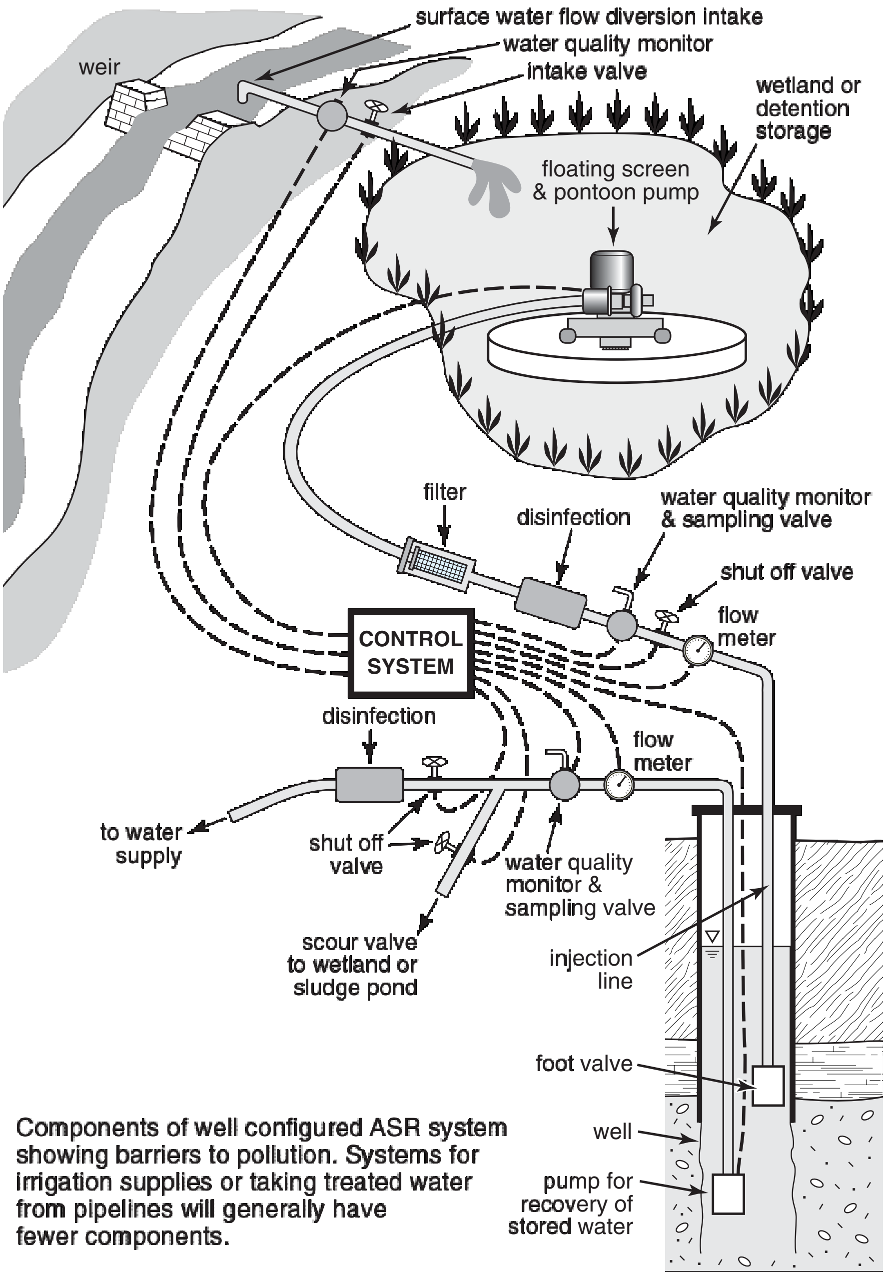

Figure 3. Components of a well-configured stormwater ASR system showing barriers to pollution (from CSIRO Land and Water)

5. Risk-Based Management Plan & Barriers Against Pollution & Damage

Proponents of an ASR project should implement a risk-based management plan to assess and manage the risks of pollution of groundwater and failure to meet required water quality criteria for the recovered water. An example of a commonly used risk-based management system is a Hazard Analysis and Critical Control Points (HACCP) Plan. An international guideline for establishment of HACCP for the food industry proposes twelve steps (FAO/WHO, 1996), and these are summarized relating to water sources (NWQMS (2004) Australian Drinking Water Guidelines, and NRMMC/EPHC (2005) Draft Guidelines for Water Recycling) as follows:

1. Assemble a project team with appropriate knowledge and expertise
2. Identify the product (eg recovered water) and processes to generate it
3. Identify the intended use (and possible unintended uses) of the recovered water
4. Construct a flow diagram of the system and assemble pertinent information and key characteristics
5. Perform a site evaluation to confirm the flow diagram processes
6. Perform a hazard identification and risk assessment of threats to the water supply system
7. Determine Critical Control Points within the system, where management of water quality related to each hazard can be monitored and system operation can be controlled
8. Establish critical limits for monitoring parameters at each control point
9. Develop the monitoring requirements for each control point
10. Determine corrective actions and responses for periods when critical limits are not attained
11. Establish procedures for managing monitoring data and operation records for the system
12. Develop protocols for verifying that the system is producing acceptable water in accordance with requirements.

This general risk-based management approach is further elaborated in detail in both NWQMS Drinking Water Guidelines, 2004 and NRMMC/EPHC Draft Guidelines for Water Recycling, 2005. A worked example is also provided by Swierc et al. (2005) for an ASTR project in Adelaide.

In the case below urban stormwater is considered as the source water for an ASR operation, and a similar approach may be used for recycled water and roof runoff. The first major part of the risk-based management plan (item 6 above) is to identify the potential hazards or hazardous events in the catchment and the incidents by which they may reach the intake to the wetland or detention storage (Figure 3). This leads to assessing barriers and control points whereby the residual risks are diminished. A well operated and managed system should have many, if not all, of the barriers identified in Figure 4, and discussed below.

Increasing the number of barriers incorporated in an ASR scheme, increases confidence that the environment and human health are protected. There should be a demonstration of best practice with all feasible and relevant barriers utilised to assure groundwater protection is achieved, especially for commercial (larger-scale projects). Use of these barriers has the added benefit of reducing the risk of 'clogging' the ASR injection well.

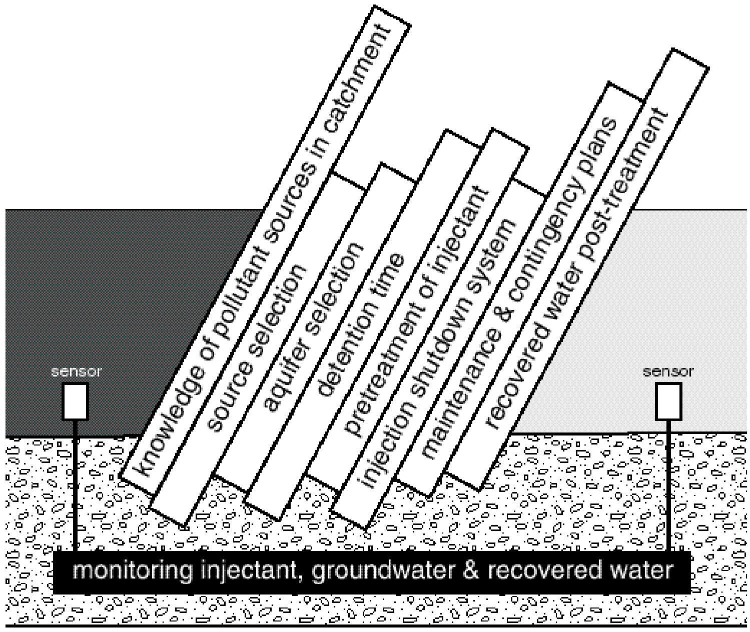

Figure 4 .Multiple barriers to protect groundwater and recovered water at ASR projects (from CSIRO Land and Water)

The eight barriers to protect groundwater and recovered water for ASR projects as illustrated in Figure 4, are elaborated on below.

5.1 Knowledge of pollutant sources in catchment

An evaluation of pollutants or hazards that could potentially be present within injectant needs to be undertaken and the nature of hazards considered will depend on land use within the stormwater catchment and the nature of industries within a sewer catchment for recycled water. The concentrations of hazards in runoff typically have seasonal or within-event patterns (eg the first autumn flush in urban catchments). Heavy hazard loadings can be avoided by being selective on the timing of diversions. In the case of ASR with recycled water, knowledge of the constituents of the effluent and of the processes used in the wastewater treatment plant is necessary to understand potential risks. Knowledge of the potential risks helps to focus water quality sampling and analysis costs in determining the viability of the ASR project.

5.2 Source selection

The purpose for which the recovered water is intended and the environmental values of the target aquifer need to be understood prior to selecting the water source. Ideally the sources of water would be from controlled catchments where the potential for hazards are low (for example: excluding industrial areas – fallout, spills etc, and capturing rainwater directly as opposed to stormwater).

Where recharge enhancement is proposed for drinking water supplies it is preferred to divert runoff from polluted surfaces away from the project, or to collect runoff only from roofs (and other relatively clean surfaces) in order to obtain the quality of water required for injection. Industrial stormwater pollution control programs have also been embedded in risk-management programs (Swierc et al 2005).

For domestic scale ASR, rainwater from roofs is likely to be the only suitable source given the management and monitoring effort likely to be widely achievable.

5.3 Aquifer selection

Aquifers with brackish groundwater are most suitable for ASR with stormwater or reclaimed water to be recovered for non-potable purposes, This requires only modest treatment to protect the environmental values of the aquifer. For aquifers already suitable as drinking water supplies, more and higher barriers are required for risk protection and these bear costs that could limit viability. Aquifers that are saline may become stratified when fresh injectant is introduced, lowering the proportion of water that can be recovered at a suitable salinity.

It is also important that other users of the aquifer are taken into consideration when selecting an aquifer for ASR. Where an aquifer may be made artesian by ASR operations, any affected wells may need to be fitted with equipment to prevent overflow. More detail is given in section 7.

5.4 Detention time

A detention pond reduces variability in water quality and therefore mitigates the effects of isolated pollution events in the catchment. Detention storage also allows time to shut down injection in the event that pollution of the surface water source occurred before the diversion to the pond could be closed.

In the event that the attenuation properties of the aquifer are to be utilised to improve the quality of the recovered water, a separate recovery well (ie ASTR) may be used to ensure adequate residence (detention) time of injectant in the aquifer.

5.5 Pre-treatment of injectant

Comparisons with native groundwater quality and its environmental values will indicate the requirements for compatible pre-treatment of water detained for injection. An understanding of the biogeochemical processes that would occur within the aquifer in response to injection of the source water will also guide the requirements for pre-treatment of injectant.

Screens should be used to sieve out leaf litter, gross pollutants, and aquatic life, and prevent these reaching the filter or the injection well. Generally these will be floating screens that also exclude any surface scums (eg from hydrocarbons and pollens) from the intake to the injection well.

Swimming pool filters, such as recirculating sand filters with backwash facilities, cartridge filters, and diatomaceous earth filters are relatively cheap and can assist in reducing concentrations of suspended sediments in injectant. While these will not affect dissolved solutes, they may reduce the frequency of back-flushing of the injection well to economic advantage, especially for turbid source waters and fine grained aquifers. Biofiltration or advanced treatments may be used to reduce labile nutrient in injectant and slow the rate of biofilm formation in fine-grained aquifers.

If disinfection is applied, it would be necessary to check for the formation of disinfection by-products to ensure that recovered water concentrations are acceptable for the intended use of the water.

5.6 Injection shutdown system

Controllers should be incorporated to shut down the injection pump or valve if the standing water level in the well, injection pressure, or water quality parameters that can be continuously monitored exceed the criteria for the environmental values of the aquifer (eg electrical conductivity (salinity), turbidity, temperature, pH, dissolved oxygen, volatile organics, etc). Use of this technology is part of best practice. The cost of remedial activities for a single pollution event may significantly exceed the cost of installing control equipment. The preventive risk management approach will be used to inform the appropriate selection of controllers and real-time monitoring indicators.

5.7 Maintenance and contingency plans

Protection of the surface water pond from contamination will be necessary. This includes constructing the pond off flood-prone land and taking care with or avoiding use of herbicides and pesticides in its vicinity. Avoid deciduous vegetation in the area and mosquitoes and other pests breeding in the detention pond.

Monitoring equipment should be recalibrated at manufacturer-specified intervals. Pumps and pre-treatment equipment need to be maintained, eg filter media replaced at manufacturer-specified intervals or volumes. Keeping records of maintenance is typically part of a good risk-based management system.

As part of the maintenance requirements is may be necessary to redevelop the well. If this was required the well redevelopment water must not be disposed of to a water body or a water course unless it is of suitable quality. This water may be used on site, possibly for irrigation or discharged to sewer (with the approval of relevant authority), or returned to the wetland.

Sediments that accumulate in detention ponds or wetlands may ultimately need to be removed, and beforehand need to be analysed to determine locations and methods for safe disposal or reuse that are environmentally acceptable. Design guidelines for stormwater pollution control ponds and wetlands are available (Lawrence and Breen, 1998 http:// www.wsud.melbournewater.com.au).

Contingency plans are required in the event of contaminated water being inadvertently injected. This would include how to determine the duration of recovery pumping, what sampling intervals are needed, and what to do with recovered water.

5.8 Treatment of recovered water

Comparing the quality of recovered water with water quality criteria for its intended uses will indicate whether there is any requirement for further treatment post recovery. For example if the recovered water was at risk of containing pathogens it may require treatment such as UV disinfection. For some forms of use, eg irrigation via drippers, it may be necessary to insert a cartridge filter to remove precipitates that block drippers. Commissioning tests on the operation will indicate if these are necessary. However it is necessary to remain vigilant for water quality changes, such as metal mobilisation in aquifers (eg arsenic, iron, and manganese) which in some geological settings may be released through the ASR operation.

5.9 Monitoring

Monitoring in itself is not a barrier to risks but acts to verify that barriers are working as described above. It is an essential part of every ASR project. The quality of injectant and recovered water needs to be sampled and analysed according to the risk-based management plan and other performance indicators important for the project should be monitored and reported. This is discussed further in section 8.

6. Quality of Water for Injection and Recovery

The quality of water that can be injected into an aquifer will be determined by the designated environmental values (beneficial uses) of native groundwater in the aquifer. Designated beneficial uses, such as raw water for drinking, stock, irrigation, and ecosystem support, are determined by reference to:

(1) State Environment Protection Policy (SEPP) – Groundwaters of Victoria (Victoria Government Gazette 1997) (Table 1) which is based on the National Water Quality Management Strategy (Australian Drinking Water Guidelines 1996 NHMRC/ARMCANZ; Australia and New Zealand Guidelines for Fresh and Marine Water Quality 2000, ANZECC/ARMCANZ) that specify guideline values for water quality parameters for various beneficial uses. Firstly one needs to determine to which 'segment' groundwater belongs (based on native groundwater salinity) and then consider what beneficial uses are protected for that segment.

(2) Local historical and continuing uses of those aquifers, where these differ from state and national guidelines. These should be taken into account at catchment level through appropriate public consultation (Guidelines for Groundwater Protection 1995, ARMCANZ).

Recharge enhancement must improve or at least maintain groundwater quality with respect to the pre-existing environmental values of the aquifer. Where there is a choice of target aquifers proponents should be encouraged to avoid aquifers that are capable of providing drinking water supplies. All practicable measures should be taken to prevent pollution of groundwater quality and pre-treatments should be considered within the risk-based management system and in determining the monitoring plan. Depending upon the degree to which any concentrations of indicators exceed background groundwater quality, and anticipated attenuation in the aquifer an area of attenuation may be determined.

7. Aquifers Suitable for ASR

All types of aquifers have been used for ASR, but in general ASR is easier to manage in consolidated aquifers where the formation provides a competent well without the requirement for screen and gravel pack. Carbonate aquifers are often preferred due to the offsetting effects of carbonate dissolution on well clogging (Herczeg et al, 2004). Fractured rock aquifers, even low yielding ones, have been used successfully for ASR (Murray and Tredoux, 2002) with injection rates in some wells exceeding airlift yields. Coarse grained sand and gravel are also very suitable for ASR storage targets, but care needs to be taken with well construction and completion, and to reduce as much as possible the concentrations of organic and colloidal material introduced into the well. Storage in fine-grained unconsolidated media is more problematic, and requires water with very low nutrient and colloidal concentrations in order to avoid chronic and irrecoverable depletion of specific capacity of the ASR well. Generally confined aquifers are preferred to unconfined aquifers because water quality is better protected from overlying land uses and to avoid the potential complications of an undesirable rise in water table elevation.

Characteristics that should also be considered when selecting an aquifer for ASR include:

- Sufficient permeability
- Sufficient storage capacity
- Ability to recover injected water
- Containment of injected water
- Low rate of lateral flow in aquifer
- Salinity of groundwater greater than that of injected water
- Avoid highly saline aquifers where density stratification is expected
- Avoid polluted aquifers
- Avoid aquifers containing potable groundwater for practicality in meeting management requirements when injectant is of a lesser quality
- Avoid locating near other groundwater users or ASR sites
- Possible damage to thin confining layers due to pressure increases
- Possible discharge of water through any wells that may become artesian
- Possible salinisation, water logging, and ecosystem effects if the aquifer is unconfined
- Effects of reduced pressure during extraction on other groundwater users
- Benefits of re-pressurisation of over exploited aquifers, including salinity and subsidence mitigation
- Local infrastructure and the heave and subsidence impacts in expansive clays
- Benefits of a saline intrusion barrier
- Effective groundwater demand management policy in force for the aquifer
- Avoid any jurisdiction boundaries

8. Monitoring Needs

The monitoring program must be developed as part of the risk-based management plan. Monitoring is necessary to provide assurance that groundwater quality is protected, that the recovered water is fit for its intended use and to initiate contingency measures if ‘failures’ occur. Monitoring is also necessary to ensure that the system performs as intended, that volumes of recharge and recovery are known and that the injection pressures are acceptable.

The effort needed for water quality monitoring will depend on the consequences and risks of contamination, which will depend on the management plan and the barriers that have been established. Signals from equipment monitoring the quality of surface water upstream of the intake to the detention storage and in the injection pipe can both be used as critical control points to shut down and prevent access of contaminated water into the pond and well. The range of parameters that can be monitored in real time is expanding and reliability of measurements is improving, but as yet these are only a small fraction of the relevant analytes. However these measurements (eg electrical conductivity (salinity), turbidity, temperature, pH, dissolved oxygen, as well as pressure and flow) can be valuable as surrogate parameters to inform when the water quality may have deviated outside its acceptable range.

For other hazards, for example pesticides, pathogenic organisms or metals, it may be several weeks before the laboratory analyses are available. This information can nevertheless be of value in demonstrating that the existing barriers are adequate, or determining whether further barriers, such as additional pre-treatment are needed. The nature of those hazards and their concentrations will determine whether some form of recovery or remedial action is required. If the time (or volume) interval between samples is sufficiently small, occasional high readings may be tolerated, as there may be sufficient information to limit the unknown mass of introduced contaminant to values smaller than those which would require aquifer decontamination procedures (eg pump and treat).

At ASTR sites a monitoring well on the pathway between injection and recovery wells would be required if the aquifer’s attenuation properties are being used to improve water quality. For ASR operations where attenuation is required to provide protection for other groundwater users, including groundwater dependent ecosystems, a monitoring well at the margins of the identified area of attenuation on the down-(groundwater)-gradient side of the site would be required..

In accordance with best management practice, regular monitoring is the responsibility of the operator. As a guide, it is recommended that operators of all projects which recharge more than 20 ML/year should install at least one continuous monitoring device (which controls a cut-off valve) for a variable which can be correlated with hazard sources. For example, in harnessing urban stormwater, the monitored variable may be turbidity, which has been found to be correlated with metal and nutrient concentrations (but is very difficult to keep operating reliably in field conditions). In some catchments where surface flows can reach high salinities (which may be unacceptable for recharge), proponents should also monitor salinity as a control variable.

Water quality parameters that are considered for monitoring are those that:

- Exceed or may exceed guideline values appropriate to the environmental value of the target aquifer and for the intended use of recovered water
- Conservative tracers that differentiate injectant from native groundwater (eg chloride and fluoride)

- Major ions, pH, dissolved oxygen (DO), dissolved organic carbon (DOC), nutrients and metals that indicate the biogeochemical status of the aquifer and the effectiveness of its attenuation processes.

The location of sampling points and the frequency of monitoring are normally identified by an iterative process, defined in accordance with the risk-based management plan. Initially samples are taken frequently and subsequently the period between samples generally increases and number of analytes generally reduces as the variability of water quality becomes better defined.

9. Economic Factors

It is important that privately owned ASR operations be economically viable so that the operator has an ongoing commitment to adhering to the risk-based management plan by maintaining the multiple barriers and monitoring their effectiveness, and the overall performance of the project. Routine maintenance is required to avoid potentially large costs of bore clogging, equipment failure, or recovery of polluted water. 'Trading off' of treatment costs against the possibility of higher costs of well redevelopment, or pollution, generally favour higher treatment options, subject. Private projects with marginal economic returns are discouraged as there is little capacity to deal with contingencies. In these cases this may suggest that:

- The scale of the project is too small
- The intended quality of recovered water is inadequate for higher valued uses
- Hydrogeological conditions are unfavourable
- Source water of suitable quality is inadequate
- Land requirements for detention storage cannot be found.

The following flow chart (Figure 5) represents only one example of how decisions to be made concerning an ASR project (in this case on the extent of treatment to improve water quality of injectant) impact on the economic feasibility of ASR. The water treatment decision generally involves large incremental costs that can affect viability of projects. Similar costs may be involved in other parts of the system and this may suggest alternatives to reduce risk and have a viable project.

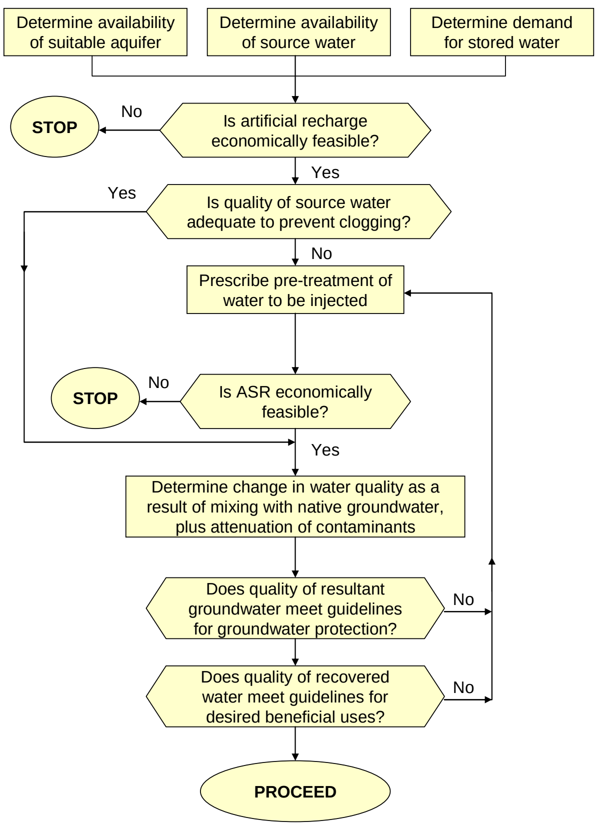

Figure 5. Decision flowchart covering economics of ASR in relation to sustainability (from Dillon and Pavelic, 1996)

10. Variants of Stormwater ASR

10.1 Recycled Water ASR

The same principles apply for recycled water ASR as for stormwater ASR. Infrastructure requirements are simpler as the pressurised distribution pipe is connected directly to the ASR well head for injection and recovery. Provision should be made for sampling of injected and recovered water, and monitoring rates and volumes of recharge and discharge from the well, and for discharge of well redevelopment water to a tank or scour pond.

Recycled water is subject to fluctuations in algal concentrations, and pH which can adversely affect clogging. It is recommended that a nearby well be constructed to monitor head gradient close to the well and relate this to recharge rate to trigger well redevelopment. This procedure should be automated to maintain the specific capacity of the well and to reduce energy costs, as redevelopment will be more frequent than required for low-nutrient stormwater injected into the same aquifer. Once filtercake compression occurs in the injection well redevelopment is made more difficult and the results may be less effective than if this was performed more frequently.

It is suggested that laboratory studies be performed on aquifer materials using the intended quality of injectant to determine the viability of the operation in relation to water quality, prior to injecting recycled water into an aquifer.

Recharge of recycled water into fine-grained unconsolidated aquifers is not recommended, unless the nutrient concentrations are very low. The level of pre-treatment of recycled water injectant may need to be higher than that required to meet an irrigation use.

Observation wells within the target aquifer on the perimeter of the identified area of attenuation, and near the injection well in any fresher overlying or underlying aquifers, are also warranted to assure groundwater quality protection and aquitard integrity.

10.2 Domestic Scale ASR

The benefits of using ASR to store roof runoff at domestic scale are:

- Reduced demand on mains water supplies.
- More efficient water management – stormwater is dealt with at its source rather than downstream, and it makes use of an otherwise wasted resource.
- Slightly reduced urban runoff into the sea or receiving waters.

In general, recharge and recovery of small volumes of water are economic only if capital and operating costs are very low. At domestic scale, this will restrict the depth of wells and the types of treatments that can be provided.

For a single household scale ASR in isolation, there is a low likelihood of adverse impacts. However, if domestic scale ASR is economic, it is expected that many householders within an area would invest. This raises the prospect of higher groundwater levels flooding cellars, increasing saline groundwater ingress to sewers, salt damp, differential movement of footings and cracking of houses, dryland salinity and death of salt- and water-sensitive vegetation, damage to pavements, including roads, and submergence of underground utility services. Conversely if water tables were to be depleted due to an imbalance between recharge and discharge, this could also affect differential settlement of footings, reduce or stop baseflows in urban streams, reduce yields of wells, and in coastal areas may induce salinisation. Furthermore ASR enhances the risk of pollution of the shallow aquifer and the potential for 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 is practical and robust. Good design of domestic scale ASR wells can reduce the amount of management owners will need to exert, but this cannot be limited entirely, and all proponents of ASR wells should be aware of their ongoing responsibilities if ASR is to produce benefits with no adverse side effects.

Therefore it is recommended that ASR in shallow aquifers not be undertaken in locations where water tables are already shallow (less than 5m) or 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 in areas where expansive clay soils occur
- Where other structures such as cellars or basements could be adversely impacted by rising water tables

Only rainwater from roof runoff is fit for use in domestic scale ASR. Preferably there should be a first-flush bypass, and a rainwater tank used as a balancing storage, with a coarse filter before the tank and a fine filter between the tank and the well to prevent entry of organic matter derived from roof runoff. The fine filter size should be comparable with the smaller pore sizes in the aquifer. (For a domestic scale demonstration site in Adelaide, which commenced injection in July 2003, a 100 micron filter appears to be effective in combination with monthly purging of the ASR well, to prevent well clogging in an alluvial aquifer).

Stormwater runoff from paving should not be used without first passing through an oil/grease trap and a sand filter.

The aquifer pressure must 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 provision for any overflow so as not to cause nuisance.

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

Two water meters are needed; one to record the cumulative volume of recharge and the other to measure recovery, with the aim to keep these approximately in balance. Annual records of recharge and discharge should also be maintained.

The well needs to have a permanently equipped pump which 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.

Where native groundwater is 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, and ideally owners should have access to a water level monitoring probe, and an electrical conductivity meter and hands-on training in how to use these, so they may take at least two readings a year (in spring and autumn).

Where a property containing an ASR well is sold, the new owner should be alerted to the management requirements, and if they are unwilling to adopt these, the well should be locked or 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 for each of the parties, covering costs of maintenance, supply of stormwater and maintenance of the well catchment, ownership of recovered water, keeping of records, and the consequences of changes in ownership of any of the properties.

10.3 ASTR Projects

The same principles apply for ASTR projects as for other forms of ASR. However, for ASTR operations the spacing between injection and recovery wells will depend on the intended residence time in the aquifer for passive disinfection, and the quality of ambient groundwater. If the native groundwater meets the water quality criteria for recovered water, the spacing can be enlarged to extend travel time and treatment within the aquifer. Otherwise the recovery well needs to be located within the injected water plume in reasonable proximity to the injection well and the separation distance will be a trade off between increasing treatment time and increasing the proportion of injectant in recovered water (eg Pavelic et al, 2004).

If the environmental values of the native groundwater support the intended use of recovered water, the monitoring network can be relatively simple with an observation well along the path from the injection well to the recovery well. If however there is a reliance on the injected water to form a plume to freshen an aquifer before recovering water fit for its intended use, the monitoring network also needs to detect the presence of remnant native groundwater in the vicinity of the recovery well. This may also involve piezometers at different levels within the aquifer, especially if broad scale layering of heterogeneity is detected. Tracer studies, for example using sulfur hexafluoride (SF_6), may be required to determine minimum travel times between injection and recovery wells without adversely affecting water quality.

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12. Glossary

Aquifer	A permeable layer of rock or sediment that contains and transmits water. An unconfined aquifer is where storage is increased by filling dry pores between grains or cracks in rocks thereby raising the water table. A confined aquifer is found beneath low permeability formations, and its storage is increased by raising the pore pressure in the aquifer giving elastic compression of aquifer materials and water. The injected water displaces ambient groundwater and mixes with it, creating a plume of injectant in the vicinity of the ASR well.
ASR	Aquifer storage and recovery (ASR) is the recharge of an aquifer via a well for subsequent recovery from the same well (as defined by Pyne, 1995).
ASTR	Aquifer storage transfer and recovery (ASTR) is the recharge of an aquifer via a well for subsequent recovery from another well, to allow a minimum residence time in the aquifer before recovery.
Aquitard	A geological layer that has low permeability and confines or separates aquifers.
Artesian	When the piezometric surface (hydraulic head) of a confined aquifer is above ground surface. An uncontrolled artesian well will spurt water out of the ground.
Coliform	Several types of aqueous bacteria characteristic of faecal pollution from warm-blooded animals; whose presence in surface waters or groundwater may indicate contamination by sewage.
Confining layer	A rock unit impervious to water, which forms the upper bound of a confined aquifer.
Contaminant	A substance of natural or anthropogenic origin present in water that may potentially reduce the capacity of the water to meet its relevant environmental values.
Disinfection	The process of eliminating pathogenic organisms from water; often achieved by chlorination or UV exposure.
Environmental values	The particular value of water in sustaining ecological systems as well as economic uses such as drinking water, irrigation, industrial and mining water supplies, often called 'beneficial uses'. Water quality criteria are specific to environmental values.
Filtration	Process of filtering a water sample or supply, to remove suspended sediment and the larger biota.
Groundwater	Water occurring in aquifers either naturally or as a result of artificial recharge.
Injectant	The water injected (pumped or fed by gravity) into an ASR or ASTR injection well.
Injection well	An ASR well or in ASTR a well that admits water into an aquifer, either by pumping or under gravity.
Management of Aquifer Recharge	A term applied to all forms of intentional recharge enhancement, including ASR and ASTR.
Pre-treatment	Any treatment (eg detention, filtration) that improves the quality of water prior to injection.
Recovery efficiency	The volume of recovered water that meets the salinity criteria for its intended uses expressed as a percentage of the volume of fresh water injected into a brackish aquifer (usually evaluated on an annual basis).
Recycled water	Treated municipal sewage effluent that has been accredited as suitable for specific forms of reuse.
Stormwater	Rainwater that runs off a catchment, generally in urban areas via a stormwater management system of gutters, pipes, drains and creeks.