Requirements for sustainable water banking

Water banking is a type of managed aquifer recharge. It works by storing water in aquifers when surplus water is plentiful, for instance after seasonal rain events, following floods, or when water demand is low and extracting water from storage for use when water is scarce.

Managed aquifer recharge can be used to store water for short periods, such as across seasons, but water banking refers to storage over longer timescales.

Water banking can strengthen water security and increase resilience to climate variability and drought.

What is Water Banking?

Water banking (WB) stores water in an aquifer for later withdrawal for use or exchange. Aquifer storage can be increased by aquifer recharge, and it can be maintained by deferring or carrying over rights to withdraw water. Storage of water occurs over longer timescales, e.g. interannnual.

What is Managed Aquifer Recharge?

Managed aquifer recharge (MAR) is the purposeful recharge of water to groundwater (GW) aquifers for subsequent recovery or environmental use. MAR is used to store water for shorter periods, such as across seasons. MAR only makes up about 1% of global GW extraction (1). There is scope for further development of WB and MAR to improve global water security and provide greater resilience to climate change.

Why Water Banking matters?

WB can be developed for a range of purposes such as (2):

- Recharging overused GW systems;
- Providing water in periods of water shortage;
- Improving water quality and preventing saltwater intrusion;
- Reducing evaporation losses from surface storage;
- Supporting environmental flows and ecosystem restoration.

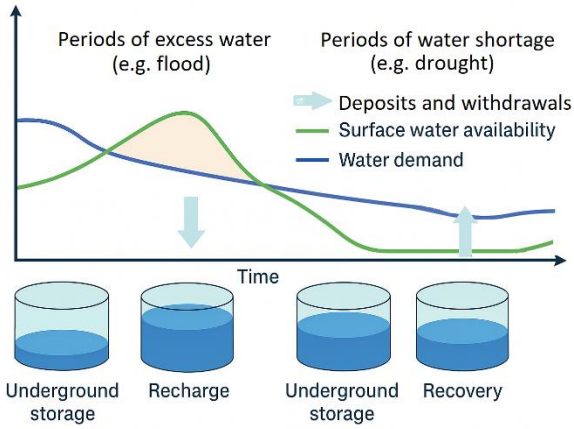

Figure 1: How water banking works

Key enabling requirements

There are several key enabling requirements for sustainable water banking (Figure 2). These can be divided into three groups:

1. Social and physical requirements
2. Policy and institutional requirements
3. Project specific conditions

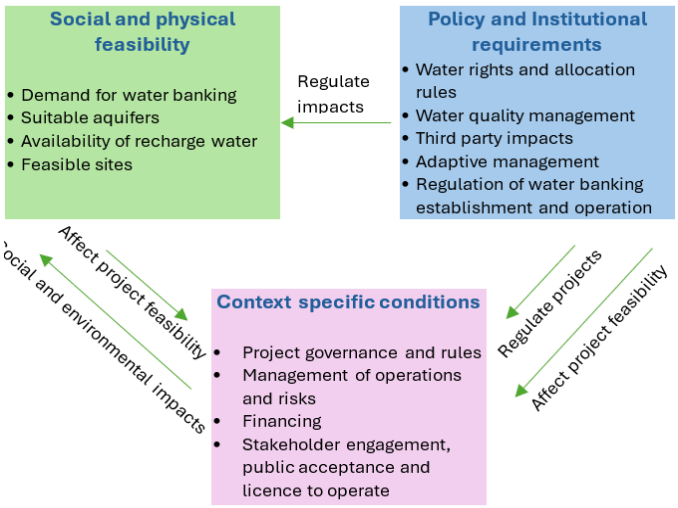

Figure 2: Key requirements for sustainable water banking

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These requirements interact in several ways (Figure 2). Policies and institutions regulate social and physical impacts of water banking. Social and physical conditions and policy and institutional requirements affect project feasibility. Projects have social and environmental impacts that need to be controlled.

This background paper identifies the key requirements needed for water banking. The paper draws on Australian and international experience and research to summarise key enabling conditions for water banking and managed aquifer recharge.

Social and Physical Requirements

1) Demand for water banking

Ongoing water demand needs to be sufficient to warrant investment in proposed WB or MAR schemes. Demand is driven by three key factors: risk management, willingness and capacity to pay and water needs.

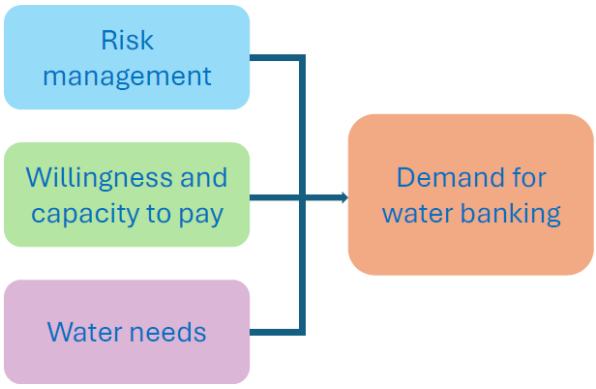

Figure 3: Drivers of demand for water banking

Risks giving rise to demand drivers include water scarcity, groundwater depletion, climate variability, and drought especially in areas with an arid climate and variable rainfall (2). Risk management is especially important for towns facing "day zero" supply risks and producers with inflexible water needs or projected increased demand for water. For example, Perth adopted a GW replenishment scheme using recycled water to increase long-term water security. This MAR scheme replenishes the Perth aquifer, and enables ongoing GW extractions, and provides an additional supply of recycled water.

Actual or perceived risks can affect demand for WB — for example, concerns about injection

> "The demand for storing water underground to use later is a key factor in deciding where water banking is viable

affecting rising water tables or water quality. Users are more likely to invest when water available through banking is cost-effective or more reliable than alternative strategies. Costs can be lower when existing groundwater infrastructure (such as wells and licences) reduces set-up expenses. Demand for water banking is usually highest in regions that already rely on groundwater, as intensive use suggests the presence of productive aquifers with storage capacity created by past extraction (3). Farmers growing high-value perennial crops (such as almonds, grapes, and citrus) have strong incentives to invest in water banking, as their constant annual water needs leave little flexibility to adjust production in response to climate variability. Often water banking involves high upfront and ongoing operating costs, and availability of funding or incentives can be a major driver of willingness to pay.

Water banking is most in demand where water is scarce, demand is growing, and new water sources are limited (4). In the Murray–Darling Basin, agriculture faces a "boom-and-bust" water supply cycle, with broadacre crops using most water in wet years but producing little in dry years (5). Storing water underground can smooth these fluctuations, providing reliable "high-security" water for farmers to meet their needs. This is especially valuable for high-value perennial and horticultural crops, where consistent water is essential to protect investments in plantings, infrastructure, and markets. Because these crops have inflexible water needs, farmers are willing to pay more for water, and investors are more likely to cover the costs of setting up and operating a water bank (3).

2) Suitable aquifers

Aquifers must be able to support an adequate rate of infiltration or injection and must have enough storage capacity to meet potential demand and intended uses of recovered water. It must be able to retain water that can be recovered when needed (3). Other key factors influencing aquifer suitability can include hydraulic gradient,

permeability, aquifer thickness, water table depth, and groundwater salinity.

Unconfined, coarse, unconsolidated aquifers with acceptable water retention are cheaper and easier to recharge than confined aquifers (6). These aquifers allow water to naturally infiltrate and move through the loose soil and rock, making recharge simpler and less expensive. In contrast, confined aquifers are covered by overlying layers, so water cannot easily enter them without injection wells, which are costly to install and operate.

> “ Suitable aquifers are essential for storing and recovering water through water banking

The groundwater chemistry of aquifers is critical to evaluate whether the mixing of source water, native GW, and minerals within the target aquifer could trigger hydrogeochemical reactions that affect the quality of recovered water (7). The effects can be good and bad – for example, changes to the chemical environment and pH may occur and metals or minerals may dissolve or build up changing how easily water can flow through the aquifer. In the MDB, elevated GW salinity may limit the suitability of MAR schemes, as mixing low-salinity recharge water with saline aquifers can result in brackish recovered water.

Testing the source water for recharge, the native groundwater and the sediments of the target aquifer enables project managers to identify and prevent contamination risks. It should be noted that MAR and WB schemes also help clean source water as it percolates through the soil and then moves within the aquifer: harmful microbes die off, nutrients are broken down naturally, and sediments in the aquifer filter out particulate matter. Mitigation options to prevent any adverse hydrogeochemical reactions during MAR/WB includes treatment of source water before recharge and/or post-treatment of recovered water. The standards to which recovered water is treated will depend on the anticipated end use. The Australian MAR guidelines provide a risk-based framework to assess and manage these risks (8).

3) Availability of recharge water

Some operational MAR schemes use SW as the source for recharge in Australia. The economically viable distance between diversion from a surface water source and a recharge location varies depending on geographic and economic factors. Experience suggests that this distance has often been around 5 km, assuming a small gradient (6).

Alternative water sources (recycled urban stormwater, wastewater and industrial water, and desalinated water) can also be used for recharge, if they can be treated to sufficient quality for the required end use and delivered at an acceptable cost.

Water treatment prior to infiltration or injection may be required to protect the receiving aquifer (e.g. managing turbidity), to prevent adverse geochemical reactions and to manage clogging. Water high in suspended solids and nutrients will impact MAR scheme viability through physical and biological clogging of infiltration basins and wells. Clogging requires active management through pre-treatment to improve water quality or operational strategies such as basin scraping and well back-flushing (3).

> “ The availability of water of suitable quality for recharge is essential - surface water or treated alternative sources (e.g. recycled water, stormwater) are an option

A key consideration for the potential development of MAR/WB is understanding the existing natural interactions between groundwater and surface water (SW), which are governed by pressure and quality gradients. Since managed recharge may alter these conditions, its implementation should be accompanied by an environmental impact assessment and a preventive risk-management plan as set out in the Australian MAR guidelines (8). Changes in subsurface storage and potential fluctuations in groundwater pressure can affect ecosystems that rely on stable groundwater conditions; the Australian MAR guidelines require defining environmental values and setting site-specific acceptance criteria for groundwater levels for such receptors (8).

Availability of water for recharge depends on existing water entitlements and rights. SW in many of the catchments in the Murray Darling Basin is fully allocated. Supplementary water allocations are available during periods of high flows but these are relatively small and existing allocations need to be purchased to provide water for recharge.

4) Suitable areas and feasible sites

While MAR projects include numerous configurations, most Australian projects include water capture, pre-treatment, recharge, storage, recovery, post-treatment and end use as illustrated in the example in Figure 4 (8). In practice there are many possible combinations of water source, infrastructure, water treatment and end use

An international study found that the main criteria identified for the assessment of site suitability for WB are geomorphology, aquifer storage capacity, soils, land use cover, combined aquifer storage and flow capacity, economics and hydrography. The focus on surface criteria is explained by greater data availability, although more remote sensing data products for GW are becoming available (9).

The most suitable areas for WB are those where there are suitable aquifers, water available for storage and proximity to areas of high demand for irrigation and/or town water supply. Criteria for the assessment of regional unconfined aquifer storage potential in the MDB, and the rationale for using them are summarised in table 1. The location and type of WB or MAR scheme is a key factor in their viability (3).

It has been estimated that there is up to 4000 gigalitres of storage space in surficial aquifers in the MDB near major rivers which could be economically feasible for MAR. This represents 16% of total accessible capacity of surface storages across the basin and approximately four years of current GW irrigation water supplies. This would provide about 0.45 m of storage for almost 9000 km³ of existing irrigation area in the MDB as a drought buffer or to preserve environmental flows (6), see Figure 5.

Sophisticated hydrogeological understanding of recharge sites and management of associated operational risks are important determinants for schemes success. Learning from long-term operations and observations can to some extent substitute for formal hydrogeological analysis (2).

Table 1: Site assessment criteria to delineate areas suitable for water banking in the Murray Darling Basin utilising unconfined aquifers

Assessment Criteria for suitable sites	**Rationale**
topographic slope <10%	infiltration and/or retention is possible
clay content <40%	economically viable infiltration rate
Suitable geology; unconsolidated sediments, alluvium, colluvium, and sand plain formations	acceptable infiltration and retention
regolith depth > 10 m	storage capacity in the unconfined system
depth to water table > 5 m	acceptable storage and flooding risk
gw salinity (TDS) <3000 mg/l	quality of recovered water

Source: adapted from Gonzalez et al 2020 (6)

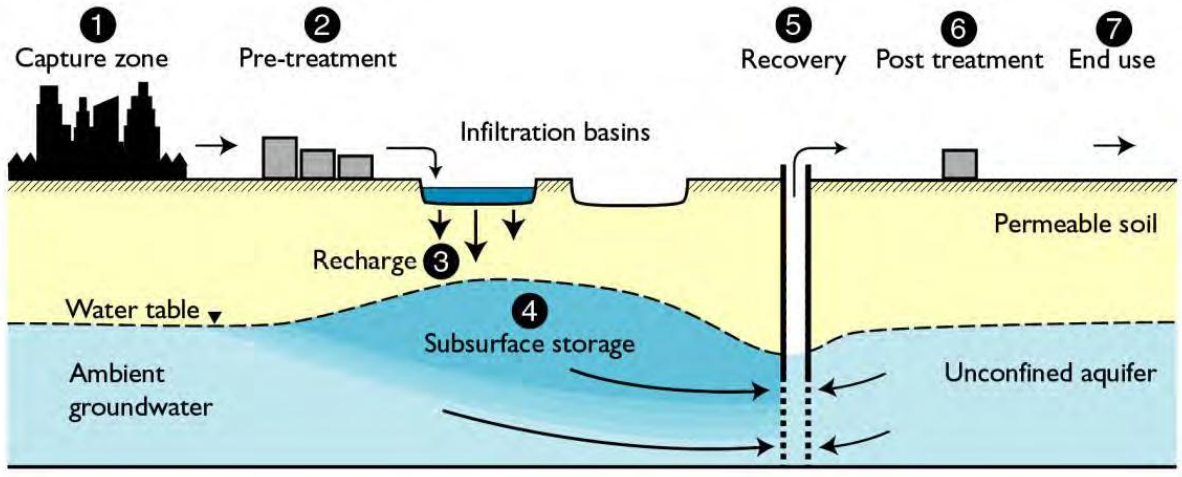

Figure 4: Components of a MAR project (8)

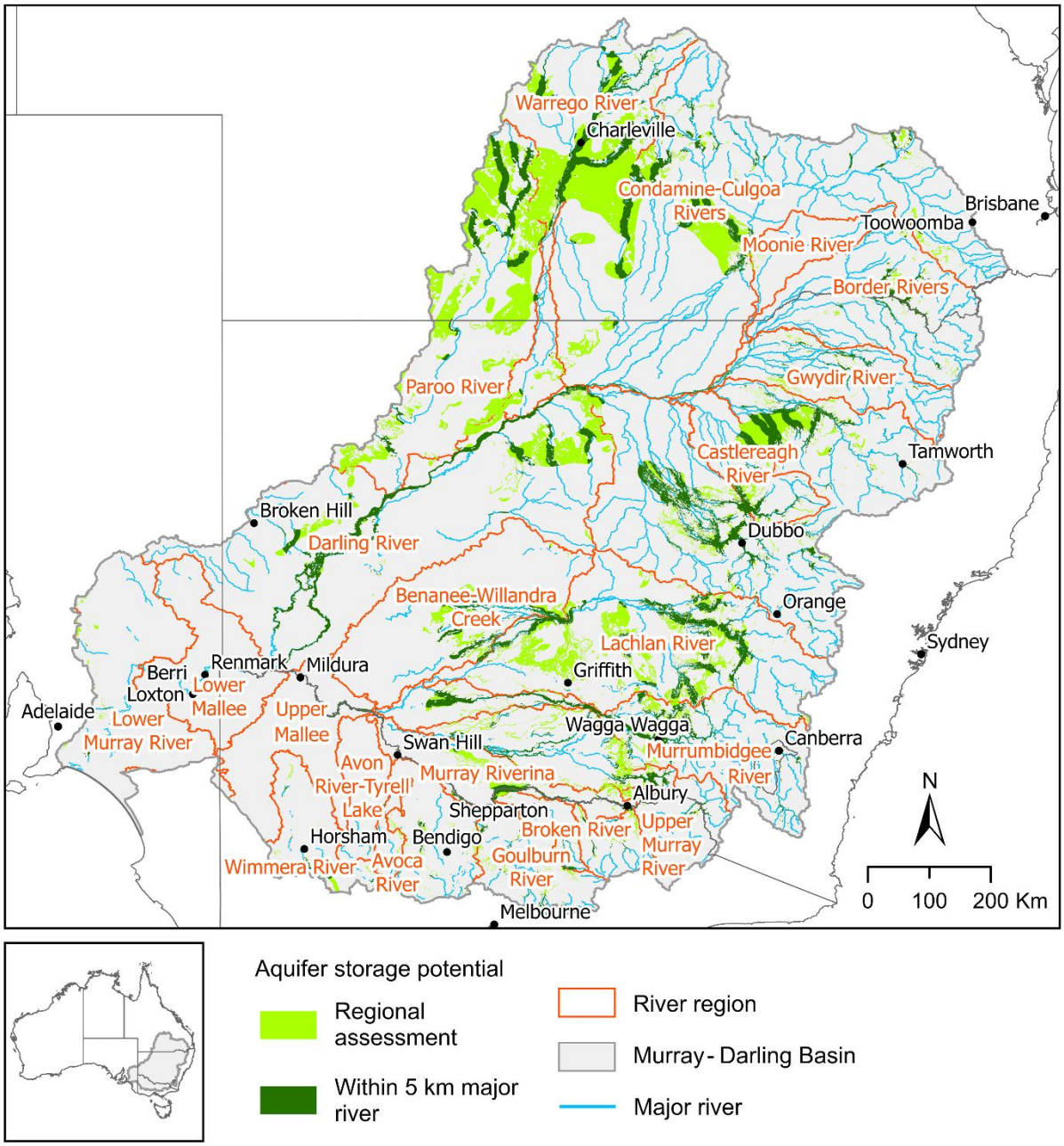

Figure 5: Murray Darling Basin potential for water banking in unconfined aquifers (based on Table 1 criteria)

Policy and Institutional Requirements

5) Water rights and water allocation rules

Policy requirements should include sustainable extraction limits to avoid long-term resource depletion, tradable water rights that allow flexible water reallocation, and allocation of SW or alternative water sources for WB to manage SW variability and water scarcity (4).

Well-defined and secure rights for GW recharge, storage, recovery and transfer are required to guarantee future access and use of banked water. Depending on the nature of the scheme the following may also be required;

- an entitlement to take SW for the purpose of recharge;
- an ongoing share of the recharge and storage capacity of an aquifer;
- an allocation relating to recovered volumes;
- approval to operate recharge and extraction infrastructure (10)

Transparent rules in water resource plans are needed for allocations to recharge and recovery entitlements, and adjustment to recovery volumes to account for leakage from storage (10). Recovery entitlements need to allow for the annual rate of retention of recoverable stored water, and recovery efficiency (11).

In systems where SW and GW resources are connected, SW and GW plans and allocations need to be integrated to avoid double counting and over allocation of water resources (11).

6) Water Quality Management

Water quality hazards assessed during the development of MAR and WB schemes include pathogens, organic and inorganic compounds, salinity and sodicity, nutrients, turbidity and particulates, radio nucleotides and temperature (11, 12). Recently concerns have emerged around the introduction of chemicals of concern getting into aquifers (e.g. PFAS, pharmaceuticals) through MAR schemes (13).

Therefore, schemes require management of water quality to ensure:

- protection of the health of users of recovered water and other aquifer users, including ecosystemes;
- prevention of clogging of recharge facilities and recovery wells;
- management of mixing in the aquifer and ensuring recovery efficiency (11).

Aquifer composition and dynamics and clogging and mixing in the aquifer are the main factors limiting recovery efficiency, which is the proportion of recovered water of suitable quality for use. Clogging is mainly influenced by the quality of recharge water and facilities management. Salinity is a major threat related to mixing in the aquifer (11).

7) Third party impacts

Rights established under WB schemes must not result in adverse third-party impacts. MAR schemes should include a risk assessment and management plan, including assessment to ensure that the scheme does not adversely affect water resources, water user entitlements, the environment or public health outcomes (10). Management may include monitoring of impacts of the scheme on connected SW and GW resources (14), and appropriate buffers or limits on recharge or extraction to ensure that the scheme does not adversely affect aquifer pressures or levels, existing entitlement holders or groundwater dependent ecosystems (GDEs) (15).

> “Water banking relies on secure water rights, clear allocation rules, careful management of water quality, safeguards to prevent harm to third parties or the environment.

8) Adaptive management

Adaptive management of water resources is needed in response to changes in demand-supply imbalances, environmental impacts and downstream effects. The Murray Darling Basin Plan is designed to be an adaptive management framework, reviewed every 10 years. This allows emerging climate change patterns, new information and tools and techniques such as WB to be considered (16,10).

9) Regulation of water banking establishment and operation

The regulation of WB and MAR establishment and operations varies across jurisdictions depending on political choices and governance structures. Governments have established different conditions for revising laws and regulations to cover MAR.

Comparison of MAR regulation across selected jurisdictions suggests that effective MAR regulation includes the following elements (17);

- enabling source water availability, entitlements to use water for recharge, and capacity to deliver water to recharge sites;
- water quality evaluation and pre-treatment of source water to a level appropriate for the intended end use and that protect native GW. Permit conditions that protect native GW may include GW quality requirements associated with MAR;
- assessment of aquifer capacity to receive and store recharged water for sufficient periods and allow recovery at sufficient rates and quality to meet intended uses;
- monitoring effects of MAR schemes including volumes of stored water, storage periods, and volumes, quality, and end use of recovered water;
- mitigating effects of MAR schemes as required to meet water quality regulations and address impacts on adjacent wells and other third-party impacts, including cumulative impacts of multiple MAR schemes.

Close coordination between regulators and cooperation among regulators and MAR proponents - throughout project design, construction and operation - facilitates compliance with regulatory processes, as well as resource protection. Effective administration of MAR regulations may be facilitated by assigning specialist MAR permitting units or individuals in responsible agencies (17).

Water accounting should assure users of the aquifer that WB and MAR schemes operate consistently with their rights. This will require fit for purpose metering and measurements of water recharged, stored and extracted, underpinned by effective compliance and enforcement systems including penalties for breaches (10). Effective monitoring of impacts of use on connected GW-SW resources is also required (14).

> “Successful and sustainable long-term WB and MAR depends on regulations that are practical, not overly burdensome and support water supply resilience.

Adoption of national MAR guidelines has increased confidence in project development, leading to greater implementation of MAR (10). The Australian Guidelines for Water Recycling: Managed Aquifer Recharge (8) establish a sound and consistent basis for protecting human health and the environment at MAR operations in the Australia’s states and territories. The Guidelines provide a risk management framework for the assessment and development of MAR projects for proponents, regulators and other stakeholders – see Figure 6.

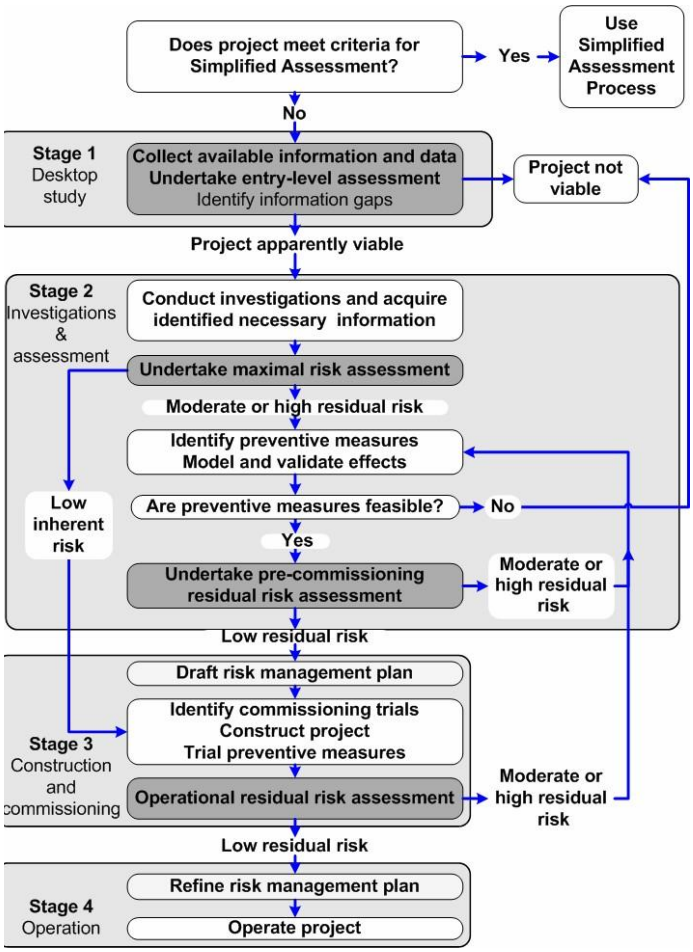

Figure 6: Risk assessment stages in managed aquifer recharge schemes (source: 8)

Context specific conditions

There are a wide range of objectives and methods for storing water in aquifers for subsequent recovery (18). Although the conditions for effective and sustainable WB and MAR schemes vary widely according to context, there are some common features.

10) Project governance and rules

Clear and transparent definition of membership decision-making authority, roles and responsibilities are essential for effective planning and monitoring of WB and MAR schemes (11).

Well defined rules are needed for water deposits, withdrawals, exchange and pricing, including limits to deposits, leasing, sales and withdrawals, and/or restrictions on exchange transactions into and out of the area where WB is located (19).

Tracking and accounting of inflows and outflows is essential given the invisible nature of GW and the potential for MAR schemes to affect existing water users (4, 20).

These institutional arrangements set the expectations of parties involved in the schemes build trust and avoid conflict.

When there are multiple participants and/or organisations involved in a project, collective WB arrangements offer a number of advantages for participants and authorities. Coordination of information on WB transactions and impacts can reduce transaction costs and improve transparency about project operations.

Transparency and good communication increases confidence of stakeholders and also raises awareness of emerging issues, for example in the early stages of drought a WB can raise awareness of the need for action to reduce drought impacts.

Collective WB management also facilitates regulatory oversight of environmental and social impacts, and can encourage operations aimed at improving environmental outcomes (4).

11) Management of operations and risks

Management of WB includes procedures to manage risks to water resources, water users or the environment. These procedures contain operation and maintenance specifications defined prior to initiating operations:

- locating and timing of availability of water used for recharge;
- metering and reporting the volume of water recharged;
- recording deposits and withdrawals;
- monitoring and regular reporting of volumes of water in the bank (peak and average), and conditions of adjacent SW and GW resources against benchmarks.

Penalties for breaches of scheme rules may be needed e.g. if water recharge or extraction limits are exceeded (10).

Priorities for tracking and accounting of flows vary according to the purposes of MAR. When GW is banked for supply risk management it is important to track reductions owing to losses and outflows in order to forecast water recovery. MAR schemes to recharge aquifers or improve instream flows must track GW flows to SW bodies (20). In either case regular measurement of water quality in the target aquifer is needed, such as threshold levels of TDS and salinity.

12) Financing

WB and MAR proponents face financial challenges during development, approvals and operation. There is often a long time lag between MAR construction costs and project benefits, and water users often have insufficient funds to support capital investments. MAR schemes often have high establishment costs because of complex approvals processes. Lack of resources for operational requirements is a major source of financial risk for MAR schemes (21).

> “Water banking requires sustainable funding to cover both the upfront costs of development, approvals and the ongoing costs of operation and monitoring.

Combinations of federal, state and local government level funding, in partnership with private investment can support development of demonstration sites and new schemes. Financing of physical WB operations - metering, monitoring and administration - must not be overlooked, and can be facilitated by WB fees and service charges (12).

13) Stakeholder engagement, public acceptance and licence to operate

Active stakeholder engagement and public education can be critical to the success of a proposed MAR project. This is particularly important for recharge of reclaimed water. Stakeholder involvement can be crucial to identify local priorities and shape the project to local conditions.

In addition to key stakeholders, the general public should be informed about the importance and vulnerability of groundwater systems, and the cost effectiveness of MAR solutions. A public that is well informed about GW conditions, management challenges, and alternative solutions is more likely to support MAR (11).

Social risks to MAR arise from lack of communication and information, pollution of recharge zones by human activities, and lack of social acceptance of recycled water (12). Public concerns about MAR using recycled water include fairness and trust issues surrounding the distribution of stormwater, infrastructure costs, environmental implications of MAR, and potential wastage of stormwater (22). These risks and concerns can be mitigated by high levels of transparency and accountability, community education and consultation, public reporting and access to data from WB and MAR schemes.

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Further reading

For more detail, please visit the CRC OneBasin wensite under:
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One Basin CRC

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