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Water recycling via managed aquifer recharge in Australia

P. Dillon

Water Recycling and Diversified Supplies, Water for a Healthy Country Flagship Program
CSIRO Land and Water

ABSTRACT

The number of managed aquifer recharge (MAR) projects has been increasing in Australia in recent years, partly as a response to drought and growing urban populations. Applications have largely been in cities with recycling of reclaimed water and stormwater via aquifers for urban irrigation, toilet flushing and industrial use. Drinking water supplies are now beginning to be developed using these same methods. In rural areas river water and reclaimed water have also been stored in aquifers during the wet season to supply irrigation water in the dry season. To facilitate these various developments, national guidelines for managed aquifer recharge have been developed, along with discussion papers dealing with economic and policy aspects. Even so, there are still challenges in integrating managed aquifer recharge into urban water planning and infrastructure, and in determining its effective use in groundwater resources management particularly for depleting systems. This paper will describe some of the interesting developments and the information available to assist proponents and regulators of MAR projects.

Key words: ASR, Australia, managed aquifer recharge, MAR projects, stormwater

El reciclado de agua mediante la recarga artificial en Australia

RESUMEN

El número de proyectos de recarga artificial (MAR) en Australia se la incrementado en los últimos años, en parte como respuesta a la sequía y al crecimiento de la población en las ciudades. Las aplicaciones de esta técnica en las ciudades se han realizado infiltrando agua depurada o agua procedente de tormentas en los acuíferos para su posterior utilización para el riego urbano, el uso en inodoros o el uso industrial. El suministro de agua de bebida está empezando también a utilizar estas técnicas. En zonas rurales, también se almacena el agua depurada y el procedente de tormentas en acuíferos durante la estación húmeda para suministrar agua para regadío en la estación seca. Para facilitar todas estas operaciones, se han redactado directrices a nivel nacional para la gestión de la recarga artificial, que se han complementado con documentos de discusión sobre los aspectos políticos y legales involucrados. Sin embargo, aún quedan aspectos que mejorar, sobre todo para integrar la recarga artificial en la planificación e infraestructuras de abastecimiento urbano, así como para determinar su viabilidad en la gestión de los recursos hídricos subterráneos en sistemas con importantes descensos de los niveles piezométricos. Este artículo describe algunos de los procedimientos desarrollados, así como la información disponible para ayudar a usuarios y legisladores sobre los proyectos MAR.

Palabras clave: agua de tormenta, ASR, Australia, MAR, proyectos MAR, recarga artificial

Managed Aquifer Recharge

Managed aquifer recharge (MAR) is the purposeful recharge of water to aquifers for subsequent recovery or environmental benefit. Aquifers are replenished naturally by infiltration from rainfall and from streams. The human activities which enhance aquifer recharge can be put into three categories:

1. Unintentional - such as through clearing deep-rooted vegetation, by deep seepage under irrigation areas and by leaks from water pipes and sewers
2. Unmanaged - including stormwater drainage wells and sumps, and septic tank leach fields, usually for disposal of unwanted water without thought of reuse
3. Managed - through mechanisms such as injection wells, and infiltration basins and galleries for rainwater, stormwater, reclaimed water, mains water and water from other aquifers that is subsequently recovered for all types of uses.

This paper focuses only on this final category, but acknowledges the opportunities to convert from unmanaged recharge to managed recharge with the aim of recovering water for use and protecting the environment.

MAR can be used to store water from various sources, such as stormwater, reclaimed water, mains water, desalinated seawater, rainwater or even groundwater from other aquifers. With appropriate pre-treatment before recharge and sometimes post-treatment on recovery of the water, it may be used for drinking water supplies, industrial water, irrigation, toilet flushing, and sustaining ecosystems.

Common reasons for using MAR include:

- securing and enhancing water supplies
- improving groundwater quality,
- preventing salt water from intruding into coastal aquifers,
- reducing evaporation of stored water, or
- maintaining environmental flows and groundwater-dependent ecosystems, which improve local amenity and biodiversity.

Consequential benefits may also include:

- improving coastal water quality by reducing urban discharges,
- mitigating floods and flood damage, or
- facilitating urban landscape improvements that increase land value.

MAR can play a role in increasing storage capacity to help city water supplies cope with the runoff variability in Australian catchments exacerbated by climate change. It can also assist in harvesting abundant water in urban areas that is currently unused.

An expanding range of methods is used to recharge aquifers depending on local conditions and many of these are described elsewhere (eg. Tuinhof and Heederick 2003, Dillon 2005). The simplest and cheapest form can occur where the aquifer is unconfined, soils are permeable and land is available to construct infiltration ponds. However confined aquifers can also be used and are preferred for generating drinking water supplies because of the water quality protection provided by the aquitard. Confined aquifer recharge requires injection and recovery from the same well (called aquifer storage and recovery, ASR, Pyne 2005) or from different wells (aquifer storage transfer and recovery, ASTR).

History of Managed Aquifer Recharge in Australia

The first managed aquifer recharge operations in Australia were infiltration basins established in the mid 1960s on the Burdekin Delta, Queensland. These have been operated and maintained continuously for over 40 years and are currently the largest Australian system at 45GL/yr. (Volker (ed) 1981, Charlesworth *et al*, 2002). Water from the Burdekin River was recharged to maintain elevated groundwater levels and thereby prevent the occurrence of coastal saline intrusion as a result of extensive groundwater irrigation for sugar cane production.

Recharge weirs were built on Callide and Lockyer Creeks in south east Queensland in the 1970s, and recharge via wells commenced in 1970 in the Angas-Bremer irrigation area of South Australia and expanded to 30 wells recharging 2.4GL/yr in 1992 (Gerges *et al*, 2002). This recharge helped reverse groundwater salinisation in a viticultural irrigation area. In 1979 on the commissioning of the Little Para Dam, a new water supply dam for the city of Adelaide in South Australia (Dillon, 1984), recharge releases (1.5 GL/yr) were initiated to substitute for the reduction in natural recharge downstream on the Northern Adelaide Plains. Aquifers naturally recharged from that stream support a groundwater-dependent market gardening industry.

In 1992, urban stormwater ASR was initiated at Andrews Farm South Australia in limestone and in 1994 at Regent Gardens in fractured rock (Gerges *et al* 2002). By 2008 there were 24 operating stormwater ASR projects in the Adelaide metropolitan area recharging 7GL/yr and the first stormwater ASR project had commenced injection trials in Melbourne. An infiltration gallery for stormwater recharge was established at Kensington, New South Wales in 2007.

Reclaimed water ASR began at Bolivar South Australia in 1999, via infiltration ponds at Halls Head, Western Australia in 2000 (Toze *et al*, 2002) and via infiltration galleries (covered trenches lined with gravel) at Floreat Park, Western Australia in 2005 (Bekele *et al*, 2006). Soil aquifer treatment of reclaimed water began in Alice Springs in May 2008 at a scale of 600ML/yr and this scale is likely to ultimately reach 1.8GL/yr (Knapton *et al* 2004).

ASR for drinking water supplies began with mains water began at Jandakot, Western Australia in 2000 (Martin *et al,* 2002) and with water from a shallower aquifer at Warruwi, Northern Territory in 2001 (Pavelic *et al,* 2002). Trials to inject stormwater into a brackish aquifer at Parafield ASTR project began in 2006 aimed at producing drinking water on recovery (Rinck-Pfeiffer *et al*, 2005). This has now been demonstrated with water bottled and distributed as drinking water. (Dillon *et al*, 2008) The next stage is to demonstrate a sustainable quality of water that is safe to put into mains water supplies and meets public acceptance.

Stormwater disposal wells in Mt Gambier, SA, that have operated since the 1880s, were proven in the 1990s to contribute to the city's water supply drawn from Blue Lake. Subsequently Wolf *et al* (2006) have established risk management plans that, on being

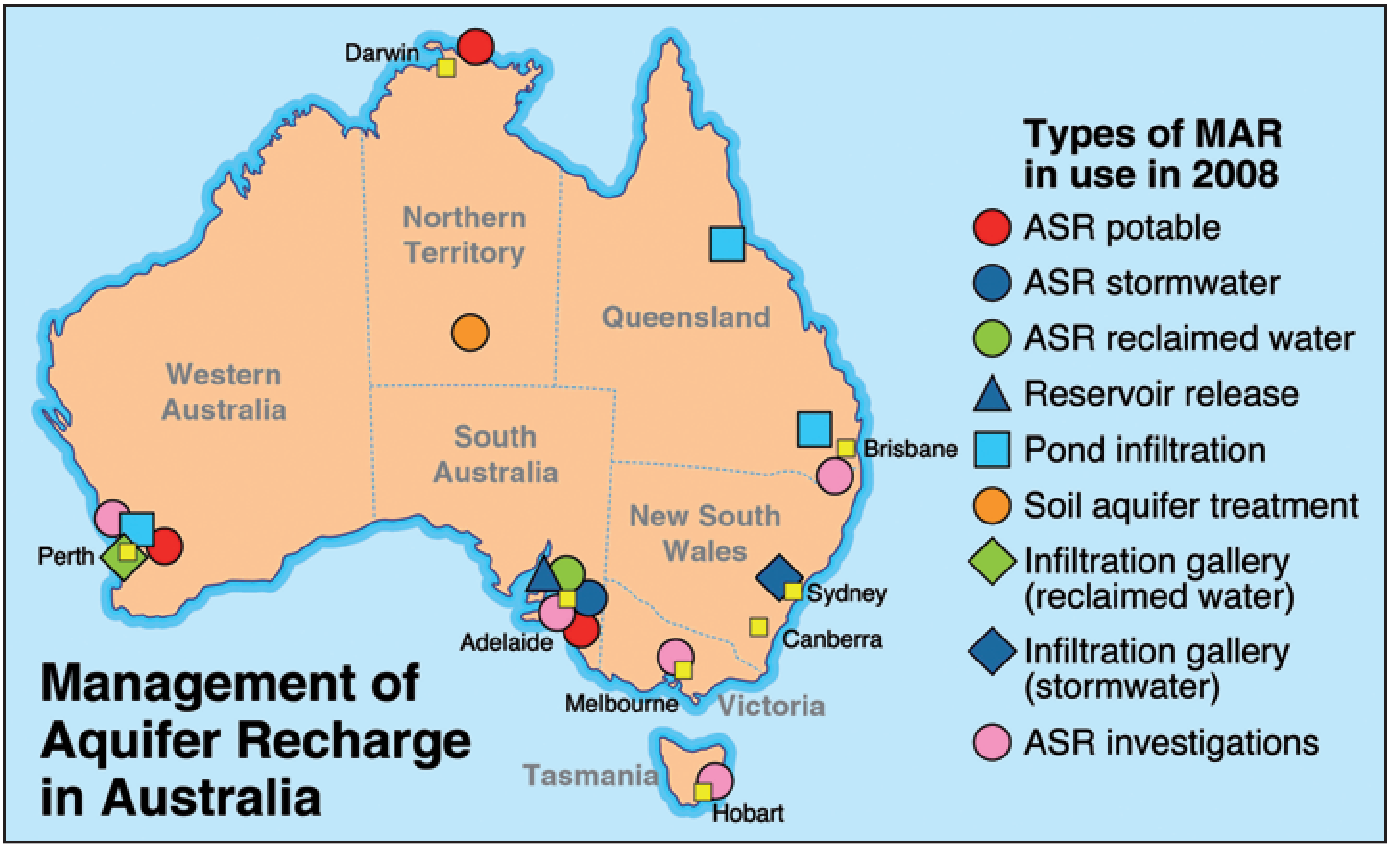


Figure 1. Locations and types of MAR in Australia in 2008
Figura 1. Lugares y tipología de instalaciones de recarga artificial en Australia en 2008

adopted, will turn unmanaged recharge to MAR. In Perth, recharge of roof runoff and stormwater into pits and basins on the sandy Swan Coastal Plain makes a substantial contribution to the water recovered from wells for household garden irrigation and also to a few mains water supply wells. Blanket risk assessments are proposed to convert this formerly unmanaged recharge to managed aquifer recharge.

In summary the number of types of MAR projects and the scale of projects have been expanding quickly in recent years. However it has taken a long time to reach this point and motivators that assist in uptake of MAR projects have been identified and are now being addressed.

Factors that assist in development of MAR projects

The six following factors have been identified as the key needs that when addressed will contribute to accelerating the rate of uptake of MAR in Australia.

1. information concerning the opportunities for MAR, particularly of maps showing the availability of suitable aquifers
2. local demonstration projects with technical and cost information made available
3. coherent water allocation policies to adequately account for MAR
4. guidelines on MAR for protection of human health and the environment
5. a holistic approach to developing future water supplies taking account of all the environmental, social and economic costs and benefits of each alternative
6. unifying fragmented water resources management responsibilities within jurisdictions.

Active steps are underway to address at least the first five of these, and this paper will mention each of these and focus on those requiring most innovation, notably guidelines and policy framework.

The National Water Commission has initiated several projects to map the opportunities for MAR in selected major urban areas, in regional centres and in rural areas where water resources are stressed. This is a relatively straight forward task for groundwater or mineral resources agencies who acquire and store the relevant hydrogeological data and maps and maintain geographic information systems (eg Hodgkin 2004). Consultants have been involved where agency personnel are not available to collate the data. The main task is to define areas with high well yields (high transmissivity), where aquifers also have additional storage capacity (eg deep water tables or confined aquifers that can withstand additional heads) and where water quality is compatible with additional storage. Generally areas in unconfined aquifers adjacent incised streams or groundwater-dependent ecosystems are avoided.

If native groundwater is saline additional considerations to produce acceptable recovery efficiency of fresh recharge are to avoid areas with steep lateral hydraulic gradients, or fractured or karstic media. Simpler hydrogeological conditions are favoured over complex ones, because fewer monitoring wells are needed to interpret aquifer behaviour. If there are multiple aquifers present usually a map is prepared of MAR suitability for each aquifer and a composite map is used to show the best prospects everywhere regardless of aquifer. These maps themselves are not a substitute for site investigations, but they are valuable in helping to focus investigations on the most prospective sites based on existing information. It is hoped that an international initiative in the area of groundwater mapping will be able to assist other countries with this element.

Local demonstration projects are beginning to be dispersed more widely in Australia, as described previously, but there are many areas without a local project and so developers of water supply projects often appear unaware of groundwater, especially if it is brackish. MAR can make use of brackish aquifers to store fresh surface water. Ward *et al* (in press) describe the effects of hydrogeological and operational characteristics of ASR sites on the recovery efficiency in brackish to hypersaline aquifers, taking account of density effects.

Where MAR projects have been established and are successful, replication is quick to follow within the same city. However transferring experiences from one city to another is difficult. This hopefully will become easier through the use of maps of MAR opportunity, but local circumstances normally require adaptation of specific solutions that may differ from those employed elsewhere. Proponents and regulators also need to gain experience in implementing and evaluating projects and a local demonstration project provides this experience first hand (Martin and Dillon 2002).

Technical information on MAR operations are increasingly available in the proceedings of the series of International Symposia on Managed Aquifer Recharge. Proceedings of the last two symposia may be downloaded from the International Association of Hydrogeologists Commission on MAR website: www.iah.org/recharge. This includes guidance on strategies for MAR in semi-arid areas (Gale 2005, UNESCO 2002) and cites other national strategies (eg South Africa; Murray *et al* 2007). Cost information is more difficult to find but the National Water Commission have published a report that assembles known recent Australian information (Dillon *et al* 2009). This found that stormwater ASR could produce supplies for less than half the cost of seawater desalination and using only 3% of the energy. Rural pond infiltration was found to be an order of magnitude cheaper than ASR systems.

Policy frameworks and guidelines are described in the sections below, after first considering the steps in establishing a MAR project.

Water resources planning for urban areas suggests that alternative sources will be identified costed and the cheapest source that meets all other criteria will be selected. In Australia these decisions are made by state governments generally on the advice of their water utilities. The other criteria such as environmental costs and benefits of alternatives need to be taken into account in a transparent way. Dillon *et al* (2009) suggest a conceptual framework for this taking account of issues such as coastal water quality, urban amenity, flood mitigation, and greenhouse gas emissions.

Unification of fragmented water resources management responsibilities within jurisdictions is an issue for jurisdictions and cannot be addressed in this paper. However in general the principle that reducing the number of agencies to deal with allocation and quality issues for both surface water and groundwater will simplify approval processes for MAR projects. An alternative is to form a cross-departmental panel to coordinate approvals with one agency assigned responsibility for sign off.

Steps in Establishing a MAR project

There are five essential elements for every successful MAR project:

- a sufficient demand for recovered water
- an adequate source of water for recharge
- a suitable aquifer in which to store and recover the water

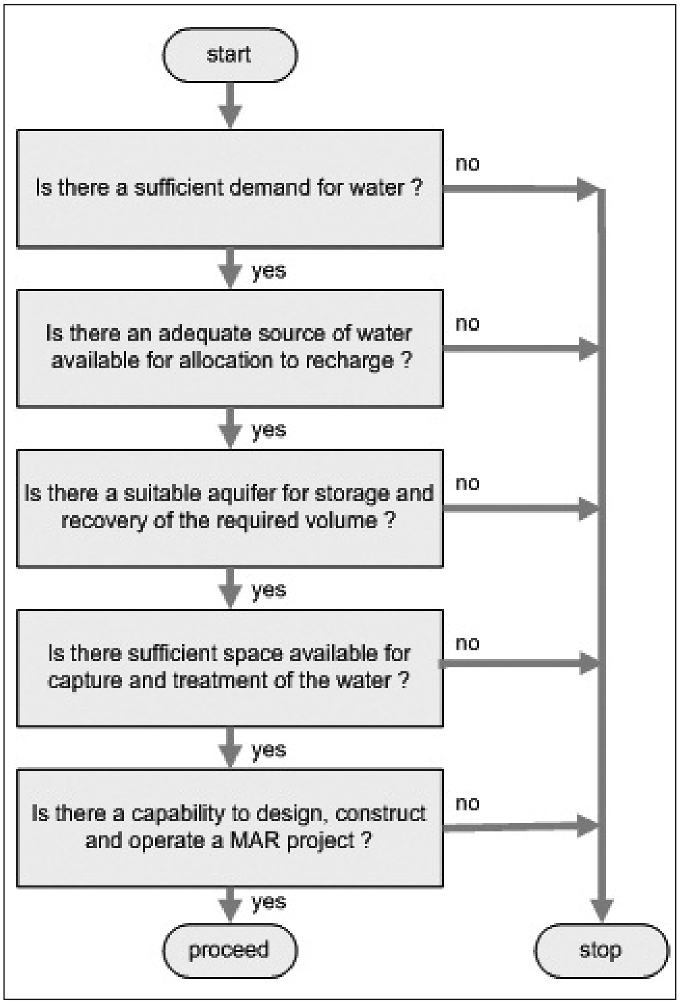


Figure 2. A checklist for considering whether to undertake a managed aquifer recharge project
Figura 2. Pasos a considerar durante las fases de un proyecto de recarga artificial

- sufficient land to harvest and treat water
- capability to effectively manage a project

Australian Guidelines for Managed Aquifer Recharge (NRMMC et al, 2009) require a desktop (entry level) assessment, essentially the above checklist, to assess the viability of a proposed MAR project together with subsequent questions to assess its likely degree of difficulty.

Viability assessment focuses first on demand for recovered water because demand is the driver for investment in a sustainable project that protects the quality of groundwater and of recovered water. The remaining questions address entitlements to source water quantity, the physical capability of the aquifer to store additional water, the availability of land to allow water harvesting and treatment and the capability to manage a project (which can be developed through demonstration projects).

These basic water access entitlement and planning regulation issues are addressed before considering water quality which generally requires more detailed knowledge. Water allocation decisions will generally be based on existing information set within the context of the whole water catchment and aquifer system, and on the proposed volumes of recharge and recovery. These either result in a decision to proceed to the next step or that the proposed project is unviable.

Positive answers suggest that the project is potentially viable, and lead to a checklist that helps inform proponents of the degree of difficulty of their conceived project. This serves as a guide to the amount of effort required in project investigations and commissioning trials in order to manage human health and environmental risks in accordance with the National Water Quality Management Strategy. For example storing water in an aquifer used as drinking water supply will require considerably more management effort than storing water in a similar aquifer that is brackish because projects will need to demonstrate that they protect all existing beneficial uses of the aquifer. Similarly projects undertaken near groundwater-dependent ecosystems will require more monitoring and possibly a higher level of pre-treatment than those in the same aquifer but further from such ecosystems.

Costs of MAR investigations and trials are not trivial and, having completed this checklist, the proponent should know whether their proposed project has a low or high degree of difficulty and the types of information which will be of most value in the investigation stage. Because of the costs of these investigations it is normal to first seek assurance that at least the core approvals for MAR are likely to be obtained, before undertaking such investigations, noting that some approvals will not be possible until after the investigation stage.

If the project looks potentially viable, having taken account of the likely degree of difficulty, at this the first stage, the MAR Guidelines (NRMMC et al, 2009) lead proponents through the investigations (Stage 2) and commissioning trials (Stage 3) to an operational project (Stage 4) as described later.

Regulation of MAR

MAR can provide some challenges for regulators due to the range of considerations required. Water quantity and quality issues for both surface water and groundwater generally need to be addressed for any MAR project (see Table 1).

Water quality evaluations will require more exact localised information on aquifer properties and source water quality, some of which is likely to require site-specific investigations. This explains the prime importance of the viability assessment of the MAR Guidelines (NRMMC et al, 2009). The next sections of this paper deal with the left and right side of this matrix (Table 1) respectively.

Policy framework for MAR

For the first MAR projects in any area there will be no requirement to have clearly defined water allocation policies in relation to MAR. Just as with the early stages of groundwater development, there is no need to restrict wells or extraction so long as the resource can meet demand without adverse outcomes for users or the environment. Ultimately the time may come when human intervention in the system creates new problems and wise management suggests that policies be prepared for this eventuality.

The water resources planning framework proposed for MAR in Australia (Ward and Dillon 2009) follows an existing system of entitlements, allocations and use conditions for surface water and groundwater. A regulator for each catchment or groundwater system assigns an *entitlement* to users of water in that system after allowing first for an environmental entitlement.

Attribute	Quantity (not part of MAR guidelines)	Quality (addressed in MAR guidelines)
Management Issue Resource	Water and Storage Entitlements and Allocations	Human Health and Environment Protection
Surface water	• Environmental flow requirements • Water allocation plans and surface water entitlements • Inter-jurisdictional agreements	• Catchment pollution control plan • Water quality requirements for intended uses of recovered • Risk management plan for water quality assurance
Groundwater	• Groundwater allocation plan and groundwater entitlements • Resource assessment accounting for groundwater-dependent ecosystems • Demand management • Allocatable capacity and entitlement for additional storage in the aquifer • Inter-jurisdictional agreements	• Groundwater quality protection plan for recharged aquifer • Water quality requirements for intended uses of groundwater • Risk management plan for water quality assurance beyond attenuation zone, accounting for aquifer biogeochemical processes

Table 1. Water resources management and environmental protection issues to be addressed in establishing MAR projects
Tabla 1. Gestión del agua y aspectos de protección medioambiental a tener en cuenta al poner en marcha proyectos MAR

In dry years there may be less water available than can meet each shareholder's entitlement, and the regulator determines the *allocation* within that year or period, normally as a specified percentage of each entitlement. This ensures that each user shares uniformly in the restrictions imposed by dry years or years when groundwater storages are low. Allocations vary from year to year, and even from month to month in some river systems, whereas groundwater allocations are often set over longer time scales, typically 5 years.

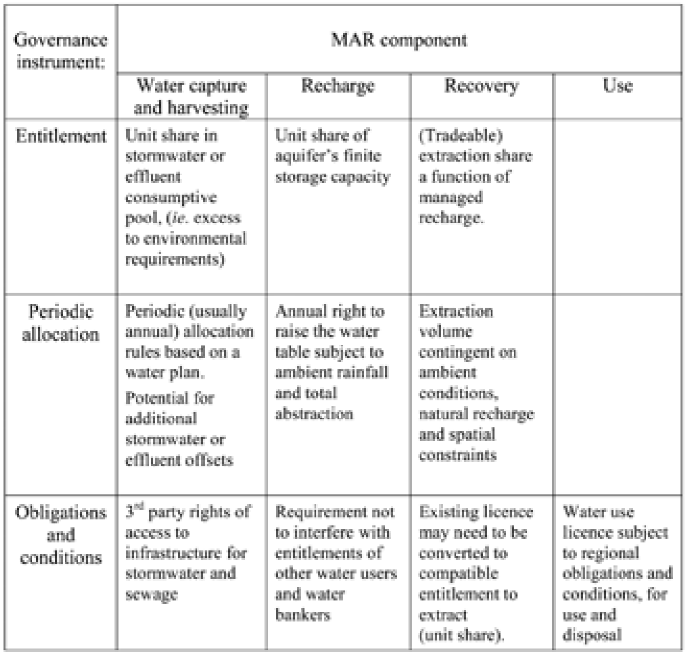
Finally *conditions of use* may also be imposed, for example to foster increased irrigation efficiency, or to give priority to say drinking water supplies over other uses when allocations are very low. An additional ingredient in these water allocation arrangements is the ability for trading of entitlements and allocations among existing and new water users within the catchment or groundwater system. That is one user can sell part or all of their perennial entitlement or their current year's allocation to another user. This assists water to be used for its highest valued uses within a catchment or basin.

There are four discrete components for any MAR project which warrant separate entitlement, allocation and use conditions to allow effective management of one or many MAR projects within a catchment or aquifer; (1) water capture and harvesting; (2) recharge, (3) recovery, and (4) use. Table 2 shows a robust separation of water rights for discrete elements of a MAR system as a possible policy framework for addressing MAR on a sustainable basis. For further details see Ward and Dillon (2009).

Guidelines to Protect Human Health and the Environment

The MAR Guidelines (NRMMC et al, 2009) are part of the Australian Guidelines for Water Recycling within the National Water Quality Management Strategy. The MAR guidelines specifically aim to protect the environmental values of all intended uses of recovered water and of the aquifer beyond a transient attenuation zone, and to prevent adverse impacts. This is done by assessing potential hazards and the risks associated with each, and identifying preventive measures to manage the risks.

The hazards addressed in the guidelines are:



Governance instrument:	MAR component			
	Water capture and harvesting	Recharge	Recovery	Use
Entitlement	Unit share in stormwater or effluent consumptive pool, (*ie.* excess to environmental requirements)	Unit share of aquifer's finite storage capacity	(Tradeable) extraction share a function of managed recharge.	
Periodic allocation	Periodic (usually annual) allocation rules based on a water plan. Potential for additional stormwater or effluent offsets	Annual right to raise the water table subject to ambient rainfall and total abstraction	Extraction volume contingent on ambient conditions, natural recharge and spatial constraints	
Obligations and conditions	3rd party rights of access to infrastructure for stormwater and sewage	Requirement not to interfere with entitlements of other water users and water bankers	Existing licence may need to be converted to compatible entitlement to extract (unit share).	Water use licence subject to regional obligations and conditions, for use and disposal

Table 2. A proposed policy framework based on robust separation of water rights for discrete elements of a MAR system

Tabla 2. Marco de actuación propuesto basado en una clara superación de derechos de agua para elementos concretos de un sistema MAR

- Pathogens
- Inorganic chemicals
- Salinity and sodicity
- Nutrients
- Organic chemicals
- Turbidity/particulates
- Radionuclides
- Pressure, flow rates, volumes and levels
- Contaminant migration in fractured rock and karstic aquifers
- Aquifer dissolution and aquitard and well stability
- Impacts on groundwater dependent ecosystems
- Greenhouse gas emissions

For each hazard the guidelines document sources or causes, the effect on public health and environment, how it can be managed, including preventive measures, the proposed validation, verification and operational monitoring, and list the acceptance criteria for the various stages of risk assessment. Several stages are required because not all necessary information is available at the start and some assumptions or predictions can only be validated after construction.

A simplistic view that treating water to near drinking standards before recharge will protect the aquifer and recovered water is incorrect. For example chlorination, to remove pathogens that would be removed in the aquifer anyway, can result in water recovered from some aquifers containing excessive chloroform. In some locations, drinking water injected into potable aquifers has resulted in excessive arsenic concentrations on recovery due to reactions between injected water and pyrite containing arsenic. Source water that has been desalinated to a high purity dissolves more minerals within the aquifer than water that has been less treated. Consequently the MAR guidelines adopt a scientific approach accounting for three ways that aquifers interact with recharged water:

1. Sustainable hazard removal - the guidelines allow for pathogen inactivation, and biodegradation of some organic contaminants during the residence time of recharged water in the soil and/or aquifer within an attenuation zone of finite size,
2. Ineffective hazard removal - these hazards need to be removed prior to recharge because they are either not removed (eg salinity) or removal is unsustainable (eg adsorption of any metals and organics that are not subsequently biodegraded, or excessive nutrients or suspended solids),
3. New hazards introduced by aquifer interaction (eg metal mobilization, hydrogen sulphide, salinity, sodicity, hardness, or radionuclides) - there is a need to change the quality of recharge water to avoid these (eg change acidity-alkalinity, reduction-oxidation status or reduce nutrients).

The response of an aquifer to any water quality hazard depends on specific conditions within the aquifer, including temperature, presence of oxygen, nitrate, organic carbon and other nutrients and minerals, and prior exposure to the hazard. The guideline indicates the state of current knowledge on attenuation rates of pathogens and organic compounds under a range of conditions, and provides for new local knowledge to be taken into account in assessing risks and determining sizes of attenuation zones and siting of monitoring wells (see Fig 3).

In most aquifers, and with appropriate pretreatment of water to be recharged, the attenuation zone will be small and generally of the order of 20 to 200 m from the recharge area or well. Water that travels further has had sufficient residence time in the aquifer for attenuation of pathogens and contaminants to below the relevant guideline values for native groundwater and intended uses of recovered water. As the attenuation zone is defined only for enduring attenuation processes, on cessation of the MAR operation this zone will shrink and disappear as ultimate-

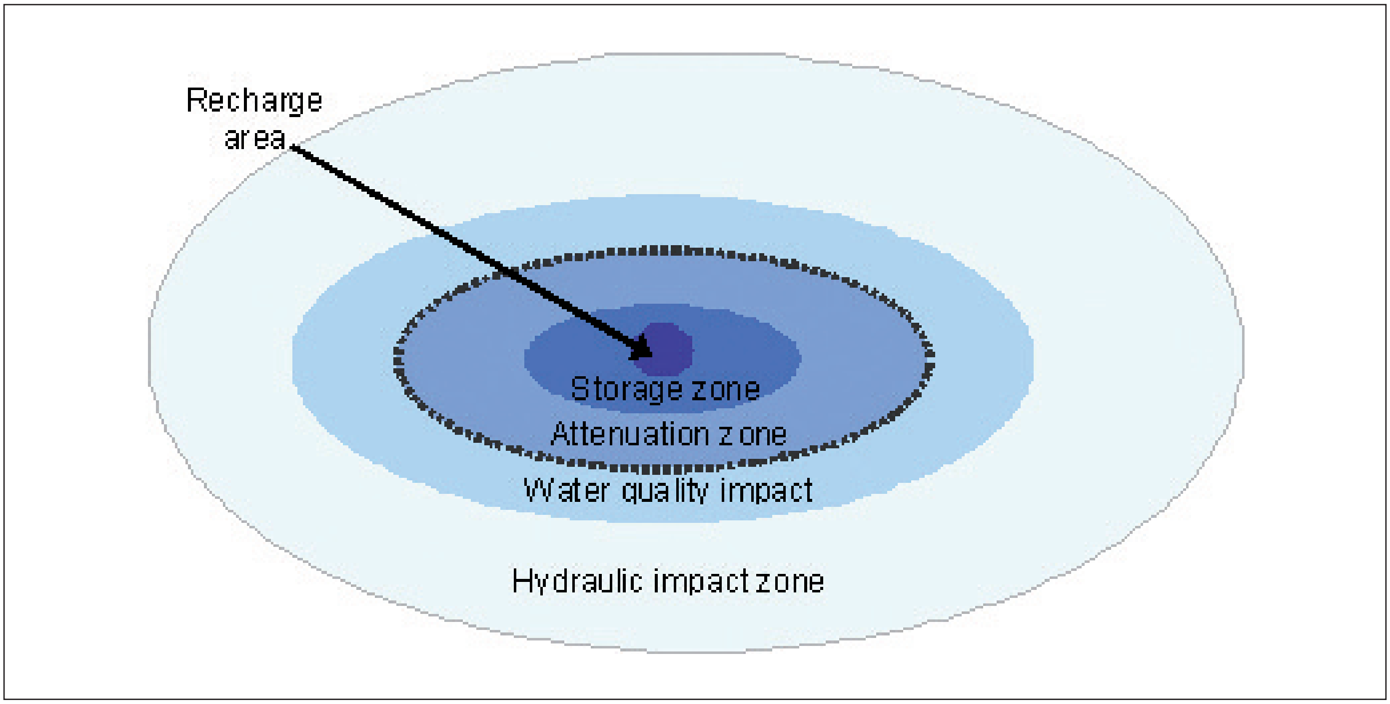


Figure 3. Schematic showing zones of influence of a MAR operation. Monitoring wells to verify attenuation are placed on the boundary of the attenuation zone (ie on the dotted line)
Figura 3. Esquema que muestra diferentes zonas de influencia en un proyecto MAR. Los piezómetros de control para comprobar la atenuación se localizan en la frontera de la zona de atenuación (por ejemplo, en la línea de puntos)

ly the whole aquifer will meet all its initial environmental values (a term that embraces applicable beneficial uses and ecosystem support).

The zone of aquifer in which water quality may be measurably affected by MAR may be larger, but in this outer domain the water quality should continuously satisfy the initial environmental values of the aquifer. The effects of MAR operations on hydraulic heads (pressures) may be measurable over a much larger area, especially in confined aquifers. If the aquifer is originally too saline for the uses of recovered water, a storage zone can be identified that contains water which, when recovered, is fit for its intended use.

Guidance on other hazards such as excessive flow rates and pressures is aimed at protecting against high water tables and nuisance discharges of MAR projects in unconfined aquifers or by making other wells artesian, and against bursting of aquitards (confining layers capping confined aquifers).

The guidelines also provide advice on several MAR operational issues:

1. Clogging (which in low permeability aquifers can be a tighter constraint on quality of recharge water than health and environmental protection requirements)
2. Recovery efficiency (proportion of recharged water that can be recovered at a quality fit for its intended uses, which may be a constraint in brackish aquifers)
3. Interactions with other groundwater users
4. Protection against saline water intrusion
5. Operations designed to protect groundwater dependent ecosystems (GDEs)
6. Management of purge water, basin scrapings and water treatment by-products

A chapter is devoted to monitoring, addressing the three main purposes, and taking account of modern instrumentation, data acquisition systems and web-based reporting to reduce the effort and increase the information content for the purposes of ensuring that risks are managed effectively.

Conclusions

Over the last decade Australia has learned much by undertaking demonstration projects for various types and purposes of managed aquifer recharge in a range of hydrogeological and catchment settings with different types of water and end uses. Research at these sites has provided a scientific foundation to underpin guidelines for MAR. Experience gained forms a basis to assist with mapping of opportunities for MAR, to evaluate economics of MAR with respect to alternative water supplies and to develop a policy framework consistent with the national water reform agenda. These developments are intended to stimulate appropriate and sustainable use of MAR to develop cost-effective reliable new water supplies. So far less than 60 GL/yr of water is supplied via MAR in Australia, and opportunities are likely to exceed 300 GL/yr. More transparent urban water resources planning and investment, institutional adjustments and continuing communication, research and training will be needed to ensure that the full benefits of MAR are captured in Australia. It is hoped that Australian experiences will be useful for other countries in need of securing urban and rural water supplies for drinking and non-potable uses.

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