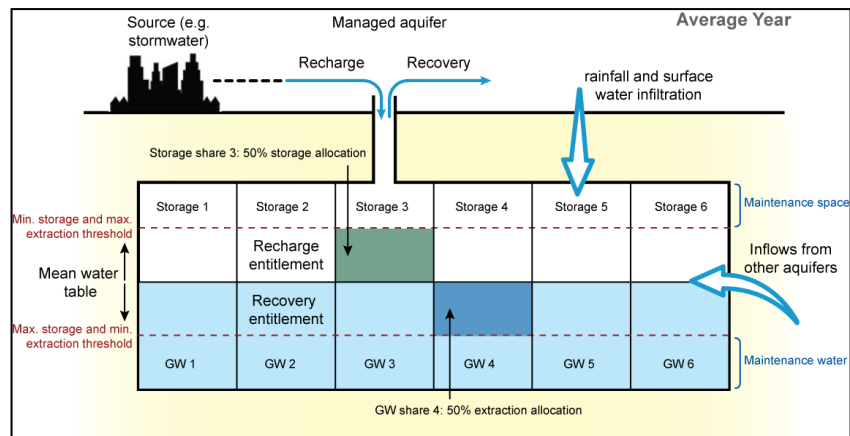




Robust policy design for managed aquifer recharge

John Ward and Peter Dillon

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Abbreviations and acronyms

AGWR	Australian Guidelines for Water Recycling
ASR	Aquifer storage and recovery
ANZECC	Australian and New Zealand Environment Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
COAG	Council of Australian Governments
EPHC	Environment Protection and Heritage Council
MAR	Managed aquifer recharge
NHMRC	National Health and Medical Research Council
NRM	Natural resource management
NRMMC	Natural Resource Management Ministerial Council
NWC	National Water Commission
NWQMS	National Water Quality Management Strategy
NWI	National Water Initiative
PC	Productivity Commission
RNWS	Raising National Water Standards
S	Salinity
T	Hydraulic retention time

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Executive summary

The National Water Initiative (NWI) (COAG 2004) remains the primary and enduring national blueprint for the reform of institutions and governance in Australian urban and rural water jurisdictions. One of the contemporary challenges for the urban water sector is meeting community and political expectations, articulated in the NWI, for the cost-effective supply of fit-for-purpose water at agreed levels of security. Managed aquifer recharge (MAR) has assumed a recognised and important role in the portfolio of urban water management strategies being implemented to meet that challenge.

As the level of MAR increases, the choice and implementation of alternative policy instruments, governance arrangements and incentives to help promote and coordinate MAR also assume increasing importance. In addition to ensuring adherence to water quality obligations, governance frameworks will need to provide for rights of access, rights to exclude, rights of ownership and the rights to manage source, stored and recovered water in a changing world.

Current Australian MAR schemes are subject to an array of discrete policy provisions, at times attempting to comply with competing and uncoordinated policy requirements for each of four MAR operational elements (source-water harvesting, aquifer storage, recovery and end-use). MAR operations are obliged to comply with well-established water quality guidelines and legislation to ensure human health and environmental integrity. However,

- jurisdictional policies providing for access to Australian urban source water for MAR remain fragmented and poorly defined
- there are no Australian examples of fully specified and enforceable rights entitling operators to a secure, non-contentious share of a defined aquifer storage space
- current legislation determines that upon aquifer recharge, source water is subject to the extraction and management rules of native groundwater. The right to extract MAR-recharged water in a fully allocated and potentially overdrawn groundwater system remains poorly or informally defined.

The absence of well-defined entitlements to access stormwater and recycled water and recover aquifer recharge is likely to result in uncertain aquifer recharge and extraction, litigation, potential degradation of receiving environments and the failure of MAR to achieve its full potential value in Australian water resources management.

The acceleration of implemented and intended MAR projects has warranted a systematic and comprehensive analysis of alternative policy options and frameworks consistent with the NWI. As part of the Raising National Water Standards program, Ward and Dillon (2009) combined the main operational elements of MAR with the principles of the robust separation rights into a unified framework, suggesting a systematic governance arrangement that complies with NWI reform objectives. The framework allows for the independent and flexible management of each element of a MAR operation, summarised in Table 1.

Based on a comprehensive water plan, robust separation requires a three-tiered system of separate and independently managed instruments to distribute and allocate shares of consumptive water efficiently over time; these are entitlements, periodic allocations and final-use obligations. Ward and Dillon applied the principles of robust separation to each aspect of a MAR scheme, evaluating the feasibility of meeting NWI reform objectives and identifying likely operational impediments.

Table 1: NRM governance instruments for MAR based on the robust separation of rights

<i>MAR governance instrument</i>	<i>Source water harvesting</i>	<i>Recharge</i>	<i>Recovery</i>	<i>End-use</i>
Entitlement (tradeable)	Unit share in stormwater or effluent consumptive pool, (i.e. available water in excess of environmental flows).	Unit share of aquifer's finite additional storage capacity.	Extraction or recovery share (function of managed recharge volume).	N/A
Periodic allocation (tradeable)	Periodic (usually annual) allocation rules. Potential for additional stormwater or treated effluent with high flows or development 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.	N/A
Obligations and conditions of use	Third party rights of access to infrastructure for stormwater and sewage mining.	Requirement not to interfere with entitlements of other water users and MAR operators.	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.

Australian urban water agencies and industries were invited to critically review the MAR policy and governance framework proposed by Ward and Dillon, recommending revisions sharpened through the lens of experience and operational and implementation challenges specific to each jurisdiction.

This Waterlines publication synthesises practitioner and agency insights and recommendations for the robust design of MAR operations, summarised as:

Source waters: stormwater harvesting is subject to intermittent, short duration and potentially high flows compared to systems with a stronger, more predictable base flow component. Hence assigning stormwater harvesting entitlements may be possible but initially impractical because of the high transaction costs of managing unpredictable flow volumes and frequencies. One initial solution would involve the issuing of volumetric licences by a local council (the infrastructure owner) to all stormwater MAR-harvesting operations within the same catchment. As the MAR harvesting operations mature and certainty improves, licences could be converted to tradeable entitlements and additional public or private harvesting infrastructure constructed.

Sewage-harvesting entitlements would specify obligations to ensure that any changes in effluent quality should neither adversely compromise the uses of water discharged from the sewage treatment plant, nor the discharge loads of contaminants and nutrients.

Aquifer recharge and storage: recharge entitlements in general will not be an issue in over-exploited aquifers, as there would be adequate aquifer storage capacity for multiple MAR operations, and MAR would be welcomed as a means of restoring hydrological equilibrium.

In aquifers that are in existing long-term balance or where piezometric levels are trending upwards over a number of years, recharge capacity is finite. Recharge entitlements and periodic allocations will need to specify actions to avoid excess recharge and subsequent

rising water-tables, potentially causing flooding, water logging, damage to building structures, dryland salinity, unintended discharge of groundwater or causing wells to become artesian.

In a brackish aquifer, spatially proximate wells can affect the shape of fresh-water plumes of neighbouring wells. Close coordination of operations will be required to minimise the adverse effects on groundwater hydraulic pressure and the salinity concentrations of recovered water. The recharge entitlement will need to include spatial specifications for well location to ensure buffering between operators and minimise operator conflict.

Recovery of stored water: substantial discussion centred on the recovery of aquifer recharge. Dimensions described in determining recovery entitlements include:

- the proportion of recharged volume that may be recovered
- the time period over which recharge credits may be recovered
- linkages between the volume that may be recovered and the time period (e.g. a depletion rate)
- the maximum annual recovery
- the transfer of entitlements and allocations to recover water to other groundwater users.

A transitional pathway is suggested that allows the progression from each jurisdiction's current policy position of source water harvesting, recharge, recovery and end-use towards NWI-conforming governance arrangements. The transitional pathway is intended to guide inclusive, ongoing and constructive discussion in urban jurisdictions.

The trigger points at which a jurisdiction would move from a permit-based system to an entitlement system for MAR in a given catchment or groundwater basin are illustrated through two contrasting Australian examples. The 'open-closed- typology described by Falkenmark and Molden (2008) was applied to the historical development of surface and groundwater resources in the Murray-Darling Basin and northern Australia groundwater systems. The northern Australian example best represents the current early stage of stormwater harvesting, sewage recycling and MAR development in Australia.

Existing legislation and policies will require careful effort to adapt to market innovations in urban water management to ensure the benefits of MAR are free from adverse consequences. Modifying policies now to conform to a nationally consistent framework based on the principles of the NWI will give investors confidence in MAR, facilitate its use to achieve broad NRM and urban water objectives, and minimise the likelihood of perverse outcomes.

1 Introduction

The National Water Initiative (NWI) (COAG 2004) remains the primary and enduring national blueprint for Australian urban and rural water reform. Despite considerable change in Australia's urban and rural water circumstances in the five years since the NWI was ratified, the policy prescriptions and objectives continue to be widely accepted as salient and appropriate for Australia.

Recent reviews by the National Water Commission (NWC 2009), the Productivity Commission (PC 2008) and the Council of Australian Governments (COAG 2008) conclude that while the reform process has made substantial progress in addressing the constraints and tensions associated with rural water resources, the reforms have had limited influence on the management of urban water systems. The reviews recommend an institutional and economic analysis emphasising the policy requirements needed to clearly define secure and flexible entitlements to facilitate, where appropriate, a market-based transfer of water volumes. Transferable entitlements, central to the NWI reform process, are also likely to play an important role in managing recycled water, inclusive of managed aquifer recharge (MAR).

The robust separation of rights (Young and McColl 2003), implemented as independently managed and tradeable entitlements, periodic allocations and final-use obligations, has played a key role in the NWI reform architecture.

As part of the Raising National Water Standards program, Ward and Dillon (2009) developed a set of NWI-consistent principles to guide policy initiatives that promote, coordinate and maintain the development and adoption of MAR in Australian urban centres. Combining the main operational elements of MAR with the principles of the robust separation rights into a unified framework suggested a systematic governance arrangement that complies with NWI reform objectives. The framework allows for the independent and flexible management of each element of a MAR operation, often characterised by uncoordinated and potentially exclusive policy objectives.

This MAR Waterlines publication synthesises the insights and recommendations gained from a series of workshops attended by members of state and Commonwealth agencies and industries concerned with managing urban water systems, especially MAR. Participants were invited to critically review the MAR policy and governance arrangements proposed by Ward and Dillon, and suggest revisions sharpened through the lens of operational and implementation challenges specific to each jurisdiction.

Focusing on water and natural resource management (NRM) policies and their current readiness for MAR, this publication spells out some of the issues relating to the coordinated design and implementation of urban water policy, accounting for hydrogeological settings; the level of water utilisation in the surface water catchment supplying source water for MAR; and coordinating MAR recovery with existing native groundwater extractions in the proposed storage aquifer. It describes the role of MAR in urban water systems, the characteristics of the robust separation of water rights, and recommendations from the workshops, applying robust design principles to the four operational elements of MAR: source water harvesting, aquifer recharge, the recovery of stored water and final use.

2 The role of managed aquifer recharge in urban water management

MAR is the intentional recharge of water to aquifers for subsequent recovery or environmental benefit, gaining a recognised role as one element in the portfolio of urban water management strategies. There are four primary and distinguishable operational processes or elements of the urban water-management cycle that are utilised by MAR: the harvesting of source waters, the storage of recharge in an aquifer, the recovery of stored water and end-use. Sources of water, following appropriate treatment, can be recharged, stored within an aquifer and then recovered at a quality suitable for a specified end-use. All the operational elements are subject to compliance with state regulations and standards of human and environmental health, addressed in the Natural Resource Management Ministerial Council (NRMMC), the Environment Protection and Heritage Council (EPHC) and the National Health and Medical Research Council in the Australian MAR guidelines (NRMMC, EPHC, NHMRC 2009a).

Source waters for aquifer recharge include stormwater, reclaimed water (including water treated to potable standards), desalinated water and natural waters. The harvesting, storage and recovery of source waters in aquifers have the potential to buffer seasonal water shortages, mitigate the stress of drought, supplement environmental flows and defer the development costs of new water supplies in Australian cities. MAR has the capacity to augment domestic and industrial supply by converting urban water waste streams and high-flow flood events into more reliable groundwater base flow. As a corollary, the resource characteristics of MAR source waters are rapidly changing from one of a waste stream requiring disposal to one of economic and commercial value.

Recovered MAR water can cost-effectively satisfy diverse water demands by supplying users requiring non-potable water at generally lower treatment costs. Satisfying the demand for water differentiated by quality with fit-for-purpose MAR water effectively extends the potable mains-water supply of water-stressed urban systems and defers the costs of potable water augmentation. Other advantages of MAR include minimisation of evaporation losses characteristic of traditional surface storages and attenuation of pathogen and contaminants during aquifer residency. The latter may be of use for future potable applications (Dillon and Toze 2005).

MAR resources can be used for various purposes with different priorities, depending on circumstances. For example, in conjunction with demand management, MAR resources can contribute to the restoration of over-exploited aquifers, meet human needs through direct supply or potable substitution, supplement/replace environmental flows, protect against saline intrusion and sustain water-dependent production processes through drought periods.

Any one MAR project may confer multiple benefits and address multiple policy objectives to varying degrees, e.g. urban stormwater aquifer storage and recovery on the Northern Adelaide Plains:

- substitute for water supplies drawn from the water-stressed River Murray and Mount Lofty Ranges catchments
- reduce discharge of suspended solids to ocean outfalls contributing to marine habitat restoration
- provide net replenishment of an aquifer heavily exploited for irrigation
- provide a commercial return as recovered water can be profitably sold to meet the demands of localised non-potable uses at less than the cost of potable water.

Although MAR has a potentially high aggregate social value through contributions to multiple NRM and economic objectives, it is predominantly the commercial uses of MAR that create the current incentives for MAR projects. However, co-investment by the Commonwealth and states has created MAR projects where shorter-term commercial gains and longer-term social benefits coincide.

Converting surface water with no or low security entitlements to fully specified source and groundwater entitlements creates opportunities for commercially competitive MAR operations. Currently urban stormwater or recycled water is not securely entitled across the majority of Australian jurisdictions. Opportunities for MAR are particularly evident in urban areas where the price of potable water is rising to cover the recent backlog of capital investment in securing supplies, coupled with the imperative to reflect the full cost of water supply. As rainfall-dependent sources are depleted during dry periods, the value of recovered water is expected to be higher than during the periods of high recharge. That is, storing water in the aquifer can add value to the water resource. The marginal increase in the value of recovered MAR water is likely to be enhanced in competitive water markets or where reticulated water prices more accurately reflect water's relative scarcity and full supply costs.

In establishing new MAR projects, the management of water resources needs to be addressed in concert with local health and environmental protection. The latter is addressed in the Australian MAR guidelines (NRMMC, EPHC. –NHMRC 2009a). Table 1 summarises the key water quantity and water quality attributes considered in the analysis and design of integrated policy frameworks to facilitate MAR operations.

As the scale of MAR operations increases, the choice and implementation of alternative policy instruments, governance arrangements and incentives to assist with promotion and coordination also assume increasing importance. The lack of policy in this area in the face of accelerated MAR developments has been the primary motivation for this body of research.

Table 2: Integrated natural resource management and health environment issues to be addressed for effective governance of MAR (adapted from Dillon et al. 2009a)

	<i>Quantity Water source and storage entitlements and allocation</i>	<i>Quality Human health and environment protection</i>
Surface water	Environmental flow requirements (including urban stormwater and sewage effluent). Water allocation plans and surface water entitlements. Inter-jurisdictional agreements.	Catchment pollution control plan. 'Water quality requirements for intended uses of recovered water' (<i>Australian guidelines for water recycling</i> (AGWR) phases 1, 2). 'Risk management plan for water quality assurance' (AGWR phases 1, 2).
Groundwater	Groundwater allocation plan and groundwater entitlements. Resource assessment accounting for groundwater-dependent ecosystems. Demand (consumptive use) management. Allocatable capacity and entitlement for additional storage in the aquifer. Transfer of entitlements from MAR operations. Inter-jurisdictional agreements.	Groundwater quality protection plan for recharged aquifer in accordance with <i>Groundwater protection guidelines</i> (ANZECC–ARMCANZ, 1995). Water quality requirements for intended uses of groundwater ('Water quality guidelines for fresh and marine waters, 2000', AGWR phase 1 2006 or 'Augmentation of drinking water supplies, AGWR phase 2A 2008). Risk management plan for water quality assurance beyond attenuation zone, accounting for aquifer biogeochemical processes.

3 Policy changes to facilitate MAR development

Ward and Dillon (2009) classified Australian state policy instruments according to their role in the management of source-water harvesting, aquifer recharge and the recovery of stored water. The primary objectives of the evaluation were to identify the degree of NWI policy alignment, instrument consistency and potential impediments to market approaches to efficiently allocate urban water. Table 3 summarises the classification.

Table 3: Summary of MAR entitlements and allocations in Australia jurisdictions and International policy frameworks to manage MAR operations

<i>Jurisdiction</i>	<i>Entitlement and allocation policy for stormwater or sewage</i>	<i>Entitlement and allocation policy for recharge</i>	<i>Entitlement and allocation policy for recovery (including transfer)</i>	<i>End-use obligations</i>
ACT	yes	no	no	yes
NSW	no	no	no	yes
NT	no	no	no	yes
Qld	no	no	no	yes
SA	no	no	yes—site specific	yes
Tas	no	no	no	yes
Vic	no	no	no	yes
WA	no	no	no	yes
Arizona	no	Site specific	Site specific	Site specific
California	no	Site specific	Site specific	Site specific
Colorado	no	Site specific	Site specific	Site specific
France	no	Site specific	Excludes transfer	yes

All jurisdictions are characterised by partial integration between institutions and managing agencies providing for MAR. MAR schemes are subject to the provisions of an array of policies, at times attempting to comply with competing and incompatible policy requirements for each operational element (source-water harvesting, storage, recovery and end-use). As a result, the potential for alternative market-based approaches for MAR has received minimal attention.

Generally, jurisdictional policies providing for access to urban source water for MAR remain fragmented and poorly defined. Arrangements for access to recycled water and wastewater are likely to proceed via negotiated contracts between interested parties. Stormwater ownership and access entitlements are likely to prove more contentious. There are no documented examples of fully specified and enforceable rights entitling MAR scheme operators to a secure, non-contentious share of a defined pool of stormwater.

South Australia, Western Australia and Victoria are supportive of MAR, expressed as either the adaptation of existing Acts or the introduction of new legislation tailored to MAR. For example the South Australian *Local Government Stormwater Management Amendments Act 2007* includes stormwater infrastructure within defined surface waters, making explicit the provisions and capacity to regulate the capture of stormwater. However, surface water is not a prescribed resource in Central Adelaide water management plans, allowing for free

Stormwater access, i.e. there is no security or an excludable right for those operators that invest in stormwater as a source for MAR.

There are no examples in Australian jurisdictions of fully specified and enforceable rights entitling operators to a secure, non-contentious share of a defined aquifer storage space. To further compound uncertainty, the status of MAR source water is redefined as groundwater when introduced into an aquifer. Without prior consent, it is therefore subject to the licensing and allocation provisions of prescribed or regulated groundwater systems.

The main reason for aquifer storage is to enable reliable access to a defined and independently managed volume of water in times of increased water demand or to meet contractual obligations. Secure entitlements to recover stored water are therefore critical in MAR operations. Generally, current legislation in Australian jurisdictions determines that upon recharge, source water is subject to the extraction and management rules of native groundwater. The right to extract MAR-recharged water in a fully allocated and potentially overdrawn groundwater system remains poorly or informally defined. Tensions will be especially acute during periods of aquifer stress, when groundwater extraction allocations are likely to be severely restricted or prohibited. Periods of water stress are precisely when stored MAR water can best augment restricted urban water supplies. To improve the security of water entitlements for commercial operators, MAR recovery entitlements are likely to require institutional differentiation, operating under differing recovery rules from those governing entitlements to extract native groundwater.

4 Robust design: aligning MAR policy with the National Water Initiative

As the number of intended and implemented MAR operations increases, the need for clear policy, implementation strategies, governance arrangements and incentives to assist in the promotion and coordination of MAR assumes increasing importance. All of these will need to be consistent with the NWI and be clear about the exclusive rights and obligations to own, access, manage, recharge, extract and/or use MAR source water, aquifer recharge space and recovered water.

Ward and Dillon (2009) outlined a systematic policy framework based on applying the principles of the NWI to each of the four fundamental operational components of a MAR project: source-water harvesting, recharge, recovery and end-use.

The NWI describes a unified framework of separately managed policy instruments, drawing on the principles of the robust separation of the rights assigned to water interests (Young and McColl 2003). A water plan establishes the community values and science-based guidelines to appraise the state of a water system and prescribe the rules to determine the environmental and consumptive 'pools'. When there are multiple interests in the consumptive 'pool', the separation of water rights requires a three-tiered system of instruments to distribute and allocate shares of consumptive water efficiently over time. Those policy instruments are:

1. **Entitlement**—defines the characteristics and number of unit shares of the pool and the distribution of shares to individual interests.
2. **Allocation**—defines the process to periodically allocate the amount of water to each share, and accounts for a variable water supply.
3. **Use obligations**—prescribes or proscribes the obligations of water use and takes into account existing water users and third party effects.

Table 4 combines the four operational elements of MAR (harvesting, recharge, recovery and use) with the principles of the robust separation of water rights (entitlements, allocations and use conditions) into a unified framework. The framework suggests a systematic governance arrangement that allows for the coordinated, independent and flexible management of MAR operational elements. The systematic approach reveals opportunities to align MAR operational components with NRM and economic policies central to the NWI and to the development and management of MAR.

Table 4 Natural resource management governance instruments for MAR based on the robust separation of rights

<i>MAR governance instrument</i>	<i>Source water harvesting</i>	<i>Recharge</i>	<i>Recovery</i>	<i>End-use</i>
Entitlement (tradeable)	Unit share in stormwater or effluent consumptive pool, (i.e. available water in excess of environmental flows).	Unit share of aquifer's finite additional storage capacity.	Extraction or recovery share (function of managed recharge volume).	N/A
Periodic allocation (tradeable)	Periodic (usually annual) allocation rules. Potential for additional stormwater or treated effluent with high flows or development 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.	N/A
Obligations and conditions of use	Third party rights of access to infrastructure for stormwater and sewage mining.	Requirement not to interfere with entitlements of other water users and MAR operators.	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.

Most urban jurisdictions in Australia lack water quantity policies that enable the full realisation of MAR benefits and are capable of resolving the tension and conflicts of competing individual interests. In contrast, the National Water Quality Management Strategy now contains 'guidelines for managed aquifer recharge' within the second phase of the *Australian Guidelines for Water Recycling* to ensure that human health and the environment are protected at MAR operations (NRMMC, EPHC, NHMRC 2009). Effective urban water management requires an approach that coordinates water quality standards to ensure public and environmental health with NWI-consistent policies to manage volumetric supplies and consumption of urban water. However, policies concerned with property rights of water quantity have received limited attention and are not yet established for all elements of MAR operations in Australian and international jurisdictions.

4.1 Source-water harvesting

Source-water harvesting entitlements and periodic allocations in rural catchments, urban stormwater and sewage are considered separately.

4.1.1 Rural catchments

In rural catchments described by a water plan¹, water from streams and lakes intended for use in MAR should be treated the same as for any other water diversion under the NWI.

¹ A water plan establishes the community values and science-based analysis to appraise the state of a water system and prescribe the rules to determine the environmental and consumptive pools.

Thus, using the robust framework, no additional policies are required for harvesting of surface waters in rural catchments.

Figure 1: Distribution of entitlements for environmental flow, basic human needs and consumptive use

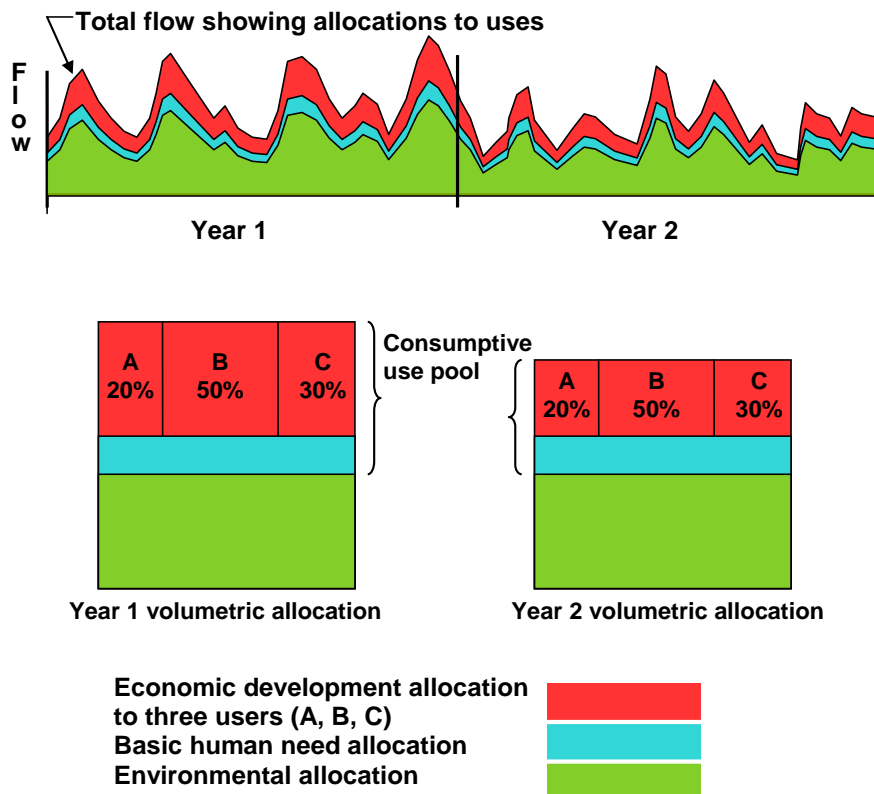


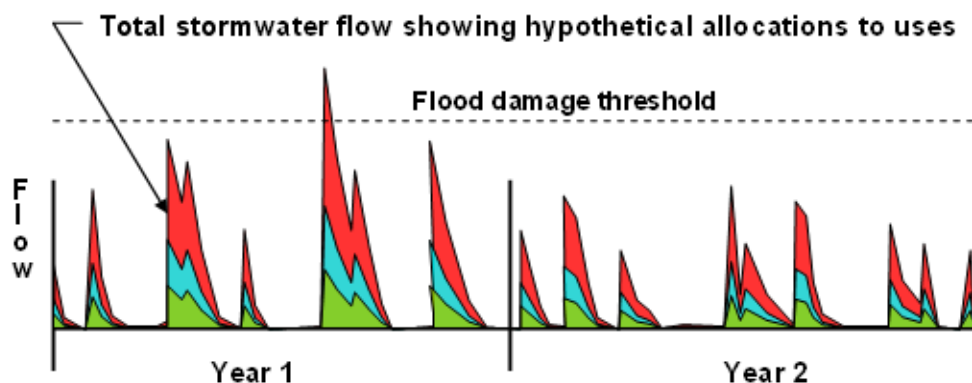
Figure 1 shows a potential distribution of entitlements for environmental flows, basic human needs and consumptive uses in two consecutive years, in response to varying resources. Each entitled water interest, including a MAR operator, has the right to access and manage their respective periodic allocation. In wet and dry years each user's proportional allocation rises and falls according to the total volume available for consumptive use. For simplicity, here environmental allocations are shown as a constant proportion of flow. However, there are schemes that account for variable ecosystem needs.

4.1.2 Urban stormwater catchments

The management of stormwater in Australian urban stormwater catchments is rarely subject to a regime of entitlements, allocations and end-use obligations described by a water plan. Hardening of urban landscapes has typically meant that runoff coefficients are an order of magnitude higher than during pre-European settlement, and so considerable harvesting could occur without impinging on natural environmental flows. It is suggested that a system of stormwater entitlements for private and public landholders within the catchment (including householders) to organisations that invest in stormwater harvesting infrastructure and to the environment be established. The assignment of entitlements could be an adaptation of existing rural catchment water entitlements requiring water register conventions that reduce the stormwater reporting obligations of individual households. A water register, similar to that used for rural surface water systems, represents an accounting convention that tallies the stormwater credits and debits for each entitlement holder. The net effect of urban development, including impact on total flows, especially in inland cities, needs to be considered when determining the level of water diversion and consumption in water plans.

Figure 2 shows that stormwater flows in an urban catchment usually occur intermittently and in short durations. Consequently, environmental flows, the consumptive pool and flow-sharing arrangements are more problematic than in systems where flows have a stronger base flow component and are more predictable, such as in rural catchments.

Figure 2: Intermittent short duration of stormwater flows in urban catchments



Assigning entitlements to individual water interests may be possible but initially impractical because of the high transaction costs of managing unpredictable flow volumes and frequencies. The variability of water quality, including the so-called 'first flush', the typically small detention capacity in relation to total flow volumes and the need to mitigate high flows that cause flood damage add to complexity to the exercise.

Hence it is unlikely that the volume of the consumptive-use pool of stormwater will be known at the time when a harvester must decide whether to divert water and how much. Generally stormwater infrastructure is managed by a local council authority; although the sovereign status of the water itself varies across jurisdictions (SA NRM 2007, Ward et al. 2008, Ward and Dillon 2009). For illustrative purposes, this report assumes that a catchment represents the stormwater infrastructure managed by a single local government authority.

One initial solution would involve the issuing of volumetric licences by a local council (the infrastructure owner) to all stormwater MAR harvesting operations within the same catchment. To increase cost effectiveness through economies of scale and promote operator cooperation, licence holders could rely on a common harvesting operator. In this example the infrastructure would be publicly owned, and over time the harvesting operation within the catchment could be contracted through a competitive tender process, thus promoting innovation and maximising aggregate benefit. As the MAR operation matures and certainty improves, licences could be converted to tradeable entitlements and additional public or private harvesting infrastructure constructed.

The default alternative, that MAR located upstream has priority over downstream locations, is likely to deny access to existing stormwater harvesters, diminishing security of supply for downstream operations. Sharing arrangements for Queensland overland flows provide a policy template for downstream-upstream stormwater conflicts (Department of Natural Resources 2007, Young and McColl 2009).

In the future, entitlements to a volumetric share may rely on emerging technology for real-time automated control of diversions, based on forecast rainfall and runoff prediction models and more comprehensive water quality monitoring and control systems. As cities increase investments in water-sensitive urban design, increased stormwater detention and subsequently entitled harvesting and subsurface storage become increasingly feasible.

4.1.3 Sewage

Currently there are limited re-use opportunities for sewage by third parties in urban areas (see Marsden and Jacobs (2005), Productivity Commission (2008) for an example in Sydney). A system of entitlements, allocations and end-use obligations to harvest and reuse sewage is required to:

- facilitate high value water recycling
- protect the security of environmental flows
- document third-party obligations for discharge of treated sewage effluent
- reduce sewer chokes due to deposition of solids at low flows.

Harvesting obligations would ensure that any changes in effluent quality should neither compromise the uses of water discharged from the sewage treatment plant, nor the discharge loads of contaminants and nutrients. Where additional treatment costs are incurred by harvesting operators to achieve these obligations, these would be reflected in the price of water to the end-user.

4.2 Aquifer recharge

Aquifer recharge takes many different forms adapted to the local situation. Recharge can be via wells, infiltration basins, galleries and induced by pumping groundwater from sand deposits next to a water body to induce infiltration. Dillon et al. (2009a) note that there are two main types of aquifers—those that lie beneath a layer of clay (confined) and require injecting water through a well to recharge, and those that are unconfined and allow water to seep through permeable soils, recharged by infiltration basins and galleries.

Recharge entitlements in general will not be an issue in over-exploited aquifers, as there would be adequate aquifer storage capacity for multiple MAR operations, and MAR would be welcomed as a means of restoring hydrological equilibrium. More will be said on this in considering recovery entitlements and incentives for groundwater user collectives to establish MAR.

In aquifers which are in existing long-term balance or where piezometric levels are trending upwards over a number of years, recharge capacity is finite. Excessive recharge could cause watertables to rise, potentially causing:

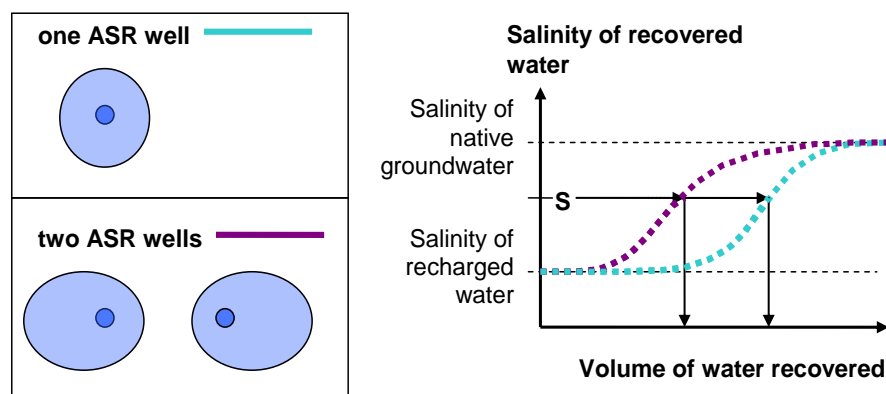
- flooding of basements
- waterlogging
- differential expansion of clays and damage to building structures
- dryland salinity
- unintended discharge of groundwater, or
- causing wells in confined aquifers to become artesian.

Both the Australian MAR guidelines (NRMCC, EPHC, NHMRC 2009a) and the MAR framework described here (Dillon et al. 2009a, Ward and Dillon 2009) require that these risks be examined and addressed. To allow for multiple recharge operations, there needs to be an equitable and transparent way of distributing available recharge capacity between MAR operators. If water resource managers do not take this into account, increasing and uncoordinated competition for the available aquifer storage capacity can potentially lead to litigation due to interference effects between sites. Such effects may include increased

pumping costs, which compound adverse environmental impacts, and reduced recovery efficiency in brackish aquifers.

Aquifer storage and recovery (ASR) is the process of injecting water into an aquifer for recovery at a later date. Figure 3 describes an ASR operation in a brackish aquifer where the salinity threshold for recovered water uses (S) is less than the native groundwater salinity. If a second ASR well comes into operation near an existing ASR well, the volume of water recovered at a salinity fit for use will decline unless closely coordinated, as each operation affects the shape of fresh water plumes of neighbouring wells'.

Figure 3: Salinity of recovered water from close proximity ASR wells in a brackish aquifer



Close coordination of operations would be required to minimise the adverse effects on groundwater hydraulic pressure (resulting in increasing energy costs for injection and recovery) and salinity concentrations of recovered water. Hence it is suggested that the recharge entitlement include spatial specifications for ASR well location to ensure buffering between operators and to minimise operator conflict. As an initial step, a number of individual recharge entitlement holders may choose to contract a single recharge operation.

Recharge capacity is unlikely to be exceeded for the first MAR projects operating in any aquifer. If adequate source water is available and competition for the storage capacity increases, the rights of existing and new recharge operations will require protection. The specification of buffer zones in the recharge entitlement, which would prevent proximate MAR operations, is one approach to protecting existing operations, and it can be easily monitored. To minimise the potential for litigation and reduce operational costs it is also possible to issue recharge entitlements to a single operator for multiple recharge sites within a defined aquifer zone. Recharge entitlements, subject to constraints reflective of local aquifer conditions, could be transferable when an aquifer is approaching full recharge assignment.

4.3 Recovery of stored water

Recovered water is generally a function of the volume of water recharged into the aquifer. Uses of recovered water may include drinking-water supplies, irrigation, industrial supplies, toilet flushing, etc. In addition, ecosystems can be sustained or existing groundwater uses protected by raising piezometric heads to support base flows, maintain lakes or groundwater-dependent vegetation, and by protecting against saline intrusion. In this section we discuss policy implications identified in the workshops that account for hydrogeological characteristics, recharge dispersion, native water quality and aquifer equilibrium.

Managed aquifer recharge can provide a flexible means of enhancing or sustaining both water supplies and aquifer storage when managed by appropriate policies for the recovering recharged water. It should not be regarded as a substitute for demand management (i.e. managing consumptive use) policies, but it can make these easier to implement and play a

complementary role in augmenting traditional water supplies and restoring over-exploited aquifers (Dillon et al 2009b).

Security of recovery entitlements for MAR operators is an important consideration for investment. Recovery entitlements need to be linked to the volume actually recharged and subject to recovery rules clearly specified right from the start of operations. In line with rural water plans, review every five to 10 years should be a part of the groundwater allocation planning cycle. Hence metering and reporting of recharge and recovery will be essential to support claims of entitlement. Monitoring of groundwater levels and salinity will assist in evaluating the public versus private benefits of the MAR scheme. Based on the ratio of private to public benefits, a cogent argument could be mounted to shield recovery entitlements earned by MAR operators from any reductions in annual native groundwater allocations.

Dimensions to consider in determining recovery entitlements include:

- the proportion of recharged volume that may be recovered
- the time period over which recharge credits may be recovered
- linkages between the volume that may be recovered and the time period (e.g. a depletion rate)
- the maximum annual recovery
- the transfer of entitlements and allocations to recover water to other groundwater users.

4.3.1 The proportion of water recovered

In the case of over-exploited aquifers, where groundwater levels are in long-term decline, recovery from MAR operations could be limited to a specified percentage of recharge volume. The unrecovered balance represents a net contribution towards restoring aquifer hydrological equilibrium. Based on the workshop discussions with jurisdictions' regulators, an entitlement to recover 90% of recharge is considered reasonable. As an aquifer's variable storage capacity becomes more certain, it may be necessary to adopt a case by case approach that accounts for storage heterogeneity. A recovery of 90% of recharge volumes would contribute to a less stressed state in the system and provides a windfall net benefit to other groundwater users in return for access to otherwise unused aquifer storage capacity. A 10% margin on profitability would be within the contingency of commercially viable operations. Projects for which proponents claim that a 90% recovery of the recharged volume threatens viability are possibly not feasible.

Recovery from ASR in over-exploited and brackish aquifers in South Australia has been limited to 80% of recharge volume for locally pragmatic reasons. When recovery reached about 80% of recharge the salinity of the recovered water reached the limits for its intended beneficial use. Limitations on recovery volumes relative to the volume of MAR recharge impose additional costs on MAR operators, while producing benefits for other groundwater users in the same aquifer (such as reduced pumping costs or reduced salinity concentrations). Methods that account for the net costs and benefits to all parties as a result of MAR operations would provide an incentive for MAR where surface water allocations are available. It is suggested that a recovery entitlement of 100% of the volume of MAR recharge water be ordinarily provided in aquifers that are not over-allocated. Whether the salinity of recovered water constrains the proportion of recovery compared to recharge would be determined from a salinity meter on the recovery main, but should not be set as an arbitrary default constraint.

Regulators in all jurisdictions agreed that in over-allocated aquifers entitlements to recover recharged water should have a higher level of security than entitlements to native groundwater. That is, the entitlement to recover recharged water should be retained and not subject to similar reductions in native groundwater allocations if groundwater levels were to decline, recognising the effort and net benefit contributed by the MAR operator in recharging

the aquifer. Table 5 shows the proposed recovery entitlements for different aquifer characteristics.

Table 5: Recovery entitlement descriptions for different aquifer characteristics

	<i>Over-exploited aquifer</i>		<i>Aquifer in equilibrium</i>	
	Long hydraulic retention time, T (T>30 years)	Short hydraulic retention time, T (T<30 years)	Long hydraulic retention time, T (T>30 years)	Short hydraulic retention time, T (T<30 years)
1. maximum cumulative % recovered ²	90% (S)	90% (S)	100% (S) ³	100% (S) ³
2. time period for recovery (years)	30	T	30	T
3. Depletion rate for stored water (%) ²	0 (S)	100/T (S)	0 (S)	100/T (S)
4. Max. recovery in any year	<max. annual recharge	<max. annual recharge		
5. Transfers permitted	yes	yes	yes	yes

In locations where it is necessary to reduce groundwater extraction, the cost of recharge may be less than the cost of reducing demand from the aquifer. In such locations, and particularly if MAR schemes were to be constructed to provide increased security to existing users of groundwater, up to 100% of the recovery entitlement could be transferred or traded to existing users in return for surrendering part of their equivalent entitlement of native groundwater. The percentage of groundwater entitlement forfeited could be based on the degree of over-allocation of the resource and the extent to which this is offset by MAR operations. In this way all beneficiaries contribute to the costs of MAR operations and the recharge operator is not penalised for providing a public benefit. Communities of groundwater users could combine (e.g. groundwater users associations) to undertake MAR with entitlement transfers to their own wells, subject to aquifer characteristics and compliance with NRM provisions. Alternatively, publicly funded operations could be established and paid for through fees associated with groundwater entitlements to cover the costs of MAR operations to sustain aquifer volumes.

There is no need to limit the percentage of recovery to less than 100% of the volume injected in groundwater systems in long-term hydrologic equilibrium. One hundred percent recovery would be the long-term goal of effective groundwater management, based on native groundwater extractions and recharge enhancement. For some brackish aquifers in hydrological equilibrium, the MAR operation may make more water recoverable at an acceptable salinity concentration than the volume of water recharged. Given that recovery entitlements carry greater security than native groundwater it is proposed that in such cases the MAR operator could apply for an entitlement to native groundwater proportional to the volume exceeding the original recovery entitlement.

² Maximum percentage recovered in a brackish aquifer is constrained by the salinity (S) of the recovered water needing to be fit for purpose. Recovery ceases when water reaches this salinity threshold or the percentage constraint, whichever occurs first.

³ In some brackish aquifers the salinity constraint may not be reached until recovery significantly exceeds 100% recharge. In such cases the MAR operator could apply for entitlement to native groundwater for the amount in excess of their recovery credit (100% recharge volume).

4.3.2 Time period over which recharge water may be recovered

Major fresh groundwater systems with extensive storage capacity and long residence times would have minimal additional 'natural' discharge as a result of MAR. The full recharge volume should be available for recovery over long time periods. In these aquifers, the rules governing the time period for recovery should be balanced by administrative practicality and the need to provide incentives to conserve water for the future. In Arizona for example, a moving 30-year net recharge/recovery balance is allowed. The volume that may be recovered by a MAR scheme in any year is the amount up to the accumulated recharge less abstraction over the preceding 30 years. This provides an incentive to retain water in storage, in case there is a serious drought ahead, while allowing considerable flexibility to meet present needs. Periods shorter than 15–20 years are likely to result in favouring present consumption over longer-term water conservation. The potential losses of entitled water at the end of the moving average accounting period and deferred investment returns are potential factors affecting the timing of recovered water.

In contrast, thin coastal aquifers with steep lateral hydraulic gradients are one example of aquifers with high rates of turnover (that is short storage time, determined as the ratio of storage volume to aggregate groundwater discharge including abstraction). As the volume recharged does not persist within the aquifer, the time period to recover recharge credits should be shortened to reflect the short storage time constant, see Figure 4. Table 5 above summarises recovery entitlement descriptions.

4.3.3 Depletion rates for stored water

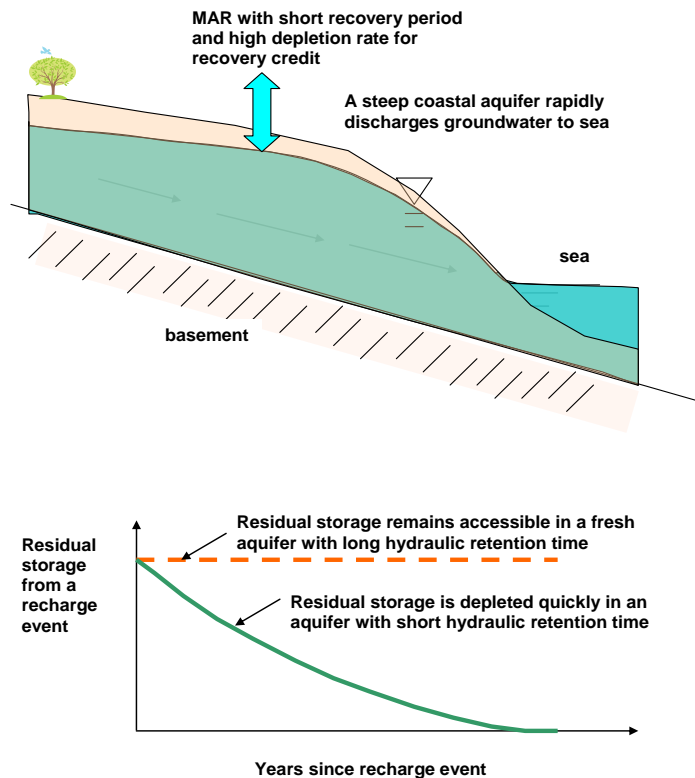
In aquifers with short residence times, the volume of recharge accessible for recovery declines with time due to natural discharge (see Figure 4), i.e. the residual storage is depleted and is fully expended over the hydraulic residence time in the aquifer. The process of recharging the aquifer may also increase the rate of natural discharge. The estimated hydraulic retention time used to determine the depletion rate of recovered water needs to account for changes in natural discharges in aquifers where MAR contributes a significant fraction of natural groundwater flow. Hence establishing fully disclosed recovery rules that are a function of the mean aquifer hydraulic residence time is recommended to reflect the natural regime.

Where hydraulic residence time exceeds 30 years there is no need to determine a depletion rate as the specified time period over which water may be recovered (30 years) already avoids the carryover of non-recoverable entitlements.

In brackish aquifers the proportion of less saline recharge volume that can be recovered at a quality suitable for the intended use (defined as the recovery efficiency) will increase over successive recharge seasons. Monitoring of electrical conductivity of recovered water indicates when to cease recovery operations. However, the proportion of unrecovered water that remains accessible at a suitable quality will decline with time. Declining water quality in these circumstances, analogous to a volumetric depletion rate, applies in all brackish aquifers and is accentuated where hydraulic residence times are short.

It should not be necessary to set depletion rates because of salinity concentrations for two reasons. First, it is difficult to predict salinity attenuation. Second, the Australian MAR guidelines (NRMMC, EPHC, NHMRC 2009a) require operators to follow a risk-management plan that delivers water quality fit for purpose. However, operators will need to be aware of guideline obligations as their water supply agreements to third parties would define the extent of their responsibility for water quantity, continuity and quality of supply.

Figure 4: Schematic of short aquifer hydraulic retention time and high recharge depletion rates in a steep coastal aquifer



4.3.4 Maximum recovery in any year

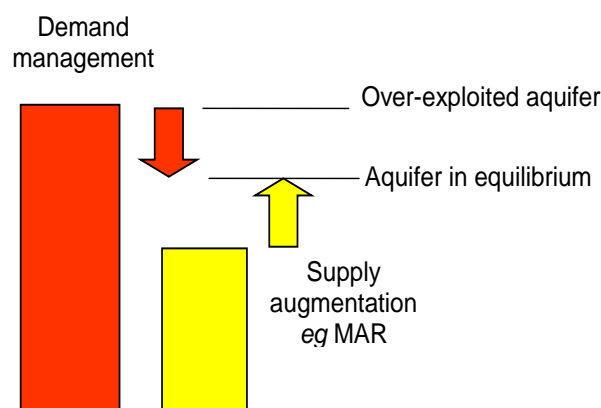
Although the maximum cumulative percentage recovered is specified, it is possible to conceive of situations where a MAR operator has accumulated a recovery volume over a number of years and aims to recoup that volume within a single accounting period (nominally one year). In such situations the recovery volume would be much higher than normal recharge or recovery rates. Intense recovery operations over a short duration could cause a significant cone of depression with adverse short-term impacts on adjacent groundwater users (particularly in confined aquifers) or on groundwater dependent ecosystems (particularly in unconfined aquifers).

A suggested mitigating approach would restrict the annual extraction volume of a recovery entitlement holder in an over-exploited aquifer and an aquifer with short hydraulic retention time to the maximum annual recharge. These restrictions would limit any hydraulic pressure reduction in neighbouring wells or ecosystems, which are an operating condition under the Australian MAR guidelines (NRMMC, EPHC, NHMRC 2009a). However, the ability to prove pressure reductions in an aquifer with multiple pumping wells and variable recharge is likely to be difficult and litigious. Limiting the annual extraction to the maximum recharge achieved in any year in part links potential pressure reductions with the aquifer's capacity to transmit water. Annual recovery restrictions are likely to maximise the ability to draw on reserves in drought years and provide protection against multi-year droughts by ensuring that not all reserves are drawn down in the first drought year. Such recovery restrictions are likely to impose unnecessary constraints in a fresh aquifer in equilibrium and have therefore been omitted from Table 5.

4.3.5 Transfer of recovery entitlements

Allowing the transfer of recovery entitlements and allocations complies with the NWI objectives of facilitating markets where appropriate, and allocating water to higher value purposes. Market exchange and transfers provide a means of compensating MAR operators for recharge that contributes to benefits shared by the aquifer community, such as restoration of over-allocated aquifers and maintenance of hydrologic equilibrium. Importantly, market exchange of either recovered water or recovery entitlements can substantially reduce public expenditure on aquifer restoration. Transfers of recovery entitlements or allocations provide a means for groundwater user cooperatives to invest in recharge as an alternative to, or in combination with, reducing consumption (demand management). Figure 5 illustrates how MAR schemes can combine recharge and recovery measures to restore equilibrium in previously over-exploited aquifers (i.e. consumptive extraction exceeds base flow sufficient to maintain dependent ecosystems and aquifer function).

Figure 5: Complementary MAR recharge and recovery to restore equilibrium in over-exploited aquifers



Rules governing transfer of entitlements and allocations will be necessary to prevent adverse consequences for the aquifer, the environment, and other groundwater users. For example, in South Australia, groundwater entitlements cannot be traded down-gradient in a stressed groundwater system. This very simple rule stops transfers of entitlements and allocations into existing cones of depression where groundwater is locally over-exploited.

It is recommended that this approach be applied broadly to MAR operating in groundwater systems that are over-allocated, avoiding increased energy costs of pumping and salinisation of the aquifer due to increased drawdown. This aspect is illustrated in section 4.3.6 and Figure 6.

4.3.6 Distance of recovery entitlement transfer, gradient, direction and aquifer pressure

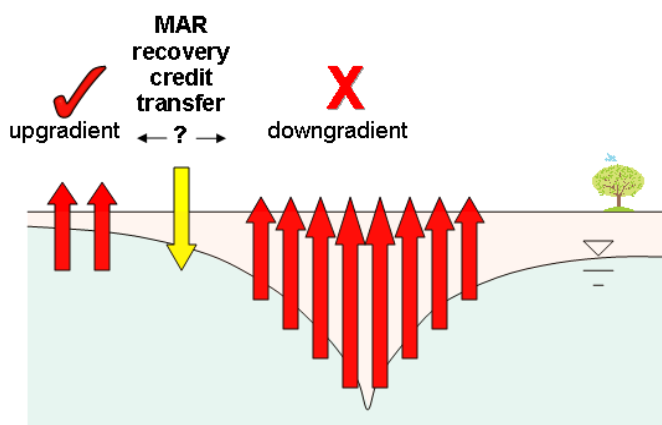
The transfer of recovery entitlements and allocations depends on distances between the transacting parties, gradient, direction, aquifer pressure, water quality, and transfer quantity with respect to the recharge entitlement holder. MAR recharge and recovery periods will generally be in wet and dry seasons respectively. As a general principle, the permissible location of traded recovery entitlements is guided by the requirement to minimise impact on other users, the aquifer and the environment.

The cones of impression and depression around injection and recovery wells in confined aquifer systems can be extensive and may represent a serious constraint to entitlement and allocation transfers. In contrast, in unconfined systems, typified by more localised hydraulic impacts of recharge and extraction, restrictions on transfer locations are likely to be of less

consequence. For salinity intrusion barriers, transfers of entitlements or allocations well away from the coastal margin will help sustain groundwater levels at the barrier where water is injected.

In large or transmissive aquifer systems it is unlikely that the increased groundwater volumes can be reliably differentiated as either recharge or native ground water. Generally, it is not necessary to demonstrate that the water recovered is the recharged water, or that the hydrostatic pressure at the point of recovery has been directly affected by recharge. Recovery entitlements should not be traded down-gradient into cones of depression, as illustrated in Figure 6. Subject to these conditions, transfers of MAR recovery entitlements between groundwater management units would be subject to the same constraints as trading of native groundwater.

Figure 6: Down-gradient restriction placed on MAR recovery entitlements in an overdrawn aquifer



4.3.7 Changes in ambient groundwater salinity

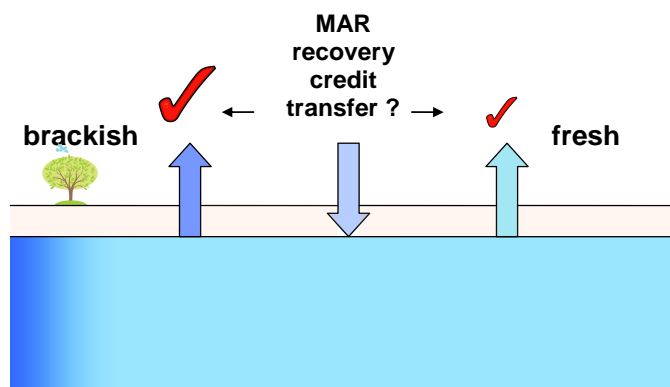
At the location of the MAR site, health and environmental approval under the Australian MAR guidelines (NRMMC, EPHC, NHMRC 2009a) requires no degradation of local groundwater beneficial uses (beyond a small and temporary attenuation zone). Hence the salinity of recharge water will generally be similar to or less than that of native groundwater at the recharge site. Recharging marginally more saline water that meets aquifer beneficial uses may occur to increase groundwater storage, avert the potential ingress of saline water and sustain or expand supplies. In an aquifer that has a lateral salinity gradient it is therefore possible to recharge water of a higher salinity than occurs in other parts of the same aquifer.

Although it is desirable to transfer the recovery entitlement from recharge of lower salinity water to a similar or higher salinity zone within an aquifer, in order to have a net freshening effect or no affect on the aquifer salt balance there will be occasions where it is attractive to also transfer recovery entitlements to lower salinity zones in the same aquifer. To reduce the risk of diminished water quality over time in aquifers characterised by a salinity gradient, it is suggested that recovery entitlements or allocations traded to lower salinity wells be proportionally reduced using a 'salinity exchange rate'. The salinity exchange rate in part addresses low salinity native groundwater being replaced by higher salinity recharge water. There would be no exchange rate applied for transfers to wells where groundwater has the same or higher salinity than the recharge water.

For simplicity, it is proposed that the 'salinity exchange rate' is calculated as the ratio of the salinity of groundwater at the point of recovery to the average salinity of recharged water, see Figure 7. For example if the average salinity of recharged water is 1000uS/cm and ambient groundwater at the point where the recovery entitlement is to be transferred is 800 uS/cm then the recovery entitlement volume would be reduced at the receiving well to 80% of the traded volume. The proposed exchange rate requires ongoing monitoring of the salinity of recharged water and recovered water. The concept aims to encourage a MAR operator to recharge lower salinity water (assuming a variable salinity source) and gives a competitive

advantage to water entitlement transferees in zones of similar or higher salinity than the recharged water.

Figure 7: Illustration of proportional reduction of transferred recovery entitlements and allocations in an aquifer subject to a salinity gradient



4.3.8 Inter-aquifer transfers

The question as to whether recharge in one aquifer can result in recovery entitlements in another is not simple. Transfers of recovery entitlements and allocations could be prevented if the aquifers are not hydraulically connected. However, circumstances can occur where an entitlement (or allocation) to recover recharged MAR water into a fresh aquifer could be transferred to a brackish aquifer, enabling abstraction of brackish water associated with environmental benefits for one or both aquifers. As an example, a municipality in South Australia recharges stormwater in an over-allocated aquifer and it recovers water from a separate brackish-saline aquifer to top-up an urban lake with considerable amenity value (SA NRM 2007). As a principle, it is suggested that the environmental, social and economic benefits and costs for all stakeholders are considered in determining conditions of inter-aquifer transfer of MAR recovery entitlements.

The Australian MAR guidelines require water quality and quantity metering and recording of annual recharge and recovery volumes to verify the protection of the environment at MAR sites. In most operations additional water quality parameters, such as salinity of recharge water and the receiving aquifer, will also be recorded, and these data should be available to monitor compliance with NRM requirements and human health regulations.

4.4 End-use

As a requirement of the entry-level assessment of new MAR projects under the Australian MAR guidelines (NRMMC, EPHC, NHMRC 2009a), the end-uses for recovered water are required to conform to existing and proposed catchment and groundwater management plans. End-users of recovered MAR recharge must demonstrate that the use and disposal of water complies with existing urban planning, environmental impact and health policies.

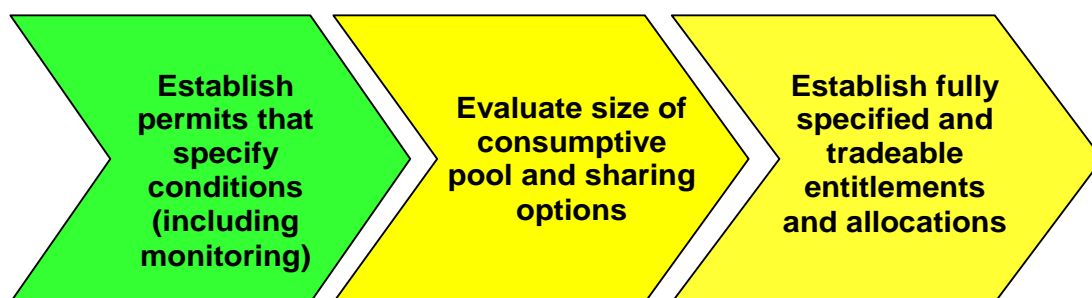
Groundwater management plans have not been prepared for some urban areas. It is noted that stock and domestic wells in urban areas can cause over-abstraction of shallow aquifers and that this class of wells is currently excluded from groundwater allocation plans. Failure to account for domestic wells may mean management plans are incapable of protecting aquifers and connected ecosystems. An effective means of managing these systems may need to rely on regulatory provisions at the whole of aquifer scale rather than individual well interventions.

5 Transitional arrangements to an entitlement system

As indicated in Table 3, most jurisdictions are a long way from an NWI-consistent MAR entitlement system. However, all have in place existing water-affecting regulations and bore construction permit-based systems to allow a limited number of individual MAR projects to proceed. Further clarity and a synthesis of science and community attitudes is required to enable water sharing arrangements and consumptive pool entitlements to be unambiguously defined in urban areas.

We suggest a transitional pathway is needed to progress from each jurisdiction's current position towards intended NWI-conforming governance arrangements. Figure 8 illustrates the proposed pathway. Table 6 details the proposed transitional pathways for policies relating to source water harvesting, recharge, recovery and end-use. This transitional pathway is intended to guide inclusive, ongoing and constructive discussion in urban jurisdictions.

Figure 8: Pathway for policy implementation from regulation to entitlements



The trigger points at which a jurisdiction would move from a permit-based system to an entitlement system for MAR in a given catchment or groundwater basin are illustrated through two contrasting Australian examples of transitional arrangements from resource development to resource management using the 'open–closed' typology of Falkenmark and Molden (2008). The typology was applied to the historical development of surface and groundwater resources in the Murray–Darling Basin (MDB) and northern Australia by Ward et al. (2009) (see Figure 9 and Figure 10). The northern Australian example best represents the current early stage of stormwater harvesting, sewage recycling and MAR development in Australia.

Figure 9: Open–closed development pathways—Murray–Darling Basin (Source: Ward et al. 2009)

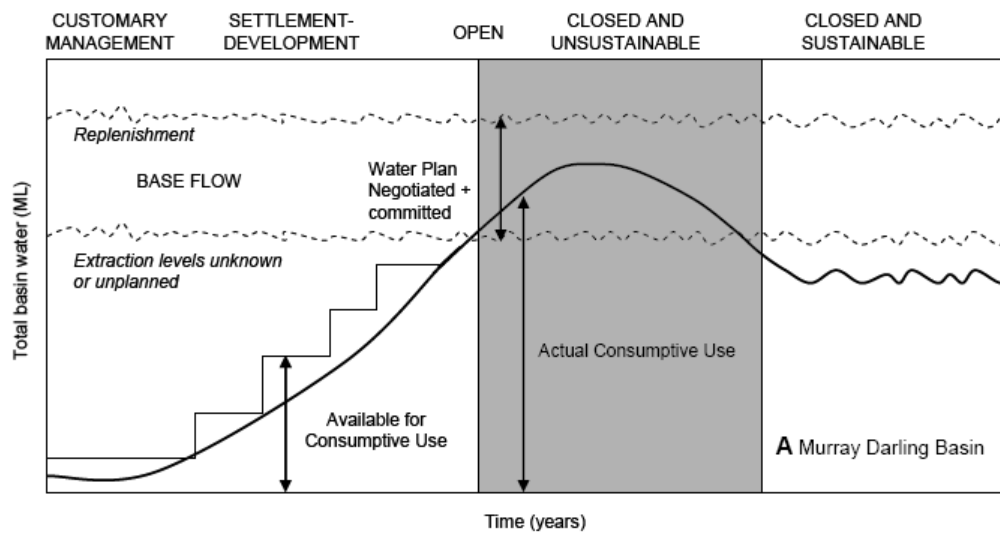
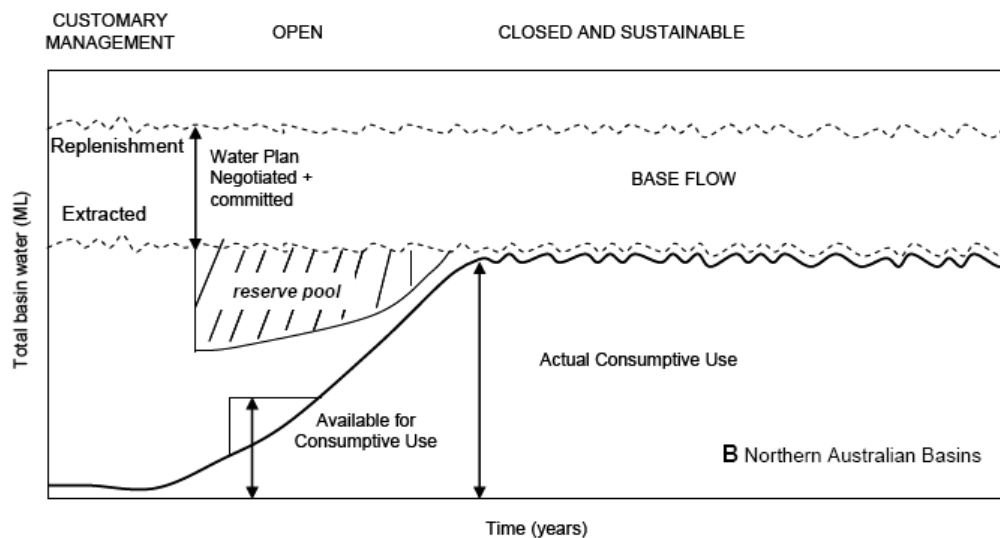


Figure 10: Open–closed development pathways of the northern Australian basins (source: Ward et al. 2009)



An open basin is able to satisfy the full suite of domestic, industrial, agricultural or environmental water commitments for the whole year. Environmental flow commitments include downstream allocations to meet societal needs, to dilute pollution, maintenance of aquatic ecosystems, flushing sediments and controlling saline intrusion. Open basins also have surplus water entitlements and are able to meet additional water demands. Closed basins are characterised by over-assigned entitlements and are unable to satisfy the full suite of domestic, industrial, agricultural or environmental water commitments for part of the year.

The terminology used in Figure 9 and Figure 10 is as follows: *replenishment* describes system inflows, *base flow* represents environmental flows, *available for consumptive use* is the harvestable volume related to infrastructure constructed over the years and *actual consumptive use* is the volume of diverted source water or aquifer extraction. The waved lines

are indicative of inflow variation and are a graphic representation of the highly episodic and ephemeral water resources, with similarities to stormwater flows and aquifer recharge.

Figure 9 is a diagrammatic illustration of the development of the Murray Basin from customary management before European settlement, through expansion of agriculture under an open system where water was taken via permits until it became evident that environmental flows were being depleted. At that point in water appropriation, the system was classed as closed, no new permits were issued and tradeable entitlements were based on historical permits. A key point of this conceptual diagram is that the water plan, a negotiated NWI-consistent plan establishing the accepted level of system modification, i.e. sustainable base flow and extraction volumes, was developed after it was already apparent that the system was unsustainable.

The Murray–Darling Basin (MDB) system is currently unsustainable and will be until distributed entitlements are reduced and environmental flows restored. The current period of adjustment requires significant compromise and structural adaptation, incurring substantial political, commercial and social costs. A review of the development pathway of the MDB yields substantial lessons and advantages for water management in northern Australia and for MAR.

Figure 10 is a graphic representation of potential northern Australia water management arrangements, which provides a template for institutional triggers relevant to MAR operations.

1. Water planning is introduced early in the development pathway. The open phase is of sufficient duration for the equitable and efficient assignment of entitlements if required. Knowledge can be updated to reduce uncertainty about environmental response to water harvesting, recharge or recovery. For MAR operations that move into a development/modification phase following feasibility evaluation and the activation of water demand factors, we suggest that a NWI-consistent water plan be required.
2. A precautionary reserve pool is proposed, in addition to the extractive pool and base flow specified in the NWI. The reserve pool shrinks over time, representing the increasing level of certainty about the consumptive pool of source water or aquifer storage capacity, based on monitoring and demonstration projects. The reserve also provides an opportunity to test compliance and sanctioning actions.
3. As a corollary, the number of available entitlements is initially restricted, with additional entitlements potentially made available as the reserve pool is reduced in volume. Importantly, an alternate permit system may be the simplest, most cost-effective and feasible approach when the reserve pool volume is proportionately high. At commencement of reserve pool reduction, permits could be easily transferred to entitlements according to the water planning specifications. Restricting the number or proximity of MAR operations also averts localised interference effects among MAR operators before such effects can be predicted.
4. Water markets are unlikely to play a substantial role until the reserve pool is exhausted (i.e. all entitlements have been assigned to various interests).

The proposed framework minimises exposure to the adverse outcomes of the settlement-development phase, including failure to recognise the consequences of uncoordinated extraction, political interference and development that is not economically viable. The transitional pathway avoids the substantial social, political, economic and environmental costs of the closed and unsustainable phase. The sequenced institutional transition described here is intended to stimulate thinking and provide policy design principles that maximise the benefits of currently under-utilised resources, improve urban water management, sustained in spite of climate variability and changes in population and land use.

Table 5 provides additional detail in designing transitional policy and institutional pathways for MAR source water harvesting, aquifer recharge, recovery and end-use.

Table 6: Transitional pathways for policies in source water harvesting, recharge, recovery and end-use

<i>Sequence of development</i>	<i>Starting point—regulation</i>	<i>Preliminary estimates of consumptive pool</i>	<i>Preliminary sharing procedures</i>	<i>Entitlement, periodic allocation, obligations</i>	<i>Comments</i>
Source water harvesting—rural water catchments				Unit share in rural runoff consumptive pool, (i.e. excess to environmental flows) specified following existing catchment water allocation plans.	Procedures are already in place in all states.
Source water harvesting—urban stormwater	<p>Issue permit for harvesting stormwater for first MAR project in catchment with detention storage up to specified size. Conditions of permit include monitoring and annual reporting of daily stormwater flow, recharge volume and recovery volume.</p> <p>Note this is not a volumetric or proportional entitlement to the consumptive pool.</p> <p>Initiate process to identify priorities for use of stormwater accounting for water sensitive urban design (WSUD), flood mitigation and value of uses.</p>	<p>Estimate environmental flow of stormwater for downstream ecosystem support in urban catchments.</p> <p>Formulate a draft stormwater allocation plan, including estimates of the size of consumptive pool and of interceptions and diversions with priorities higher than stormwater harvesting (e.g. rainwater harvesting at source).</p> <p>Estimate the stormwater share allocated to first MAR operation, based on data acquired under its permit.</p>	<p>When proposals arise for second and subsequent MAR projects in a stormwater catchment, perform modelling to define environment flows and identify potential impacts on downstream stormwater harvesting.</p> <p>Identify process to allocate share in stormwater consumptive pool, based on priorities for stormwater use, and existing and intended future uses and trading arrangements.</p> <p>Include processes and provisional entitlement in public consultation on draft catchment water allocation plan.</p>	On approval of the plan, assign unit share in stormwater consumptive pool and establish procedure for trading entitlements and allocations to conform, as far as practical, to existing rural water catchment entitlement and trading systems.	For inland cities urban runoff may already be included in catchment water allocation plans. If catchments are fully allocated, proponents of urban MAR projects will need to purchase an entitlement from existing entitlement holders (as per fully allocated rural water catchments).

<i>Sequence of development</i>	<i>Starting point—regulation</i>	<i>Preliminary estimates of consumptive pool</i>	<i>Preliminary sharing procedures</i>	<i>Entitlement, periodic allocation, obligations</i>	<i>Comments</i>
Source water harvesting—sewage	<p>Issue permit to harvest sewage for first MAR project in catchment with treatment capacity up to specified size. Conditions of permit include maintaining a minimum flow and monitoring and annual reporting of daily sewer flow, recharge volume and recovery volume.</p> <p>Note this is not a volumetric or proportional entitlement to the consumptive pool.</p> <p>Initiate process to identify priorities for use of sewage, accounting for water conservation and value of uses.</p>	<p>Estimate environmental flow of sewage for downstream ecosystem support in urban catchments.</p> <p>Evaluate all impacts of source water harvesting on sewer chokes, treatment plant operations, and re-use of water from sewerage treatment plants.</p> <p>Formulate a draft sewage allocation plan, including estimating the size of consumptive pool and of interceptions and diversions with identified priorities.</p> <p>Estimate the sewage share allocated to first MAR operation, based on data acquired under its permit.</p>	<p>When proposals arise for second and subsequent MAR projects in a sewer catchment, perform modelling to define environment flows and identify potential impacts on downstream sewer harvesting and water re-use.</p> <p>Identify process to allocate share in sewer consumptive pool, based on priorities for sewage use, and existing and intended future uses and trading arrangements.</p> <p>Include processes and provisional entitlement in public consultation on draft sewage water allocation plan.</p>	<p>On approval of the plan, assign unit share in sewage consumptive pool and establish procedure to trade entitlements and allocations to conform as far as practical with stormwater and existing rural water catchment entitlement and trading systems.</p>	<p>For inland cities, urban-treated sewage discharge may already be included in catchment water allocation plans. If catchments are fully allocated, proponents of urban MAR projects will need to purchase an entitlement from existing entitlement holders (as per fully allocated rural water catchments).</p>

<i>Sequence of development</i>	<i>Starting point—regulation</i>	<i>Preliminary estimates of consumptive pool</i>	<i>Preliminary sharing procedures</i>	<i>Entitlement, periodic allocation, obligations</i>	<i>Comments</i>
Recharge	<p>Issue permit for recharge for first MAR project in aquifer with detention storage or treatment capacity up to specified size.</p> <p>Conditions of permit include monitoring and annual reporting of daily stormwater flow, recharge volume and recovery volume.</p> <p>Issuing permit requires evidence that pre-commissioning residual risk assessment meets acceptance criteria in Australian MAR guidelines and has risk-management plan.</p> <p>Note this is <u>not</u> a volumetric or proportional entitlement to the available storage capacity of the aquifer.</p> <p>Initiate process to identify priorities for stormwater accounting for WSUD, flood mitigation and use value.</p>	<p>In aquifers that are not already depleted, develop a groundwater model of target aquifer and connected aquifers, accounting for current state of knowledge of aquifer geometry, hydraulic characteristics, boundary conditions, heads, salinity, and natural recharge and discharge, and existing pumping wells.</p> <p>Use this model to identify potential storage volume available for MAR for likely scenarios for recharge and recovery.</p>	<p>When proposals arise for second and subsequent MAR projects in a target aquifer with limited storage capacity, refine modelling to determine the size of buffer distances between operations to prevent excessive interference among MAR operations.</p> <p>If this distance is impracticably large, then use modelling to define regions in which only a single operator would be allowed to operate multiple MAR sites, and the combined maximum annual recharge volume, in relation to end of dry season storage volume for intended recharge and recovery scenarios.</p> <p>Incorporate in groundwater allocation plan for community consultation.</p>	<p>On approval of the plan, assign unit share in recharge consumptive pool and establish procedure to trade entitlements and allocations to recharge to be compatible, as far as practical, with existing procedure for groundwater entitlement and trading systems.</p>	<p>In general, if volume of additional storage capacity in aquifer exceeds volume of stormwater and sewage available for allocation to MAR, this would raise the priority of developing a groundwater model and providing guidance for MAR system buffer distances or groundwater management zones.</p>

<i>Sequence of development</i>	<i>Starting point—regulation</i>	<i>Preliminary estimates of consumptive pool</i>	<i>Preliminary sharing procedures</i>	<i>Entitlement, periodic allocation, obligations</i>	<i>Comments</i>
Recovery	<p>If a groundwater allocation plan is in place, use Table 5 in the first instance as a preliminary entitlement.</p> <p>If no groundwater allocation plan is in place, use Table 5 in the first instance as a permit to recover water.</p>	<p>Observe effects of MAR on neighbouring wells. If there is evidence of adverse impacts on third parties or groundwater dependent ecosystems caused by MAR operations, revise preliminary entitlement or permit.</p> <p>If necessary, undertake groundwater modelling to account for specific local conditions and to define recovery entitlements that protect third parties.</p>	Incorporate MAR recovery entitlements in groundwater allocation plans for public consultation.	Implement revised and approved groundwater allocation plan.	
End-use	Water use permit is subject to existing regional obligations and conditions, for use and disposal.	Priorities for water use and projected changes in priority are identified in catchment water management plan.	Auditing procedure is established to verify end-uses and disposal are compatible with plans.	Entitlements to harvest, recharge and recover are based on stated end-use conditions. Any changes in end-use should have the same or higher priority in the current catchment water and groundwater allocation plans.	Procedures are already in place in all states.

6 Conclusions and recommendations

The absence of well-defined entitlements to access stormwater, recycled water, and aquifer storage is likely to result in uncertain aquifer recharge and extraction, future legal wrangles, potential detrimental impacts on receiving environments and failure of MAR to achieve its full potential value in Australian water resources management. Each Australian jurisdiction has existing water allocation policies for rural catchments and these could be extended or adapted to urban stormwater and sewer catchments to allow MAR to be treated as a prescribed water diversion. Existing policies in the Australian Capital Territory provide a potential model. Provisions are needed to address the complications in stormwater catchments, and a simple transitional solution allowing a single harvesting operator per urban catchment is proposed.

Entitlements to recharge are not a pressing need but are likely to become so as MAR develops. In the first instance, the Australian MAR guidelines, which take into account localised effects on groundwater levels, pressures and discharges, should suffice. As future multiple MAR operators compete for storage space, groundwater management plans implemented in each Australian jurisdiction could be invoked to prevent over-recharging of aquifers while protecting recharge entitlements of existing MAR operators. Again, a single operator transitional policy within an area of aquifer and provision for buffer distances between operators can be used to manage negative interactions.

Recovery entitlements, including the right to transfer, are vital to the uptake of MAR as a groundwater management tool, and could be adopted into existing groundwater allocation policies. Adoption has already begun in South Australia. Principles suggested in this publication account for a range of widely encountered hydro-geological situations. Further discussion on these is warranted to determine well articulated, equitable, efficient and transferable policies.

Existing legislation and policies will require careful effort to adapt to market innovations in urban water management to ensure the benefits of MAR are free of adverse consequences. Modifying policies now to conform to a nationally consistent framework based on the principles of the National Water Initiative will give investors confidence in MAR, facilitate its use to achieve broad NRM and urban water objectives, and minimise the likelihood of perverse outcomes.

7 References

ANZECC–ARMCANZ 1995, *Guidelines for groundwater protection in Australia, National Water Quality Management Strategy*, (Australian and New Zealand Environmental and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand), Canberra.

Council of Australian Governments 2004, Intergovernmental Agreement on a National Water Initiative, Council of Commonwealth Governments.

www.nwc.gov.au/resources/documents/Intergovernmental-Agreement-on-a-national-water-initiative.pdf

Council of Australian Governments 2008, 'Water: report to the Council of Australian Governments, prepared by the Working Group on Climate Change and Water', Canberra. www.coag.gov.au/coag_meeting_outcomes/2008-03-26/docs/CCWWG_water_report.pdf

Department of Natural Resources 2007, Condamine and Balonne Draft Resource Operations Plan, Brisbane

Dillon, P, Pavelic, P, Page, D, Beringen H and Ward J 2009a, Managed aquifer recharge: an introduction, Waterlines report no 13, Feb. 2009.

www.nwc.gov.au/www/html/996-mar--an-introduction---report-no-13--feb-2009.asp

Dillon, P, Gale, I, Contreras, S, Pavelic, P, Evans, R, Ward, J 2009b. 'Managing aquifer recharge and discharge to sustain irrigation livelihoods under water scarcity and climate change', IAHS publ. 330, 1–12.

Dillon, P and Toze, S (eds) 2005, *Water quality improvements during aquifer storage and recovery*, American Water Works Association. Research Foundation Report 91056F.

Falkenmark, M and Molden D 2008, 'Waking up to the realities of river closure', *International Journal of Water Resources Development*, 24(2) p201–215.

Marsden Jacob Associates 2005, 'Third party access in water and sewerage infrastructure: implications for Australia', Marsden Jacob and Associates, Melbourne: paper prepared for the Water recycling and third party access symposium, 14 December 2005.

NRMCC, EPHC, NHMRC 2008, *Australian guidelines for water recycling: managing health and environmental risks. Augmentation of Drinking Water Supplies*, AGWR phase 2A, Natural Resource Management Ministerial Council, Environment Protection and Heritage Council and National Health and Medical Research Council, Canberra. www.ephc.gov.au/taxonomy/term/39

NRMCC, EPHC, NHMRC 2009a, *Australian guidelines for water recycling: managing health and environmental risks. Managed aquifer recharge*, Natural Resource Management Ministerial Council, Environment Protection and Heritage Council and National Health and Medical Research Council, Canberra. www.ephc.gov.au/taxonomy/term/39

NRMCC, EPHC, NHMRC 2009b, *Australian Guidelines for water recycling: managing health and environmental risks. Stormwater harvesting and re-use*, Natural Resource Management Ministerial Council, Environment Protection and Heritage Council and National Health and Medical Research Council, Canberra. www.ephc.gov.au/taxonomy/term/39

NWC 2009, *Annual Report 2007-2008*, National Water Commission, Canberra. ISBN: 978-1-921107-63-4

Productivity Commission 2008, *Towards urban water reform: a discussion paper*, Productivity Commission, Melbourne.

SA NRMC 2007, *Stormwater management planning guidelines*, South Australian Stormwater Authority and the Natural Resources Management Council, Adelaide.

www.lga.sa.gov.au/webdata/resources/files/Stormwater_Management_Planning_Guidelines_July2007.pdf

Ward, J, Dillon, P and Grandgirard, A 2008, 'Designing tradeable rights to manage aquifer recharge according to robust separation principles', *Water, Science and Technology: Water Supply* 8(4).

Ward, J and Dillon, P 2009, *Robust design of managed aquifer recharge policy in Australia*, Report to National Water Commission, CSIRO, Water for a Healthy Country National Research Flagship Report to National Water Commission, April 2009.

www.clw.csiro.au/publications/waterforahealthycountry/2009/wfhc-MAR-policy-design-milestone3.1.pdf

Ward, J, McColl, J, Nikolakis, W, Taylor, B, Abel, N and Grafton, RQ 2009, 'A robust framework for sharing water in northern Australia', Chapter 28 of the *Northern Australia Land and Water Science Review 2009*, CSIRO Sustainable Agriculture Flagship and Northern Australia Land and Water Task Force, Canberra.

Young, M and McColl, J 2003, Robust reform: the case for a new water entitlement system for Australia, *Australian Economic Review*: 36(2); 225-34.

Young, M and McColl, J 2009, *Droplet* no.15: 'Shepherding water: unregulated water allocation and management', University of Adelaide.