Stormwater Storage and Use

2.2 Managed Aquifer Recharge

Background

Managed aquifer recharge (MAR), also known as artificial recharge, is the infiltration or injection of water into an aquifer (EPA 2005). The water can be withdrawn at a later date, left in the aquifer for environmental benefits, such as maintaining water levels in wetlands, or used as a barrier to prevent saltwater or other contaminants from entering the aquifer. As the water infiltrates or is injected into the soil, natural biological, chemical and physical processes may assist in removing pathogens, chemicals and nutrients from the water, and thus improve water quality (Source: <http://www.csiro.au>).

MAR may be used as a means of managing water from a number of sources, including stormwater and wastewater. A number of pilot studies of MAR schemes using treated wastewater have been conducted. For example, a Water Corporation MAR scheme in Halls Head, Mandurah, has demonstrated significant improvements in secondary treated wastewater following MAR (Toze et al. 2004). Groundwater replenishment by MAR is currently being investigated as a future drinking water source for Perth using reverse osmosis treated wastewater. For further discussion of MAR using treated wastewater, see the Environmental Protection Authority Bulletin 1199 Strategic Advice on Managed Aquifer Recharge using Treated Wastewater on the Swan Coastal Plain (EPA 2005).

This document considers only MAR using stormwater. The lot-scale infiltration of runoff via soakwells is not considered to be a form of MAR in this document. Soakwells are addressed in BMP 3.2 Soakwells.

Scope and viability of MAR

MAR schemes can range in complexity and scale from the precinct scale, through local authority infiltration systems for road runoff and public open space irrigation bores, through to the regional scale, which involves infiltration or well injection of stormwater and provision of third pipe non-potable water supply for domestic use.

Formal MAR schemes at a regional scale are relatively new in WA. Examples of MAR at the precinct scale include stormwater infiltration and irrigation systems adopted by the City of Geraldton and Town of...
Mosman Park. The Town of Cottesloe, supported by the Water Smart Australia Programme, is implementing MAR using stormwater to replenish the Cottesloe groundwater aquifer. A number of local governments are also currently investigating MAR using stormwater for the irrigation of public open space.

A MAR scheme can be designed to incorporate BMPs such as vegetated swales, bioretention systems and constructed wetlands for pre-treatment purposes. At the regional scale, MAR can assist a post-development catchment to replicate its pre-development hydrology through reducing runoff to the receiving environment and by reducing the importation of scheme water. MAR can also contribute to reducing the size and hence capital cost of stormwater infrastructure. This is particularly the case where stormwater is infiltrated at-source, resulting in reduced design runoff rates.

The viability of a MAR scheme is firstly dependent upon the quality of water available to be used, or level of treatment required to achieve the necessary water quality. Stormwater can contain contaminants such as oil, grease, metals and pesticides, which build up on surfaces in urban areas. These come from sources such as pavement deterioration, tyre and brake-pad wear, vehicle emissions and spills. MAR may improve water quality for a number of contaminants as a result of filtration in the aquifer, and through biochemical processes in the soil or aquifer. It is however noted that there are a number of contaminants that may not be removed by MAR, and that there exists the potential for MAR to cause contamination of the aquifer if improperly designed or managed. The potential for contamination of the soil or aquifer through which the water moves also requires consideration.

The aquifer characteristics must also be well understood and mapped before implementation of a MAR scheme. Knowledge of the aquifer characteristics is required to predict the flow and fate of injected water. Understanding and monitoring of the aquifer and injected water is required so that recovery bores can be located to ensure that sensitive receptors, such as bores, wetlands and acid sulphate soils, are not affected.

The quantity of water available for abstraction following MAR will be dependent upon a number of factors, including the potential for impacts to the regional groundwater system. The Department of Water is currently developing an allocation policy for MAR. At times, either due to recovery efficiencies or due to environmental water allocations, the volume of water available to be recovered will be less than the volume of water which has been recharged to the aquifer in the scheme.

**Regulatory requirements**

Managed aquifer recharge systems may require approvals from a number of government agencies, including the Department of Water, Department of Environment and Conservation, Department of Health and local government. In the case of large schemes or those with the potential for significant impacts, all relevant agencies must be consulted prior to proceeding with detailed design. Any MAR proposal that is likely, if implemented, to have a significant effect on the environment must also be referred to the Environmental Protection Authority under section 38 of the *Environmental Protection Act 1986*. Currently, MAR in public drinking water source areas is not supported.

MAR proposals should be assessed using a risk management framework, as set out in the *National Guidelines for Water Recycling – Managing Health and Environmental Risks* (NRMCC/EPHC 2005). Specific modules for MAR and for recycling stormwater are currently being developed as Phase 2 of these Guidelines.

A consultation and communication program should run in parallel with development of any MAR proposal. This is discussed in the *National Guidelines for Water Recycling – Managing Health and Environmental Risks* (NRMCC/EPHC 2005).
Design considerations

At the MAR planning stage it is necessary to compile an inventory of existing environmental values attributed to the groundwater system, such as drinking water, aquatic ecosystem values and primary industries. This inventory may be included within an urban water management plan (UWMP) or a stormwater management plan (SMP). This should provide design objectives for planning the MAR system and identify the location of existing bores, their intended uses (e.g. monitoring, public open space irrigation) and groundwater dependent ecosystems (phreatophytic vegetation, caves, wetlands and waterways). As the aquifer may already be providing beneficial uses to others, quality, quantity and flow requirements of these users need to be considered in the aquifer selection.

Stormwater Quality

Quality of the stormwater is a primary design consideration. Water quality treatment may be required prior to infiltration or injection into groundwater. MAR that uses infiltration as the recharge method may need little or no pre-treatment prior to recharge. The level of treatment depends on factors including the quality of the water used for the recharge, the local groundwater conditions, the intended use of the recovered water and local regulation. One of the key issues is the variability of stormwater, through factors such as the timing between rainfall events, rainfall intensity and distribution, and variability in catchment land uses. Treatment also has the added benefit of removing sediment and reducing the risk of ‘clogging’ the infiltration or injection system.

Each MAR proposal must identify potential pollution sources within the catchment and plan risk management strategies, including pollution contingency plans. An evaluation of the pollutants that may be present within the injected water needs to be carried out on a catchment basis as pollutants vary with land use. The concentrations of pollutants typically have seasonal or within-event patterns, and heavy pollutant loadings can be avoided by being selective in the timing of diversions. Comparisons with the aquifer water quality and environmental values will indicate the requirements for treatment of water detained for injection. Knowledge of the potential pollutant profile helps to define water quality sampling and analysis costs when determining the viability of the MAR project.

The Beach Health Program 2004-06 (Department of Water 2007) conducted a baseline study of the types and concentrations of contaminants in and around 65 traditional coastal stormwater drains in the Swan Region. The study found that stormwater at Perth’s marine beaches is contaminated predominantly with microbes and heavy metals. Nutrients, petroleum hydrocarbons, organic chemical compounds and suspended solids are also present in stormwater but to a lesser extent. Proposals must evaluate the need for pre-treatment of stormwater prior to MAR to address these potential contaminants.

Many structural BMPs are suitable as pre-treatments for MAR schemes. In general, methods that have long detention times are advantageous to reduce pathogenic microorganisms in addition to other pollutants. An advantage of using treatment with large storages (e.g. constructed wetlands) is the dilution effect if an isolated pollution event occurs, thus reducing the risk of aquifer contamination. See the BMPs in Chapter 7 for non-structural controls to reduce pollution and treat stormwater quality.

Aquifer Characterisation

The in-situ water quality of the aquifer also requires consideration. Groundwater salinity, acidity, total dissolved solids and hydrogen sulphide levels may limit the potential for MAR; conversely MAR may dilute problematic local groundwater qualities. Infiltration or injection of stormwater may not be suitable in areas with high groundwater levels. Acid sulphate soils should be investigated, as these may decrease the quality of recovered water. There is the potential for MAR to increase the concentration of some
contaminants by leaching these from the aquifer; it is therefore crucial that both the stormwater and aquifer are fully characterised, physically, chemically and biologically, prior to approval or implementation of a MAR scheme.

Water quantity issues include the recoverable volume and the impact on the surrounding environment. Under pre-development conditions, groundwater entering or recharging an aquifer system is in equilibrium with the groundwater discharge from the system. Groundwater flows are generally discharged into waterways, wetlands, oceans or deeper aquifers. When groundwater withdrawal takes place, a hydraulic gradient due to pumping changes the base flow regime. Detailed hydrologic investigations must be carried out as part of the MAR design process, including identification of ecological water requirements (EWRs) sufficient to maintain and protect groundwater dependent ecosystems under drying climatic conditions.

Factors to consider in evaluating the suitability of an aquifer include:

- environmental values of the aquifer including ecosystem maintenance of caves, wetlands, phreatophytic vegetation, surface water systems and human uses (irrigation, drinking water supply)
- adverse impacts on the environment and other aquifer users (e.g. reduced pumping pressure for nearby irrigators)
- an existing and/or future drinking water source area
- sufficient permeability and storage within the receiving aquifer
- depth of abstraction from the aquifer
- existing allocation of the aquifer and groundwater resource
- existing ambient groundwater quality and contaminant concentrations
- loss of aquifer permeability and/or infiltration due to precipitation of minerals or clogging
- possible damage to confining layers due to pressure increases
- higher recovery efficiencies of porous media aquifers
- aquifer mineral dissolution, if any
- potential for local aquitard collapse or distortion

System Controls and Monitoring

Controls should be incorporated to shut down an injection pump or valve if any of the parameters determined for the project exceed the criteria for the environmental values of the aquifer. Examples of parameters to be measured include:

- standing water level in the well
- injection pressure
- electrical conductivity (salinity)
- turbidity
- temperature
- pH
- dissolved oxygen concentrations
- volatile organics
- other pollutants likely to be present in injected water that can be monitored in real time

Other ongoing monitoring should include monitoring water levels in valuable groundwater dependent ecosystems.

Protection of the treatment and detention system from contamination is a necessary part of the MAR system design. This includes constructing treatment systems away from flood-prone land, taking care with or avoiding the use of herbicides and pesticides within the surrounding catchment, minimising planting of deciduous vegetation, and preventing mosquitoes and other pests breeding in the storage pond. Contingency
plans should be developed to cater for the possibility of contaminated water being inadvertently recharged into the aquifer. These include how to determine the duration of recovery pumping (to extract contaminated water), what sampling intervals are needed and how to manage recovered water.

A monitoring system should be designed to ensure that any treatment system is performing as expected, and that MAR is not causing any adverse impacts to the receiving aquifer. The scope and complexity of the required monitoring system will be dependent on the potential impacts of the proposal.

**Components of a MAR system**

The following material has been reproduced from *WSUD Engineering Procedures – Stormwater* (Melbourne Water 2005) with the permission of the author, to provide an overview of the main components of an MAR system.

As an example, a MAR scheme for infiltration of treated stormwater into a shallow aquifer contains the following structural elements (Figure 2):

- soakwells, swales or infiltration basins used to detain runoff and preferentially recharge the superficial aquifer with harvested stormwater
- an abstraction bore to recover water from the superficial aquifer for reuse
- a reticulation system (in the case of irrigation reuse) (will require physical separation from potable water supply)
- a water quality treatment system for recovered water depending on its intended use (e.g. removal of iron staining minerals)
- systems to monitor groundwater levels and abstraction volumes
- systems to monitor the quality of groundwater and recovered water

In addition to the above elements, an MAR system may also incorporate the following (Figure 2):

- a diversion structure from a drain
- a control unit to stop diversions when flows are outside an acceptable range of flows or quality
- some form of treatment for stormwater prior to injection
- a constructed wetland, detention pond, dam or tank, part or all of which acts as a temporary storage measure (and which may also be used as a buffer storage during recovery and reuse)
- a spill or overflow structure incorporated in the constructed wetland or detention storage
- well(s) into which the water is injected (may require extraction equipment for periodic purging)
- an equipped well to recover water from the aquifer (injection and recovery may occur in the same well)
- a treatment system for recovered water (depending on its intended use)
- sampling ports on injection and recovery lines
- a control system to shut down recharge in the event of unfavourable conditions
Refer to the Infiltration Systems, Conveyance Systems and Detention Systems BMPs for design guidelines for soakwells, swales, infiltration basins, dry/ephemeral detention areas and constructed wetlands. As this manual does not provide guidelines for ponds or constructed lakes, refer to the *Chironomid Midge and Mosquito Risk Assessment Guide for Constructed Water Bodies* (Midge Research Group of Western Australia 2006) and the *Mosquito Management Manual* (Department of Health 2006) for pond design parameters to minimise mosquito breeding risk.

**Cost**

The cost of implementing MAR systems varies significantly, depending on the level of pre- and post-MAR treatment required, peak demand on the system (and therefore the capital infrastructure costs), size of the area to be serviced, and extent of recharge and recovery infrastructure requirements. For example, injection wells tend to be much more expensive to establish and maintain than infiltration basins.
A recent analysis of a 400-lot MAR system for a residential area at Forrestdale detailed operating cost estimates as shown in Table 1. The operating unit cost of the MAR system (for garden watering only) is comparable to the current price of scheme water. It should be noted however that this MAR cost estimate does not include any capital infrastructure costs.

<table>
<thead>
<tr>
<th>Operations and Maintenance Items (Irrigation Use Only)</th>
<th>Annual Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy cost – bores and transfer pumps</td>
<td>5 200</td>
</tr>
<tr>
<td>Operations and maintenance</td>
<td>50 000</td>
</tr>
<tr>
<td>Administration costs (50%)</td>
<td>27 600</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>82 800</strong></td>
</tr>
</tbody>
</table>

**Operating Unit Cost of Non-Potable Groundwater Supply** $0.67/kL
(Source: Parsons Brinckerhoff 2005.)

GHD (2005) provide feasibility level cost estimates for a 2.3 GL/yr MAR scheme injecting and recovering stormwater from the Leederville Aquifer for the Wungong Urban Water Project at Brookdale. Total unit costs are detailed as ranging between $0.94/kL to $1.41/kL inclusive of capital, energy, maintenance and administration costs (excludes distribution costs). Capital costs for the injection scheme were estimated as ranging between $1.0–$1.4 million, with annual operating costs between $0.36–$0.60 million/yr. Recovery costs were estimated based on a separate series of bores distributed throughout the development as ranging between $0.75–$1.10/kL. However, as this proposal involves injecting water into a confined aquifer against a positive head, it would be more expensive than a scheme involving gravity feed and a smaller head (Toze, S. 2007, pers. comm.).

**Maintenance**

The developer, local authority and service provider (typically Water Corporation) are three key stakeholders in the ownership and management of the MAR systems at precinct and regional scales.

In a conventional urban subdivision, the developer enters into an agreement with the service provider on fulfilling WA Planning Commission conditions for a designated area of subdivision. The developer provides water supply, sewerage and drainage infrastructure for the subdivision. The service provider assumes ownership of the assets upon completion of the works and incorporates them into the service provider’s schemes. The service provider then operates and maintains these assets in line with their operating licence conditions.

Opportunities exist for local governments (or alternative water service providers) to undertake the management of non-potable MAR schemes as they usually manage the operation and maintenance of the public open space within shire boundaries. There are numerous examples of successful management of reuse schemes by local shires throughout regional Australia.

Monitoring equipment should be recalibrated at manufacturer’s specified intervals. Pumps and pre-treatment equipment need to be maintained (e.g. by replacing filter media at manufacturer specified intervals or volumes). Keeping maintenance records is a component of good management practice.

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1 Personal communication with Simon Toze, Principal Research Scientist, CSIRO Land and Water, 2007.
References and further reading

CSIRO 2000, Farming Ahead, No. 100, April 2000, pp. 68–69.


Department of Water 2007, Contaminants in Stormwater Discharge, and Associated Sediments, at Perth’s Marine Beaches: Beach Health Program, Department of Water, Perth, Western Australia.

Department of Water, Land and Biodiversity Conservation (undated), Fact Sheet 5, Aquifer Storage and Recovery in SA, Department of Water, Land and Biodiversity Conservation, Adelaide, South Australia.


