A Water Quality Guide to Managed Aquifer Recharge in India

This report was prepared as a result of a DFAT Project through the Public Sector Linkages Program involving CSIRO Land and Water Flagship in Australia and UNESCO International Hydrological Programme

Peter Dillon, Joanne Vanderzalm, Jatinder Sidhu, Declan Page, Devinder Chadha

CSIRO Land and Water Flagship

December 2014

CSIRO

United Nations Educational, Scientific and Cultural Organization · International Hydrological Programme

Australian Government
Department of Foreign Affairs and Trade

Australian Aid

Contents

Tables

Figures

Boxes

Acknowledgments

This document is a product of DFAT Public Sector Linkages Program project ROU14476 2010-2014 ‘Guidance on water quality in managed aquifer recharge’ involving CSIRO in Australia and UNESCO International Hydrological Program in India. The authors are grateful to many Indian scientists who attended workshops run to determine the need for and form of water quality guidance. The Australian Natural Resources Management Ministerial Council, the Environment Protection and Heritage Council and the National Health and Medical Research Council are acknowledged for the use of selected components of the Australian Guidelines for Managed Aquifer Recharge and the World Health Organisation for use of components of its Drinking Water Guidelines and other documents. Some of the example sites where these Guidelines were applied were identified and studied in two other projects; ACIAR project LWR/2010/015 ‘Improved village scale groundwater recharge and management for agriculture and livelihood development in India’ (*MARVI*), and the European Commission 7th Framework Project FP7-ENV-2011 ‘Enhancement of natural water systems and treatment methods for safe and sustainable water supply in India’ (*Saph Pani*). The contribution of collaborators in these projects is gratefully acknowledged.

Foreword

For many years India has been the international leader in the volume of water recharged and the number of recharge structures employed in national, state and local level programs to help sustain groundwater storages and irrigation livelihoods. In many cases this recharge water has been of equivalent quality to water aleady in the aquifer. However enhancing recharge often provides higher hydraulic loadings than under unmodified settings and there is potential for water reaching the aquifer being of a poorer quality than that of the native groundwater. Generally this is of little consequence for irrigation water but when the same aquifer is also being used as a drinking water source, it should be an obligation of those enhancing recharge to protect the health of those whose drinking water is affected by their operations.

The purpose of this Guideline is to provide simple steps that can be applied by people without specialist expertise in villages and towns in India to improve the protection of their aquifer from contamination arising from recharge operations. Applying these procedures, to existing and new recharge projects will help protect human health and enable each project currently called artificial recharge to be renamed managed aquifer recharge, because not only is groundwater storage enhanced but groundwater quality is considered and human health protection improved. It is hoped these guidelines will form part of wider groundwater protection programs that improve the quality of all water recharging aquifers in India and elsewhere. This guidance aims at making water as safe as can be determined based on visual observations. Future steps would be to introduce water quality analyses and risk assessments that allowed treatments to assure water safety, both for natural waters and treated urban and industrial wastewaters.

This document makes a start towards the achievement of UNESCO International Hydrological Programme VIII (2014-2021) Theme #2. *Groundwater in a changing environment*, in Focal Area 2.2 *Addressing strategies for management of aquifer recharge.* Specifically it addresses an element common to two of the specific objectives (http://www.unesco.org/new/en/natural-sciences/environment/water/ihp-viii-water-security/):

- *to develop and apply methods to assess impacts of recharge structures on water availability and quality, social and economic resilience and local ecosystems*
- *to enhance governance capacities and institutional and legal frameworks to aid effective MAR implementation.*

UNESCO is pleased to acknowledge the support of DFAT Public Sector Linkages Program and CSIRO Land and Water for advancing IHP VIII.

Alice Aureli

Chief of Section

Groundwater Systems

Secretariat of the International Hydrological Program

1 Introduction

1.1 Origin, purpose and status of this document

India is an international leader in artificial recharge (4 km^3 /year, CGWB 2005) to help replenish groundwater and sustain essential water supplies. Uptake of recharge enhancement has been phenomenally successful in volumetric terms and has supported much agricultural production and many communities that otherwise would not be sustainable. The opportunities are abundant and 85 km^3 /year of surplus runoff has been identified to augment groundwater recharge in the the revised Master Plan for Artificial Recharge to Groundwater in India (CGWB 2013).

In addition to increasing the quantity of groundwater artificial recharge also impacts on the quality of groundwater in many ways. This can freshen brackish groundwater or dilute high fluoride concentrations. In some cases it can also introduce microbiological or chemical pollutants to aquifers, or mobilise minerals from the aquifer matrix, such as arsenic, which may have a harmful effect on people and animals using the recovered water. Thus, while recharge enhancement is very often undertaken to improve groundwater supplies for irrigation and the quality of water recharged may be suitable for such use, the same aquifer is often used as a source of drinking water supply. These supplies need to be protected so that wells are no less safe for drinking water supplies with recharge enhancement in place.

However artificial recharge can be undertaken in such a way as to avoid these adverse effects by managing the quality of water being recharged, to contain pollution and prevent adverse mineral-water interactions. When such control is done intentionally to achieve greater benefits for human health and the environment this is called “managed aquifer recharge” (MAR). Until recently, water quality aspects have tended to be subjugated. In 2009 the Chairman of the Central Ground Water Board, Dr Jha, raised the opportunity to specifically account for groundwater quality protection in Indian Guidelines for Artificial Recharge (CGWB 2000) and Manual for Artificial Recharge of Groundwater (CGWB 2007). This initiated a DFAT project to draw from and adapt Australia’s experience in developing risk-based guidelines for managed aquifer recharge (NRMMC-EPHC-NHMRC 2009) and adapt this to India’s needs for groundwater protection. The revised Master Plan for Artificial Recharge to Groundwater in India (CGWB 2013) also references the purposes and types of water quality monitoring to protect groundwater quality.

Initial efforts at applying the Australian MAR Guidelines to assess risk in artificial recharge projects in India, China, Mexico, South Africa, and Jordan by hydrogeologists with a deep knowledge of those projects found that the first part of the Australian guidelines, an entry level assessment, was useful and provided a systemmatic pathway to identify all the issues to be addressed (Dillon *et al* 2010). However the quantitative risk assessment was found to be data hungry and that the water quality data necessary to complete the assessment were not available, particularly for microbial pathogens. Hence in developing guidance for India it was decided at an early stage to adapt the Australian entry level assessment, which consists of a viability assessment and a degree of difficulty assessment. However, on its own this did not canvass the causes of water quality issues of source water for recharge in a way that would suggest protective measures. The WHO sanitary survey or inspection approach is useful in systematically identifying potential hazards and hazardous events and compliments water quality monitoring for protection of drinking water quality (WHO 2012). Hence the WHO sanitary survey approach was incorporated with the Australian entry level assessment in order to produce a water safety plan commensurate with the WHO (2011) drinking water guidelines as applied to small scale systems (Denison *et al* 2005, WHO 2012).

This integrated approach (Dillon *et al* 2013) was applied to several Indian artificial projects to determine the relevance of the method. However in the absence of water quality data it cannot be claimed that the approach was validated, and that its application will assure safety. It can however be confidently claimed that the application of these guidelines, which require only basic information that is readily observable, will make artificial recharge safer. The next stage would be to apply, test and refine this document for artificial recharge in rural and urban conditions, for a wider range of water types, aquifer types, recharge methods, end uses of recharged water and capabilities of implementing institutions, to facilitate adoption by state and federal authorities. Progress via incremental improvements made over time is consistent with the key principles of water safety planning (WHO 2012) and applies locally and at systemmic level as advocated by Anderson *et al* (2000).

This document on its own has no formal status that requires compliance. However it may be helpful in informing at national level consideration on guidance that may be applied at state and local level. It is aimed to ensure that safety of drinking water is considered as an integral part of recharge enhancement planning and practice.

1.2 Scope of this guidance

1.2.1 Relationship with other guidelines

It is intended that in due course extracts from this document may be incorporated as a chapter addressing water quality to extend existing Central Groundwater Board Guidelines for Artificial Recharge (2000) and Manual for Artificial Recharge of Groundwater (2007) when these are updated. These documents provide advice on location, design and operation of groundwater repleishment projects with the current emphasis on the hydraulic performance of such systems.

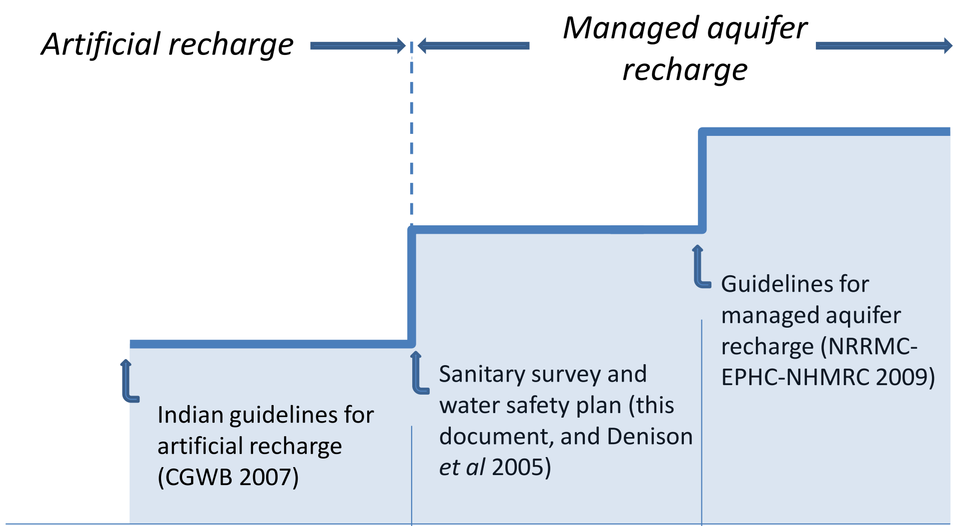
This document also refers to the Bureau of Indian Standards specifications for drinking water (BIS 1992) and guidelines for the quality of irrigation water (BIS 1986). Related guidance is available from Central Pollution Control Board (CPCB) on water quality monitoring protocols (CPCB 2007) and on well head protection and from BIS on construction of drinking water wells. Ministry of Environment & Forests (1992) policy on pollution prevention has stimulated programs such as the CPCB‘s National River Conservation Plan (NRCP) largely focused on building sewage treatment plants, which is currently being strengthened and broadened by the Government of India. Plans to end open defecation in India on health and safety grounds are currently in development, and would also have benefits for runoff water quality.

Risk analysis techniques have been used in India for occupational safety e.g. in mining (Paithankar 2011), chemical industries, and for public health in food and drug industries and health services (National Safety Council of India 2014). These approaches demonstrate existing acceptance of risk assessment methods in government and private sectors for managing health related issues.

WHO Guidelines for Drinking Water involve water safety plans and this document draws heavily on this methodology. Further background reading is given in Appendix 1. Detailed descriptions of water safey plan development and implementation, including sanitary inspections can be found in WHO (2011, 2014). Some extracts and adaptions are included from the Australian Guidelines for Managed Aquifer Recharge (NRMMC-EPHC-NHMRC 2009) which form part of the Australian National Water Quality Management Strategy, and an introduction to this document is contained in Appendix 2. The principles of these international guidelines are applicable in India but the methodology may need adaption to local conditions to pragmatically provide water quality protection. Most international guidelines require proof that water will be safe to use. To do this requires more data or different types of data than currently can reasonably be expected in many Indian groundwater replenishment projects. Hence this document may be regarded as interim guidelines for India, to assist those recharging aquifers to take actions that will make water safer, but without a guarrantee that recovered water will be safe for its intended uses, especially for drinking, without further treatment.

For public drinking water supplies the WHO Guidelines (WHO 2011) provide a comprehensive approach to managing risks to human health. This requires substantial effort for investigations, monitoring, analysis and evaluation. The Australian Guidelines for Managed Aquifer Recharge (NRRMC-EPHC-NHMRC 2009) follow the same principles for risk management for public health for all types of uses of the water and a similar approach for managing environmental risks. They therefore also require substantial water quality data acquisition to support quantitative risk assessments. Based on experience reported earlier (Dillon *et al* 2010) these approaches were unlikely to be adopted in India and many other countries in transition, due to the unavailability of the necessary data to support those assessments.

Recognizing this reality, this document aims at providing a transitional pathway whereby basic information readily observable at an existing or proposed artificial recharge site is used to improve the safety of a project. Without data this approach cannot assure effective protection of groundwater used for drinking water supplies. However the aim of this current document is to start the process of water quality being taken into account as standard practice for new and existing projects in India and other countries in transition. It can be used as a screening tool to identify sites where more rigorous investigations are required, that would then support assessments that accord with WHO or Australian guidelines.



Water quality focus :	Not explicit	Public health	Public health & environment
Risk assessment :	None	Qualitative	Quantitative
Level of safety :	Unknown	Safer	Safe

Figure 1.1 Implementing this Indian Guideline for managed aquifer recharge is a step towards safer water supplies and improved groundwater protection than current practice, but without the rigour of data acquisition to support a risk assessment necessary to assure safety.

In essence this document applies elements of the WHO water safety planning approach which is already in use in rural and urban India to protect the quality of drinking water. It draws heavily on the preliminary stage of assessment drawn from the Australian MAR Guidelines and incorporates a sanitary survey approach to identify likely hazards in the source water catchment.

1.2.2 Sources of water, types of aquifers and purposes

This document is applicable to natural source waters in rural and peri-urban catchments. While it potentially could be applied for other sources such as urban stormwater, sewage effluent, and industrial effluents these are likely to contain significantly higher contaminant loads and data collection would be needed to provide reasonable water quality protection for uses of recovered water by the schemes' proponents and by other groundwater users. The guidelines are applicable in unconfined alluvial aquifers. Further work is required for application in confined aquifers, fractured rock aquifers and aquifers used as public drinking water supplies. The reason for this is that recharge of water containing oxygen into confined groundwater that is depleted in oxygen is likely to cause oxidation of reactive minerals and potentially release metals into the groundwater at concentrations that could in some cases exceed drinking water guideline values and would not be detectable by visual observation.

These current guidelines cover a more limited range of source water types, aquifer types (Table 1.1) and existing groundwater uses than other guidelines (Table 1.1) because insufficient data were available to provide confident advice, particularly on microbial risks to public health and on release of toxic metals from aquifers. Hence following this guidance document is claimed only to make intentional recharge safer, not to make it completely safe. That cannot be done without data collection for which current capacity is quite limited. If projects are large-scale, or are in highly sensitive environments they warrant investigations and data collection, so that more rigorous assessment (e.g. Australian MAR Guidelines) can be applied as an extension from these Indian Guidelines. Establishing recharge demonstration projects with monitoring will build confidence among regulators, community and industry before embarking on more challenging projects.

Table 1.1 Comparison of coverage of this document with WHO Drinking Water Guidelines and Water Safety Plans and with Australian MAR Guidelines.

Coverage	This document	WHO Drinking Water Guidelines	Australian MAR Guidelines
Source Water Type			
Natural waters	√	√	√
Urban stormwater			√
Treated sewage effluent			√
Desalinated water			√
Industrial waste water			√
Aquifer Type			
Unconfined alluvial	√	√	√
Unconfined fractured rock	√	√	√
Confined alluvial		√	√
Confined fractured rock		√	√
Groundwater Condition			
Groundwater not used for drinking	√		√
Groundwater used for drinking	√	√	√
Groundwater nearby is public water supply		√	√
Groundwater sustains sensitive ecosystems			√
Groundwater is brackish	√		√
Groundwater is polluted			
Methodology			
Catchment assessment	√	√	
Desktop assessment based on available data, even if limited	√	√	√
Risk assessment based on investigations and monitoring data		√	√
Monitoring programs		√	√
Management of clogging			√
Recovery in brackish aquifers			√
Biogeochemical reactions in aquifer			√
Cost and Confidence			
Low cost and ease of implementation	√		
Improves health protection	√	√	√
High confidence in health protection*		√	√
High confidence in environment protection			√

* if drinking water is from a hard rock aquifer the risk of contamination may be unknown

1.2.3 Water allocation, water trading and other water governance issues

In December 2012 the National Water Resources Council approved the National Water Policy (Government of India 2012a). This presents a comprehensive approach to integrated water management of surface water and groundwater and considers quantity and quality with objectives of equity, social justice and sustainability. It declares that whereas groundwater is currently "still perceived as an individual property and exploited inequitably and unsustainably in places", that water needs to be "managed as a community resource, held by the state under public trust doctrine to achieve food security, livelihood, and equitable and sustainable development for all."

This current document presumes the adoption of the National Water Policy, to assure that taking surface water for recharge does not impoverish communities downstream, and that enhanced recharge will in fact make groundwater more plentiful enabling equitable use for the highest valued uses, such as to satisfy basic human needs. With allocation plans in place government can then optimise water efficiency improvement and recharge enhancement programs, including activities supported by the National Rural Employment Gurarantee Act (NREGA). A range of other measures including trading of recharge credits can then be used as incentive for further investment in managed aquifer recharge (Ward and Dillon 2011, Dillon *et al* 2012).

With new recharge projects, public consultation is necessary to ensure that the needs of the local community are taken into account and facilitating support for the project. This is particularly important where drinking water supplies could potentially be affected by the recharge operation.

1.3 How to use this guidance

This guide gives a short list of questions that can be used to identify the potential risks and to suggest measures to reduce these to make groundwater replenishment safer. Artificial recharge sites where these measures are implemented may then be called "managed aquifer recharge" sites. This guidance may be applied to existing artificial recharge projects and to new projects being planned. For existing sites this may be used as a screening tool to prioritise sites for water quality protection measures. For proposed new sites these guidelines may help in selecting locations where water safety is easier to manage. They may also be used alongside existing guidance (e.g. CGWB 2007) as a prerequisite for government investment.

This document is encapsulated in a checklists brochure (Appendix 6) intended to be suitable for use at local level, unencumbered with the explanatory material contained in this document as a whole. This contains the minimum essentail material and would be easier to translate into local languages as required.

2 Managed aquifer recharge

This chapter defines managed aquifer recharge, outlines the components of a managed aquifer recharge system, demonstrates a range of such systems currently in use and outlines the considerations made when selecting a recharge method. It also addresses the transition from unmanaged to managed aquifer recharge.

2.1 Definition, purposes and types of managed aquifer recharge

2.1.1 Definition and purposes of managed aquifer recharge

Managed aquifer recharge is the intentional recharge of water to aquifers for subsequent recovery or environmental benefit; the managed process strives for adequate protection of human health and the environment. Aquifers may be recharged by diversion of water into wells or infiltration of water through the floor of basins, galleries or rivers.

The water recharged into an aquifer may be:

- recovered for drinking, industrial or irrigation supplies
- stored as banked water for emergency supplies
- used to sustain environmental flows and phreatophytic vegetation (i.e. deep-rooted plants) in stressed surface water or groundwater systems
- used as a barrier to prevent saline intrusion in overexploited aquifers.

Examples of managed aquifer recharge are shown in Figure 2.1. The figure shows the seven components of the system (also listed in Table 2.1).

Climate change and increasing urban population have increased pressures on water resources and in many areas groundwater levels are falling. Therefore, more diligent management is needed to secure adequate supplies of suitable water for human and environmental needs. Managed aquifer recharge offers ways to generate water supplies and protect the environment using water that may otherwise be wasted. Below-ground storage — particularly in rural areas with low topographic relief and urban areas where there are few alternatives — allows excess seasonal water to be conserved until water is in higher demand. Well-designed and operated systems can improve groundwater quality.

Managed aquifer recharge, particularly via wells, has many advantages, including (Pyne 2005):

- low capital costs, often the most economic form of new water supply
- no evaporation loss, algae or mosquitoes (unlike dams)
- no loss of prime valley floor land
- ability to use brackish aquifers that could not be directly used for supplies
- potential location close to new water sources, and where demand for water is high
- aquifers providing treatment as well as storage
- low greenhouse gas emissions compared to remote pumped storages
- able to be built to the size required for incremental growth in water demand
- provision of emergency and strategic reserves
- improved reliability of existing supplies
- improved environmental flows in water supply catchments for urban areas.

Up to seven elements are present in any managed aquifer recharge project as shown in Figure and described with examples in Table 2.1. Recovered water may be used predominantly for irrigation, however the water quality of the small component used for drinking needs to be protected, for example by boiling or chlorination.

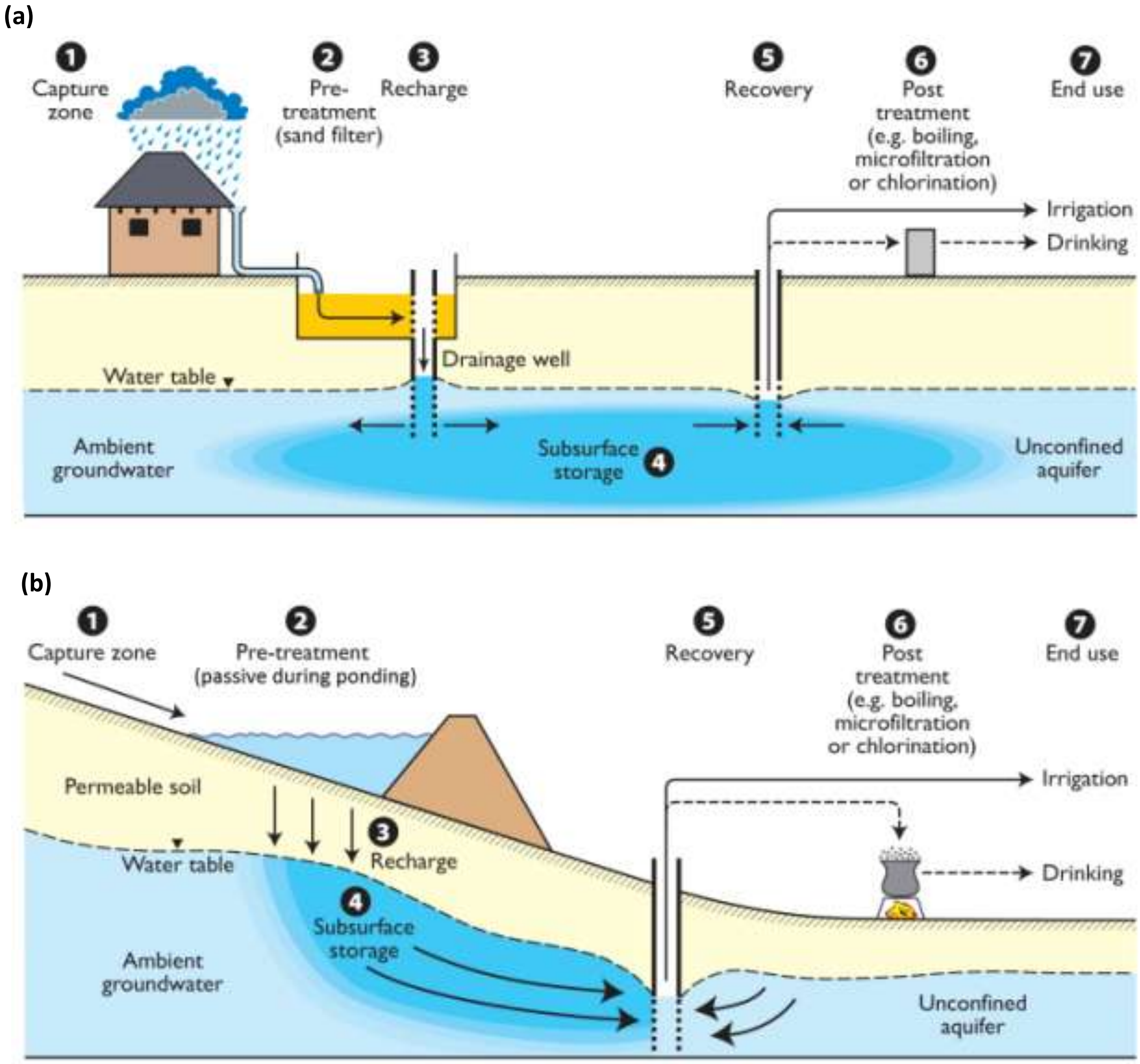


Figure 2.1 Examples of managed aquifer recharge systems that have up to seven elements, (a) rainwater harvesting where each element is distinct and (b) checks dam or percolation tank where several elements are integrated.

Table 2.2 Elements of a managed aquifer recharge system (from NRMMC-EPHC-NHMRC 2009).

Element	Examples
1. Capture zone	• Harvesting using weirs, basins or wetlands in catchments
2. Pretreatment	• Passive systems such as wetlands • Engineered treatments (if needed) to produce source water suitable for recharge, e.g. sand filters
3. Recharge	• Percolation tank / check dam / nala bund / alicut • Aquifer storage and recovery using a dug well • A variety of recharge systems are described in Section 2.1.2
4. Subsurface storage	• The aquifer that water is stored in and where aquifer passive treatment may occur
5. Recovery	• Recovery well • Intentional discharge to a groundwater-dependent ecosystem
6. Post-treatment	• Engineered treatments (if needed) to produce water suitable for its intended use, e.g. boiling water before drinking, microfiltration, chlorination
7. End use	• Irrigation, • Industrial use, • Drinking water supplies, or • Sustaining aquatic ecosystems

Note: Catchment water quality management is important and is addressed in NRMMC-EPHC-NHMRC (2008).

Several types of managed aquifer recharge are shown in Figure 2.2 (after Dillon 2005), and each type of managed aquifer recharge is briefly described below. Specific examples are documented in CGWB (2011; 2012), UNESCO IHP (2003, 2006), and Gale *et al* (2006).

The components listed in Table 2.1 are common to all systems. A range of preventive measures and monitoring techniques (outlined in subsequent chapters) may be applied to each component, depending on the specific risks associated with the system's operation.

2.1.2 Types of managed aquifer recharge

Aquifer storage and recovery (ASR)

ASR involves injection of water into a well for storage, and recovery from the same well. The aquifer may be confined or unconfined. Examples are found in tube wells in Florida and South Australia, and in dug wells in India that are recharged and have a perennial water table.

Aquifer storage, transport and recovery (ASTR)

ASTR involves injection of water into a well for storage, and recovery from a different well, generally to provide additional water treatment.

Vadose zone wells

Vadose zone or 'dry' wells are typically shallow wells in areas with deep water tables. They allow infiltration of water through the unsaturated zone to the unconfined aquifer at depth. Examples are found in Phoenix, United States. Approx 96,000 dug wells were refitted as recharge wells in India (CGWB 2011) many of these were dry because of groundwater overdraft by tube wells with submersible electric pumps.

Percolation tanks / check dams

Percolation tanks, also called check dams, nala bunds, gully plugs, alicuts and recharge weirs, are dams built in wadis (*i.e.* ephemeral stream channels that contain water only after rainfall) to detain water that infiltrates through the bed, increasing storage in unconfined aquifers. The water is extracted down-valley. Examples in India abound (e.g. in Maharashtra, Rajasthan, Andra Pradesh, Tamil Nadu).

Rainwater harvesting

In 'rainwater' harvesting, roof runoff is diverted into a well, sump or caisson filled with sand or gravel, and allowed to percolate to the water table. It is collected by pumping from a well. Many states in India (e.g. Gujurat and Tamil Nadu) now require rainwater harvesting for development approval for houses and businesses.

Bank filtration

In bank filtration, groundwater is extracted from a well or caisson near or under a river or lake to induce infiltration from the surface water body. The quality of recovered water is thereby improved and more consistent. Examples include at Palla in New Delhi (Yamuna flood plain), at Haridwar (Ganga flood plain) and adjacent Lake Tegel, Berlin, Germany.

Infiltration galleries

Infiltration galleries are geotechnically-stabilised buried trenches (e.g. with polythene cells), or slotted pipes in permeable media. They allow infiltration through the unsaturated zone to an unconfined aquifer. Examples can be found in several parks in New Delhi and in a 30km irrigation canal in Gujurat.

Dune filtration

In dune filtration, water is infiltrated from ponds constructed in sand dunes, and extracted from wells or ponds at lower elevation. The filtration improves water quality and helps to balance supply and demand. Examples are found in Amsterdam, The Netherlands.

Infiltration ponds

Infiltration ponds and channels are usually constructed off-stream. Surface water is diverted into them and allowed to infiltrate (generally through an unsaturated zone) to the underlying unconfined aquifer. Examples are found in Andhra Pradesh and in the Burdekin Delta, Queensland, Australia.

Soil aquifer treatment

In soil aquifer treatment, treated sewage effluent is intermittently infiltrated through infiltration ponds, to facilitate nutrient and pathogen removal. The effluent passes through the unsaturated zone and is recovered by wells after residence in the aquifer. Examples are found at Alice Springs, Northern Territory, Australia, Arizona and California. These are not covered by this current document but are addressed in Australian Guidelines for MAR (NRRMC,EPHC & NHMRC (2009) where substantial water quality monitoring is required.

Underground dams

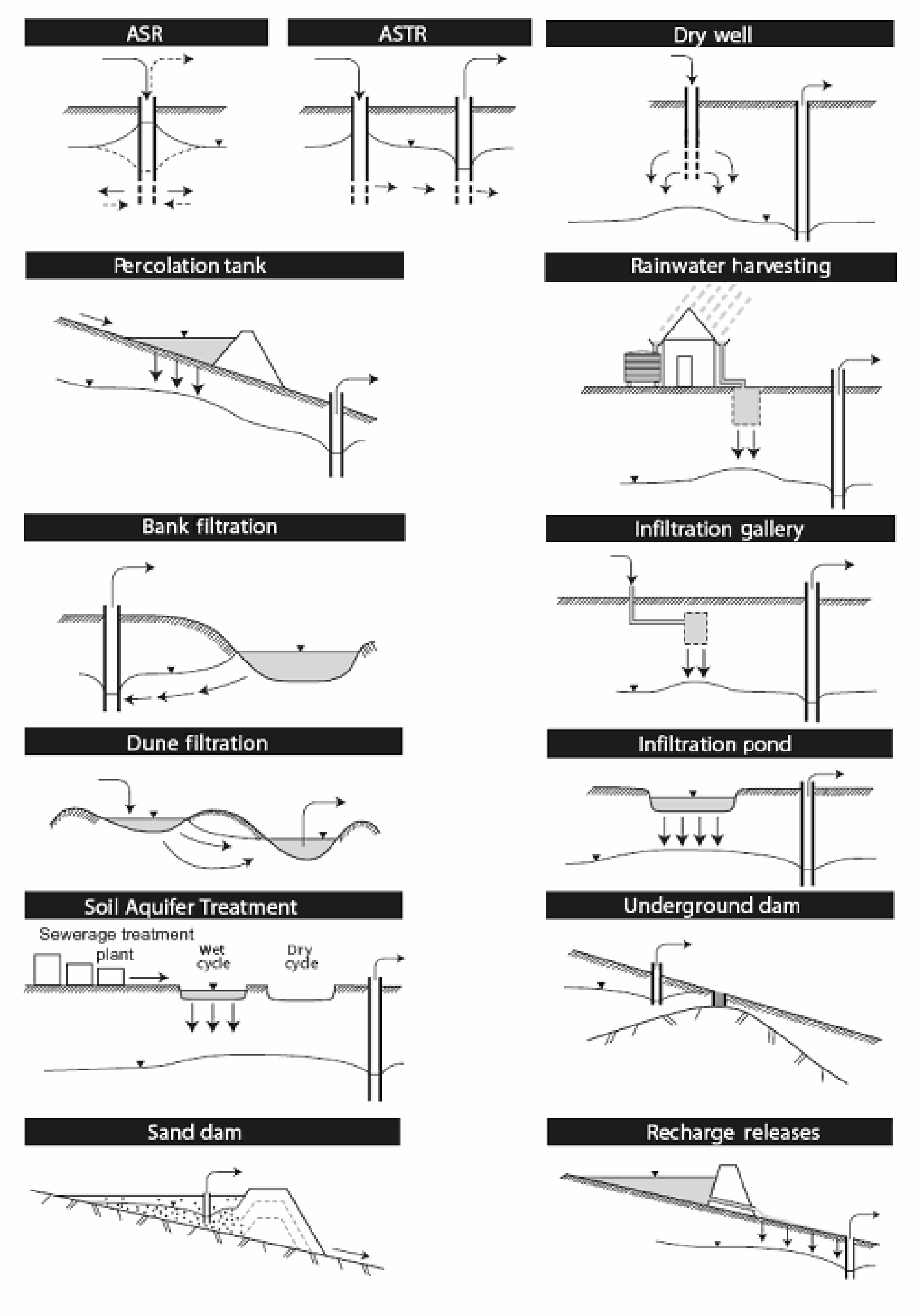
In construction of underground dams, a trench is constructed across the stream bed in ephemeral streams where flows are constricted by basement highs. The trench is keyed to the basement and backfilled with low-permeability material, helping to retain flood flows in saturated alluvium for stock and domestic use. Examples are found in northeast Brazil.

Sand dams

Sand dams are built in ephemeral stream beds in arid areas on low-permeability lithology. They trap sediment when flow occurs and, following successive floods, are raised to create an ‘aquifer’ that can be tapped by wells in dry seasons. An example is at Kitui, Kenya.

Recharge releases

Dams on ephemeral streams detain flood water. They may be used for slow release of water into the stream bed downstream, to match the infiltration capacity into underlying aquifers, thereby significantly enhancing recharge. Examples include the Little Para River, South Australia and in the Souss Valley, Morocco.



ASR = aquifer storage and recovery; ASTR = aquifer storage, transport and recovery.

Figure 2.2 Schematic of types of managed aquifer recharge.

2.2 Selection of recharge method

The method chosen for recharge depends on site-specific conditions and is outlined in CGWB (2000 and 2007). If aquifers are confined, these are excluded from the scope of these guidelines and readers are referred to NRMMC-EPHC-NHMRC (2009). Introducing water that contains dissolved oxygen into confined aquifers, say via ASR or ASTR recharge wells, can cause geochemical reactions, for example mobilizing arsenic, that needs to be addressed for safety of drinking water supplies.

If infiltration is restricted by surficial clay, then galleries, ponds, sumps or wells may be constructed to completely penetrate the low-permeability layer, exposing underlying formations that have higher permeability. The chosen configuration and size will depend on:

- the thickness of the low-permeability layer
- the required infiltration rate
- land availability and cost
- compatibility with other land uses
- ease of traffic access
- the need to avoid insect pests, or even to prevent the attraction of birds (e.g. at airports).

Some recharge methods depend on specific geomorphological characteristics; for example:

- sand dunes and swales (shallow depressions that carry water mainly during rainstorms or snowmelts)
- shallow bedrock saddles or dykes beneath alluvial streams
- restrictions in valleys of alluvial streams to allow percolation tanks or sand dams.

In urban areas land is relatively expensive, favoring methods that use land efficiently, for example, ASR or ASTR. The method used will depend on whether the aquifer is unconfined or confined, or whether there are several aquifers available for storage. In rural areas, where land prices are lower, infiltration ponds and soil aquifer treatment are the most cost-effective ways of recharging large volumes of water. As stated in section 1.2.2 this document does not address the recharge of confined aquifers. In such cases refer to NRMMC-EPHC-NHMRC (2009).

Source-water quality may also play a role in method selection. In general, if the turbidity or nutrient concentration of the source water is high or variable, well-injection methods are likely to lead to rapid clogging. In this situation, infiltration basins that can be periodically scraped or ploughed are preferred. Alternatively, if higher treatment levels are required, provision must be made for back-flushing of wells to purge them of sediment and biomass, or for discharge or recycling of water treatment byproducts.

All these factors must be considered before selecting a recharge method. Investigation costs may be substantially greater for projects involving unconfined aquifers than for confined systems because, in addition to characterizing the aquifer, an understanding of the soil profile through to the water table is needed. In some locations, it may be desirable to store waters destined for different end uses in separate aquifers, and possibly use different methods of recharge.

2.3 Situations where managed aquifer recharge is not viable

Managed aquifer recharge is only feasible if there is a suitable aquifer; that is, one that can accept a sufficient volume of water at a sufficient recharge rate for the benefits to justify the costs of establishing the project. If no suitable aquifer is detected within the affordable drilling depth, and local hydrogeological studies do not reveal a suitable aquifer near the source or sufficient demand for water to allow its economical transfer, then managed aquifer recharge is not feasible.

The average annual volume of additional recharge that can be recovered and the value of the use of the water determines how much can be expended on a viable recharge project. Good water quality, high infiltration rates and high well yields generally favour economic MAR projects.

Managed aquifer recharge is not recommended if the environmental risk cannot be reduced to an acceptably low level by economically viable preventive measures (taking all costs and benefits of the project into account). Marginally feasible projects — those with only small net benefits to the proponent — are not encouraged if incentives and capacity for effective management are low.

Groundwater discharge areas and locations with a shallow water table should be avoided as additional recharge is likely to cause water logging, salinization, or geotechnical problems for buildings and other infrastructure. Unless the managed aquifer recharge project is an integral part of a proposal for increased extraction of water, such sites should be avoided. However, management of these situations is highly constrained and water table fluctuations are likely to significantly exceed those that occur naturally.

If the available storage capacity of an aquifer is already fully committed to other managed aquifer recharge operations, then additional managed aquifer recharge is impractical and would have a negative effect on the performance of the existing operations.

Managed aquifer recharge also requires a source of recharge water for sufficient time to ensure that the recoverable volume warrants the project’s establishment costs. Urban stormwater requires land for detention storage and this can be built into landscape design. In new subdivisions, the increase in land value due to water views can exceed the costs of land used for detention storage. In established built-up areas, finding land for detention storage is much more difficult, unless managed aquifer recharge is a coherent component of an urban renewal project, as already mandated in some Indian state and municipality jurisdictions.

3 Water Quality Hazard Assessment and Protection

3.1 Framework for water safety in data sparse areas

These Indian Guidelines for MAR are designed for situations where water quality data are sparse. They follow the process shown in Figure 3.1.

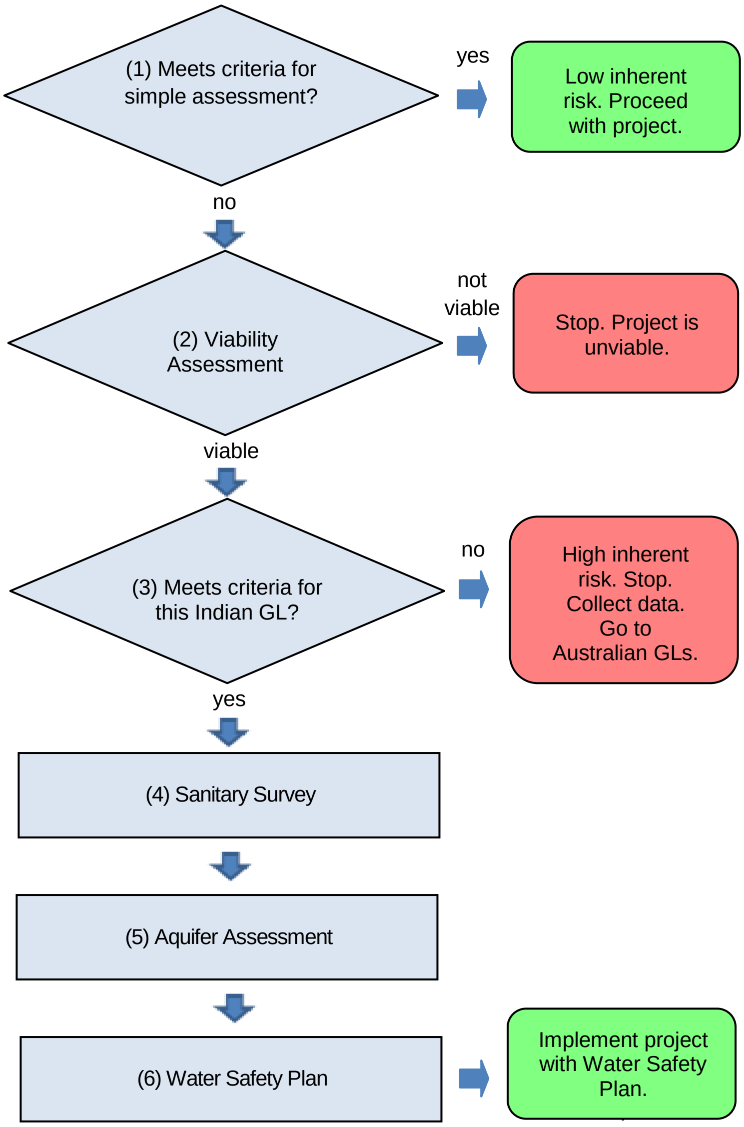


Figure 3.1 A diagram of the steps involved in applying this Indian Guideline for managed aquifer recharge including implementation of a water safety plan.

The first test is to see whether inherent risks are so low for certain classes of projects that no further effort is required. This is to avoid inconsequential effort in evaluating a plethora of existing and new projects.

A next step is to screen out new projects that are just not practical. There is no point assessing potential water quality problems if there is no aquifer capable of receiving recharge. While this seems pedantic, it is surprising how frequently proponents of recharge projects really do not understand what is needed to make a project a success in terms of water quantity.

The third test is to determine whether there are high inherent risks that demand water quality data that are rarely available in India at present to produce an adequate risk assessment. These guidelines starting point is to rule out their application to such high inherent risk cases, such as where sewage or industrial effluent is the source of recharge or public drinking water supplies would be affected and suggest an alternative route.

The main effort is focussed on those viable projects where risk is not negligible and a basic low level of effort spent in evaluating these projects will lead to implementing water safety plans that really make those existing and new recharge projects safer for their communities. The water safety plans rely on some basic information about the catchment and the aquifer system.

3.2 Simple assessment

For many groundwater recharge projects the inherent risks to public health and the environment are low and this can be easily demonstrated. This alleviates the need for more rigorous evaluation. Generic criteria to pass simple assessment (Figure) are:

- the aquifer being recharged is not used as a drinking water supply
- the scale of recharge is small, for example domestic-scale rainwater harvesting
- the water being recharged is roof runoff or natural runoff and contains no wastes, and
- the area around the recharge area is never waterlogged.

Additional criteria, may be required by the local authority to deal with local conditions. For example the local authority may specify qualifying criteria for the design and construction of recharge systems which if adhered to are deemed to meet the requirements of simple assessment.

A hallmark of these systems is that by virtue of their hydrogeological setting or their design they do not depend on skilled operators to protect groundwater quality and human health. In these cases, the commitment to responsible management is assumed by the local authority rather than by the project owner alone. The authority should have a regional groundwater monitoring plan that gives confidence on the effects of recharge structures on groundwater levels and quality, rather than depend on site-by site monitoring.

Hence in an aquifer where a local authority determines that recharge systems of a certain type scale and design comply with simplified assessment there is no need to undertake assessments on a site-by-site basis, except to ensure that sites comply with the simple criteria.

If a project does not meet the Simple assessment, determine if these Indian guidelines are applicable.

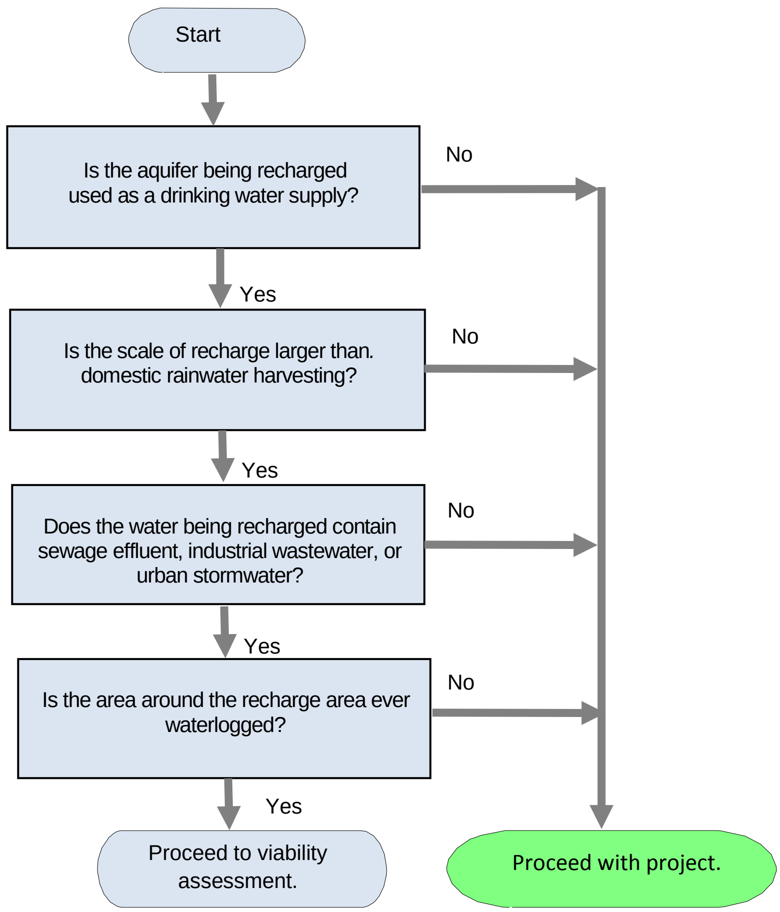


Figure 3.2 This schematic of simple assessment for managed aquifer recharge shows whether the inherent risks are so low that these guidelines need not be applied to the project being considered.

An example of a project meeting simple assessment criteria, and hence requiring no further site-specific assessment is given in Box 3.1.

Box 3.1 Example of projects meeting simple assessment criteria.

All domestic-scale roof runoff, recharged via sumps at the base of household downpipes in permeable soils with a deep water table replenishing an unconfined aquifer not used for drinking supplies, but for household irrigation. This situation has low inherent risk to human and environmental health.

In such circumstances, and within defined areas, the relevant authority may elect to approve specified recharge practices that comply with standard designs and adhere to conditions applicable to all installations. Monitoring data at a few existing installations may provide evidence of the range of conditions and control measures that protect human and environmental health. The jurisdiction would assess the cumulative effect of many similar sites, e.g. in urban areas, on groundwater levels and quality using a regional monitoring network of piezometers. It is expected that the authority would have worked through the Indian MAR guidelines for several sites to be confident of the approved designs and conditions.

If as a result of monitoring groundwater quality and levels, problems are detected such as pollution or excessive rise in water table, attributed to managed aquifer recharge, the local authority should advise local well owners of the issue and review and revise or revoke their criteria for simple assessment accordingly.

3.3 Viability assessment

The viability assessment evaluates the apparent viability of a proposed recharge project using relevant existing data and information. It is intended to inform proponents of any fatal flaws in their intended project. Figure 3. is a diagrammatic representation of the entry-level viability assessment.

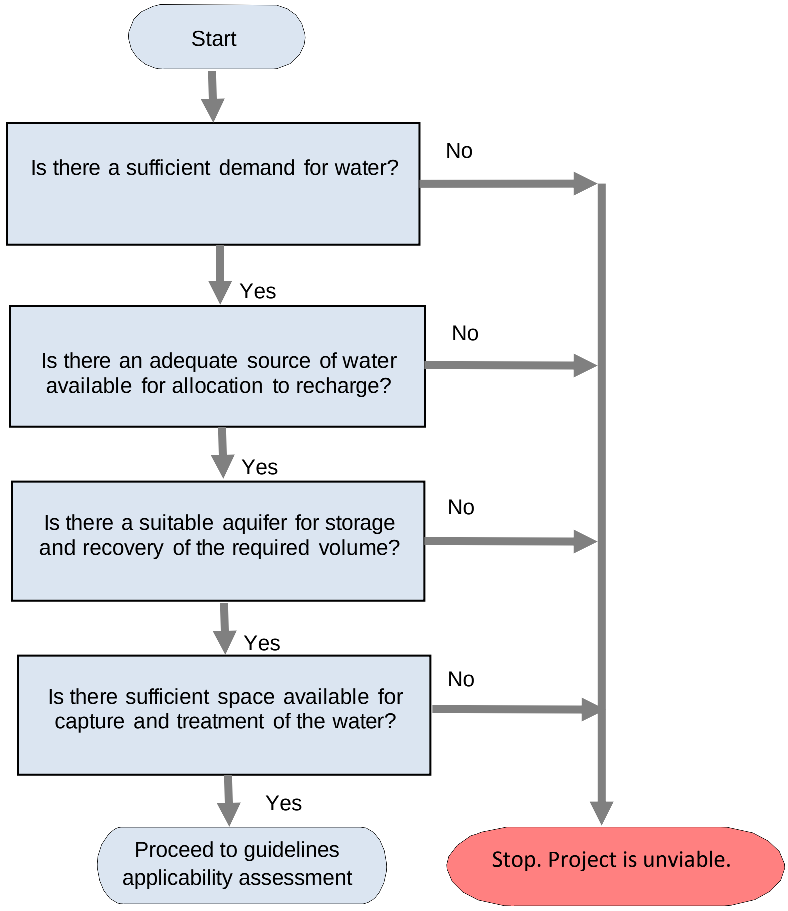


Figure 3.3 A schematic for viability assessment for managed aquifer recharge projects.

The key factors, shown in Figure 3.3, that determine viability of managed aquifer recharge from readily available information are as follows:

Demand — The ongoing volumetric demand for recovered water should be sufficient to warrant investment in the proposed project; if this is not the case, there needs to be a clearly defined environmental benefit. Either one of these criteria is essential for managed aquifer recharge. Projects involving recharge of partially treated water where recovery is incidental do not qualify as managed aquifer recharge. If there is no local water management plan, is this regarded as a valued use of water by local authorities. (For example growing a rabi crop of rice with recharged water is much less efficient use of water than growing vegetables, and should be discouraged.)

Source — Entitlement to water to be used for recharge needs to be secured. Mean annual volume of recharge should exceed mean annual demand, with sufficient excess to build up a buffer storage to meet reliability and quality requirements. In an already over allocated catchment, an entitlement to surface water is unlikely to be available. Even if there is currently no agreed catchment water management plan, under the National Water Policy (Government of

India. Ministry of Water Resources 2012a), there will be a need for States to formulate these in consultation with stakeholders.

Aquifer — Presence of a suitable aquifer is critical for managed aquifer recharge. Such an aquifer needs to have an adequate rate of recharge and sufficient storage capacity; it also needs to be capable of retaining the water where it can be recovered. Low salinity and marginally brackish aquifers are preferred, to maximise the volume of recovered water that is fit for use after fresh recharge water mixes with ambient groundwater. This assessment would be supported if there were regional maps available that showed the potential of aquifers as storages for managed aquifer recharge, and available to water resources managers in local jurisdictions and to the public via internet. In over-allocated aquifers, water managers may have additional constraints on the proportion of recharge that may be recovered.

Detention storage — For most recharge systems, dams, wetlands, ponds, basins or tanks are needed to detain sufficient water to achieve the target volume of recharge. Similarly, space needs to be available for whatever treatment process, if any, is subsequently determined to be required.

The template for the viability assessment (Table 3.1) addresses these key factors. The template includes items related to quantity of water and water allocation, which were discussed in Section 1.2.3. If the answer to all of the questions given in Table 3.1 is 'Yes', proponents then proceed to the guidelines applicability assessment.

Table 3.1 Viability assessment.

Attribute	Yes	No
1. Intended water use		
Is there is an ongoing local demand or clearly defined environmental benefit for recovered water that is compatible with local water management plans?	Continue viability assessment	Managed aquifer recharge is not recommended
2. Source water availability and right of access		
Is adequate source water available, and is harvesting this volume compatible with catchment water management plans?	Continue viability assessment	Managed aquifer recharge is not recommended
3. Hydrogeological assessment		
Is there at least one aquifer at the proposed managed aquifer recharge site capable of storing additional water?	Continue viability assessment	Managed aquifer recharge will not work
Is the project compatible with groundwater management plans?	Continue viability assessment	Managed aquifer recharge is not recommended
4. Space for water capture and treatment		
Is there sufficient land available for capture and treatment of the water?	Proceed to guidelines applicability assessment	Managed aquifer recharge is not recommended until this has been addressed

3.4 Are these Indian MAR guidelines applicable?

This next test is to determine whether these guidelines are applicable to the project under consideration, whether the project is an existing one or a new proposed project (Figure 3.). As identified in Table 1.1 this document has a restricted scope of coverage. If the inherent risks are high because source water is known to contain significant amounts of contaminants, some knowledge is required of the concentrations of those contaminants.

Risk can also be elevated when recharging a confined aquifer for two reasons. That aquifer has had the benefit of protection from pollution by confining strata over millennia, and if those are short-circuited by recharge operations, pristine water sources may become polluted. Secondly, injecting aerated water into an aquifer devoid of oxygen (anoxic) may oxidize aquifer minerals. In many places this is not problematic, however if certain minerals are present the groundwater may become contaminated with arsenic or other metals that are harmful to human health in drinking water.

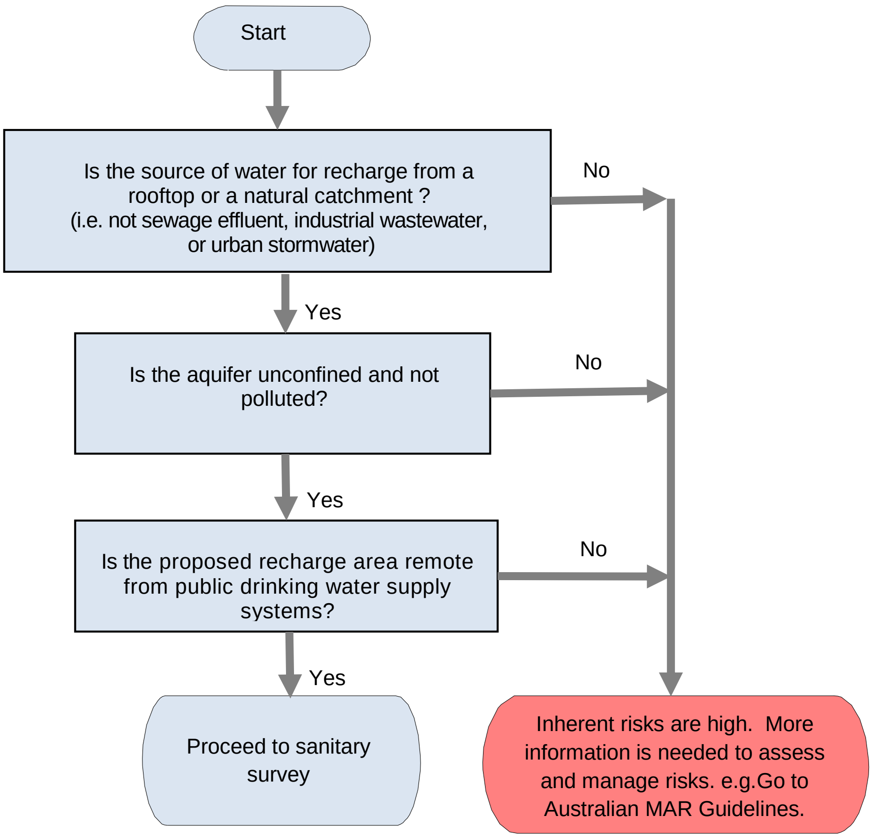


Figure 3.4 This schematic shows whether the inherent risks are too high for these guidelines to be applicable to the project being considered.

Finally if recharge is to occur nearby a public source of drinking water from an aquifer, any contamination for example by viruses could potentially impact many people. This raises the need for good quantitative information on water quality impacts so that there is no deterioration in the safety of the water supplies. In these high inherent risk scenarios it is recommended that adequate water quality evaluations of source water, the aquifer, the existing water supply, and an evaluation of aquifer minerals be undertaken. These are described in the Australian Guidelines for Managed Aquifer Recharge (NRMMC-EPHC-NHMRC 2009), with the exception of recharge to a polluted aquifer. Significant investment in water quality data acquisition would be warranted, without which it is recommended that such a project not proceed. Those projects not in that category can proceed to the next step of these Indian Guidelines for MAR, the sanitary survey.

3.5 Sanitary survey

A sanitary survey or inspection identifies hazards and hazardous events that may occur in the catchment that provides source water for the recharge facility and in the recharge facility as well as wherever the water is recovered. The survey should identify any inadequacies and lack of integrity in the proposed system which could lead to contamination. A survey can be completed by a trained individual observing catchment land uses and activities rather than relying on the availability of chemical and microbiological analyses of water samples to inform development of water safety plans for recharge systems. Presence of human or animal faeces or sewage is considered indicative of a microbiological hazard that may pose a potential human health risk. Industrial and agricultural activity evident in the catchment may suggest particular chemical hazards. The classes of water quality hazards have been listed in the Australian National Water Quality Management Strategy as; pathogens, inorganic chemicals, salinity and sodicity, nutrients, organic chemicals, turbidity and particulates and radionuclides (NRMMC-EPHC-NAHMC 2006).

Sanitation assessments are recommended under WHO drinking water guideline as a mean of ensuring intended water quality targets are met (WHO 2011). Sanitary inspection and water-quality analysis are complementary activities as inspection identifies potential hazards, whereas water-quality analysis confirms the occurrence and intensity of any contamination events. A sanitary inspection report is indispensable for the interpretation of water-quality analyses and implementing protective measures.

In some situations, water quality monitoring may be impractical due to distance from reliable accredited laboratories, lack of suitable sampling equipment, lack of trained personnel to do the sampling or lack of funds to pay for sampling and analysis. In this case the sanitary survey is the sole source of information on the likely quality of source water for recharge. In the context of these guidelines, the survey will be used primarily to suggest preventive measures that would reduce or eliminate the hazards and hence also the risk of exposure to those people using water from the aquifer, including those for whom the project was developed.

A general sanitary inspection form or site specific forms should be used to identify hazards and the likelihood of their impact on the water quality. Sanitary inspection forms initially could be more generic with series of questions to be asked regarding the water security and protection of the source, which then could be trimmed back to key questions for each type of managed aquifer recharge scheme after the review of collected data. Detailed examples of sanitary survey forms are available in WHO *Guidelines for Drinking-water Quality* (WHO 2011). Sanitary survey forms contain questions that could be categorised into three groups (Howard 2002):

- *Hazard factors* – potential sources of faecal or chemical contamination that may represent a risk to the water supply (e.g. close location of a pit latrine in relation to a recovery well).
- *Pathway factors* – potential routes of contaminants entering the source water or aquifer (e.g. leaking sewer pipes).
- *Indirect factors* – factors that represent a lack of control to prevent contamination (e.g., absence of casing around a recharge well may increase the risk of contamination in the event of a flood). The absence of these barriers do not lead to contamination but impair the ability to prevent contamination events. Table 3.2 is an example of the types of questions asked in a sanitary survey.

It will be shown later that the sanitary survey is essential input to the Water Safety Plan and will need to be repeated and barriers reinforced periodically as catchment conditions may change. It is also worth checking during an intense storm whether the preventive measures are operating effectively.

Table 3.2 Sanitary survey form.

Specific information	Hazard or Measure Present	Description of Hazard or Measure	Measures to protect public health
Catchment hazards and pathways			
1. Is there a latrine, open sewer or leaky sewer or human or animal faeces within the catchment area of the recharge facility?	Y/N	Pathogens and nutrients	Remove wastes, repair leaks, boil water recovered before drinking
2. Is there a latrine, open sewer, leaky sewer or animal faeces in close proximity to the recharge structure or to the wells from which water will be recovered ?	Y/N	Pathogens and nutrients	Remove wastes, repair leaks, boil water recovered before drinking
3. Are there industrial, transport or agricultural activities generating stockpiles, wastes, spills, or emissions reaching the surface of the catchment area of the recharge facility?	Y/N	Metals, organic chemicals, nutrients, particulates, salinity	Remove or isolate wastes, repair leaks, boil water recovered before drinking
4. Are there industrial, transport or agricultural activities generating stockpiles, wastes, spills, or emissions in close proximity to the recharge structure or the wells from which water will be recovered?	Y/N	Metals, organic chemicals, nutrients, particulates, salinity	Remove wastes, repair leaks, boil water recovered before drinking
Barriers to contamination			
5. Is there pre-treatment or means of preventing contaminated water to be recharged? – if so describe its design and resilience to power and mechanical failure, and any alarm systems?	Y/N	Failure or bypass of pre-treatment or diversion	Install diversion where possible. Install pre-treatment where possible.
6. Is there post-treatment of water to be recovered? – if so describe its design and resilience to power and mechanical failure, and any alarm systems?	Y/N	Failure or bypass of post-treatment	Boil water recovered for drinking. Use carbon filter or ultrafiltration if chemical contamination
7. Does the existence and condition of any barriers around of the recharge structure and recovery wells prevent short circuit of contaminated water?	Y/N	Presence or absence of obvious barriers	Install exclosures to exclude further wastes, seal well head to exclude runoff /floodwater

3.6 Aquifer assessment

While the sanitary survey focused on the catchment conditions and protective infrastructure that are easily identified, the aquifer assessment addresses other considerations for design and safer operation of recharge facilities. This may be applied to existing or proposed recharge projects to determine the types of control measures to mitigate risks for the hazards identified. For projects where there are significant consequences for failing to achieve groundwater quality protection, it is recommended that a full risk assessment be undertaken, as shown in Figure 3.1. The template for the aquifer assessment contains seven questions with explanatory notes (Table 3.3). The answer to each question results in suggested preventive measures.

Table 3.3 Aquifer assessment form.

Specific Information	Hazard or Measure Present	Description of Risk	Measures to prevent problems
Source water quality with respect to clogging			
1. Does source water have low quality; is water turbid, coloured, contains algae, has a surface slick or does it smell?	Y/N	Risk of clogging of infiltration surface of check dam, basin or well	Treat water before recharging aquifer to remove clogging agents. Maintenance to remove clogging layer.
Storage capacity of aquifer			
2. Does the unconfined aquifer have a shallow water table, say < 8 m in urban area and say < 4 m in rural area?	Y/N	Risk of water logging, impacts on below-ground infrastructure	Limit volume and rate of recharge to match aquifer capacity.
Impacts on neighbours and ecosystems			
3. Are there other groundwater users, groundwater-connected ecosytem or a property boundary within 100 m of the recharge site?	Y/N	Risk of adverse impacts on users or ecosystems is possible	Observe changes in levels, yields and quality and limit recharge and recovery to avoid adverse impacts.
Reactive, fractured rock, or karstic aquifers			
4. Is the aquifer known to contain reactive minerals (e.g. fluoride, pyrite) or is groundwater in this area known to contain arsenic? Does the aquifer contain soluble minerals such as calcite and dolomite?	Y/N	Potential for mobilisation of metals (e.g. arsenic), or dissolution of aquifer matrix, with induced geotechnical instability.	Sample recovered water for analysis of arsenic and other heavy metal concentrations. Stop recharge if concentration exceeds thresholds for local uses. Estimate rate of dissolution by volumes and mineral compositions in waters and assess well stability.
5. Is the aquifer composed of fractured rock or karstic (fissured or cavernous) limestone or dolomite?	Y/N	Rapid migration of recharge water to drinking wells	Inform all who drink water from wells within 1 km of recharge site to boil water before drinking or treat water before recharging.

Specific Information	Hazard or Measure Present	Description of Risk	Measures to prevent problems
Development approval			
6. Is the proposed project of such a scale that it requires development approval? Is it in a built up area; built on public, flood-prone or steep land; or close to a property boundary? Does it contain open water storages or engineering structures; or is it likely to cause public health or safety issues (e.g. falling or drowning), nuisance from noise, dust, odour or insects (during construction or operation), or adverse environmental impacts (e.g. from waste products of treatment processes)?	Y/N	Potential for public safety risks	Obtain necessary approvals from local government where relevant.

These basic questions help proponents to appreciate issues that they need to consider and where relevant take the necessary steps to prevent problems. For help refer to Chapters 4 and 5 of Australian MAR Guidelines (NRRMC-EPHC-NHMRC 2009) for the types of information that will subsequently be required to determine ways to achieve safe recharge. Proponents must play their part in protecting the aquifer from contamination. If potential issues are identified and it is unclear whether these would materialize, the protective measures should be applied and remain in force until the proponent has monitored water quality and proved that the problem is not occurring and will not occur.

Box 3.2 Example assessment for a village check dam, Gujarat. *(Source: Prof. Maheshwari, Leader of ACIAR Project MAR in Village-scale Intervention; Maheshwari et al 2014))*

The situation: Natural runoff occurs during the monsoon from a rural catchment with grazing goats, cattle. Irrigated crops are fertilized with urea and some pesticides are used. There is no sewage system, some houses have septic tanks and most farmers defecate in the fields. Water supply is by family wells. Most water is used for irrigation and drinking water comes from the same wells. There is a deeply weathered fractured rock basement overlain along the wadis by alluvial deposits. Until the 1960s the water table at the end of the monsoon was at 6m whereas in the same wells now it is at 40m. In this area with moderate relief and relatively few rain days each wadi only flows for a day after rain. Check dams were built in the early 2000s to enhance recharge and more are being considered.

Assessments:

(1) This fails the Simple Assessment criteria on three grounds; that the aquifer being recharged is used as a drinking water supply, the water recharged does contain wastes, and the check dam scale is larger than household scale recharge.

(2) Viability assessment is satisfied because there is a demand for all water that is recharged to sustain irrigation livelihoods, there is an adequate intermittent source of water, the aquifer can accommodate all recharge and the check dams were located with the consent of land holders and could initially pool significant volumes.

(3) Source water is natural, and the same quality as natural recharge, the aquifer is unconfined and there are no public supplies. So these Indian Guidelines are relevant.

(4) Sanitary Survey – Hazards: human and animal wastes are present in the catchment and close to recharge structures. Barriers: Drinking water from wells is usually boiled or allowed to percolate through silver lined ceramic pots to reduce microbial contaminants. Drinking wells have walls or casing and will not be flooded by weir pools.

(5) Aquifer Assessment – source water is very turbid and slows infiltration as well as fills the recharge weirs with silt, (> **maintenance to remove clogging layer**), the water table is deep, for most recharge weirs there are drinking water wells within 100m, there is known to be high fluoride in some locations of the aquifer but no knowledge of arsenic. The deep aquifer is igneous fractured rock.(> **encourage use of boiling/ceramic filtration for all drinking supplies**) Approval for the existing check dams was part of the funding arrangements in a drought relief program.

A water safety plan is needed and Table 3.4 provides a basis for stakeholders to form a plan.

For any existing or proposed project the answers to the sanitary survey and aquifer assessment will help to provide a rational basis for determining the preventive measures required as part of a water safety plan, and the maintenance requirements for these measures.

As stated earlier, this level of information serves as a crude guide and without reliable water quality data it cannot be claimed that these measures will be sufficient for safety, but they will certainly improve the safety of recharge operations.

A summary of results of the sanitary survey and aquifer assessment may prove useful to:

1. identify the priorities for preventive measures within any one site, and the formation of a water safety plan,

2. screen a series of existing sites to help focus attention on sites with greater hazard exposure to be assigned priority for implementing protective measures,

3. screen candidate sites for developing new recharge projects to help select sites where managing water quality will be easier.

This document focuses on the water safety plan and protective measures. Further details on investigations at managed aquifer recharge sites and full risk assessment and risk management plans are covered in NRMMC-EPHC-NHMRC (2009) and examples of the application of the degree of difficulty assessment to defining investigations to allow risk assessments are given by Page *et al* (2010).

3.7 Water Safety Plan and Protective Measures

Water safety plans (WSPs) were developed by World Heath Organisation for drinking water safety through a hazard assessment, risk assessment and risk management approach encompassing all steps in the water supply chain from catchment to consumer (WHO 2011). The WSPs represent an evolution of sanitary surveys and vulnerability assessments concept which encompass the entire water supply system. A WSP developed by engaging with the community and forming a WSP team, has three key components:

1. S*ystem assessment*-to determine whether the whole water supply chain can deliver water quality that meets identified health-based targets. This component also includes design criteria and assessment of new MAR systems;
2. *Identifying control measures* - that will control identified risks in MAR systems and ensure that the health-based targets are met. For each of the identified control measures, an appropriate means of *operational monitoring* should be defined that will ensure rapid detection of any deviation from required performance;
3. *Management and communication plans*- outlining detailed action and system assessment and documentation plans to be followed during the normal operation or incident conditions. This also includes plans for system improvement, monitoring and communication.

In this document a generic technology water safety plan was developed (Table 3.4) based on small water supply systems Denison *et al* (2005). A similar approach was adopted by ACT (2013) for Indian drinking water sources in rural areas, that also anticipated future growth in population and possible changes in land use. Other examples and templates are found in WHO (2014) that is focused in drinking water safety in small communities.

The water safety plan is based on and hazards and hazardous events and their causes identified in the sanitary survey and aquifer assessment, then for each of these identifies preventive measures, critical limits, monitoring, corrective actions and verification.

Preventive measures may include one or more of the following types of actions:

- To remove sources of contamination from the catchment contributing source water for aquifer recharge.
- To establish barriers to prevent contaminated water escaping into the water harvesting system.
- To introduce controls to divert any detected contaminated water from the recharge structure.
- To introduce monitoring and release of contaminated water from the recharge structure where possible.
- To introduce a treatment, such as a settlement pond or sand filter before recharge.
- To introduce a post treatment, such as boiling, ceramic filters or chlorination of the recovered water, or oxidation and filtration to remove excess metal concentration in recovered water before its use for drinking.
- To determine the monitoring of water quality and quantity required to understand the issues.
- In cases where it is determined that risks are too high, to abandon the recharge practice until effective control measures can be implemented.

A generic example of a risk management plan for managed aquifer recharge is shown in Table 3.4.

It is recommended that a web site be established at a national or language-based level to contain data, information and reports for demonstration projects that can be used as a reference source for those evaluating existing artificial recharge projects or considering establishing new managed aquifer recharge projects.

Training of local operators in creating and implementing Water Safety Plans is needed in order to ensure that frequent inspection and corrective actions are undertaken. While Table 3.4 indicates monthly inspection, this should be adapted to the local situation. It is recommended that a special effort is made annually in preparation for the main recharge season, and followed up during the recharge season as catchment conditions may change and protective measures may need to be reinforced or reinstated. Occasional checks of protective measures during intense storms will inform whether protective measures are operating effectively, and could lead to improvements in system design or operation to better protect water quality.

Table 3.4 Managed aquifer recharge water safety plans.

Hazardous event	Cause	Control Measure	Critical Limits		Monitoring			Corrective action	Verification
			Targets	Action	What	When	Who		
1.Human sewage entrainment in source water	Latrine leakage, open sewers, sewer pipe leaks, open defecation in catchment, and close to recharge facilities and recovery wells	More latrines with improved design, install separate sewage system from stormwater drains, or only harvest high wet weather flows, improve sewer capacity and response to chokes and leaks.	Control sewage leaks, regulate sewage discharge points in catchment	Identify sewage leaks sewage discharge points. Repair, rebuild, or implement overflow diversion. Boil drinking water.	Sanitary inspection	Monthly	Op	Remove pollutant sources, improve sanitation design, reduce sewer leakage or sewage discharge	Microbiological examination of water
2.Animal faecal matter entrainment in source water	Animal manure accumulation or cess pits in the catchment and close to recharge area and recovery well,	Exclude livestock from water harvesting and recovery structures, collect animal faeces and store in dry areas with setback distance from water infrastructure .	No overstocking in catchment, set back distances honoured, Dry storage of animal manures	Controls on animal husbandry in catchment, Repair fences, exclusion zones. Boil drinking water.	Sanitary inspection	Monthly	Op	Removing live stock out of catchment , repair or erect fencing, arrange collection and removal of faeces.	Microbiological examination of water
3.Leaching of microbial contaminants into aquifer	Infiltration of water that has been in contact with human and animal wastes	Provide adequate setback distances to drinking water wells or springs	No sources of faecal material within setback distance	Close any latrines, and enclose or seal open sewers within setback distance. Boil drinking water.	Sanitary inspection	Monthly	Op	Remove sources of faecal material within setback distance, repair /erect fencing, improve sewerage.	Microbiological examination of water

Hazardous event	Cause	Control Measure	Critical Limits		Monitoring			Corrective action	Verification
			Targets	Action	What	When	Who		
4.Entrainment of chemicals in source water for recharge	Industry, transport and agricultural activities generating stockpiles, wastes, spills, and emissions reaching the catchment surface	Regulate industrial and agricultural activities in the catchment	No unauthorised sources of chemical contamination in catchment. All pollutants in wise use & management. Minimise spills through industry standards	Remove wastes from catchment. Install bunding around industrial sites to prevent runoff to recharge system. Traffic loading regulations enforced.	Sanitary inspection	Monthly	Op	Move or bund polluting industries, regulate industrial discharge and agricultural use of chemicals	Sanitary inspection Analysis of source water and groundwater quality for pollutants.
5.Leaching of chemicals into groundwater	Leaching from landfill, waste dumps and industrial discharge	Provide adequate set back distance, regulate industrial discharge	No source of chemicals within the set-back distance	Prevent pollutant discharge within set-back distance	Sanitary inspection	Monthly	Op	Improve containment and move or control pollution sources	Sanitary inspection Analysis of source water and groundwater quality for pollutants.
6. Bypassing or failure of pre-treatment in recharge facility	Short-circuit of recharge flow. Clogging of filters, power and mechanical failures, treatment chemicals run out.	Design treatment to avoid admitting untreated water into the well for each of these hazardous events.	No recharge of untreated water	Maintain treatment system regularly. Install system to shut-down recharge when alarm activated. Boil drinking water.	Sanitary inspection	Monthly	Op	Maintain filter and any other treatment. Check alarm system operates correctly.	Sanitary inspection Analysis of source water and groundwater quality for pollutants.

Hazardous event	Cause	Control Measure	Critical Limits		Monitoring			Corrective action	Verification
			Targets	Action	What	When	Who		
7. Bypassing or failure of post treatment at recovery well	Clogging of filters, power and mechanical failures, treatment chemicals run out.	Design treatment to avoid admitting untreated water into the water supply for each of these hazardous events.	No distribution of untreated recovered water	Maintain treatment system regularly. Install system to shut-down recovery when alarm activated. Boil drinking water.	Sanitary inspection	Monthly	Op	Maintain filter and any other treatment. Check alarm system operates correctly.	Sanitary inspection Analysis of groundwater &recovered water for pollutants.

Op= MAR scheme operator

3.8 Use of this guideline as a screening tool

The results of these assessments may be summarized and used to screen existing artificial recharge projects to determine water safety plans and remedial actions that should take place immediately or in some cases before the next recharge season. The assessments may also be used to assess the degree of health protection for existing drinking water wells for a range of candidate sites for a proposed new recharge project.

References

ACT (2013). Evolving guidelines for protecting drinking water source in rural areas – a step towards self reliance. Arid Communities and Technologies, 8 page booklet. www.act-india.org

Anderson J., Adin A., Crook J., Davis C., Hutquist R., Jimenez-Cisneros B., Kennedy W., Sheikh B. and van der Nerwe, B. (2000). Climbing the Ladder: A Step by Step Approach to International Guidelines for Water Recycling. Proc. 3rd International Symposium on Wastewater Reclamation Recycling and Reuse, Paris, July 2000.

Bartak, R., Page, D., Sandhu, S., Grischek, T., Saini, B., Mehrotra, I., Jain, C.K. and Ghosh, N.C. (2014) Application of risk-based assessment and management to riverbank filtration sites in India, Journal of Water and Health, doi:10.2166/wh.2014.075.

Bureau of Indian Standards (1986). Guidelines for the Quality of Irrigation Water. IS 11624 (1986, Reaffirmed 2009): UDC 631.671.03 : 626.810 (026) https://archive.org/details/gov.law.is.11624.1986

Bureau of Indian Standards (1992). Drinking Water Specification: IS: 10500, 1992 (Reaffirmed 1993) http://hppcb.gov.in/eiasorang/spec.pdf

CGWB (2000). Guide on Artificial Recharge to Ground Water. Central Ground Water Board. Ministry of Water Resources, Government of India. New Delhi, May, 2000. http://www.cgwb.gov.in/documents/Guide_on_ArtificialRecharge.pdf

CGWB (2005). Master plan for artificial recharge to groundwater in India. Central Ground Water Board, Ministry of Water Resources, Government of India. http://cgwb.gov.in/documents/MASTER%20PLAN%20Final-2002.pdf

CGWB (2007). Manual on artificial recharge of groundwater. Central Ground Water Board, Ministry of Water Resources, Government of India, 185p. http://www.scribd.com/doc/27641855/Manual-on-Artificial-Recharge-of-Ground-Water-by-Ministry-of-Water-Resources-India

CGWB (2010). Ground Water Quality in Shallow Aquifers of India. Central Ground Water Board, Ministry Of Water Resources, Government of India, Faridabad. http://cgwb.gov.in/documents/waterquality/gw_quality_in_shallow_aquifers.pdf

CGWB (2011). India; Selected Case Studies: Rainwater harvesting and Artificial Recharge. . Central Ground Water Board, Ministry of Water Resources, Government of India. http://www.slideshare.net/D5Z/n3z338 (accessed 5 Aug 2014)

CGWB (2013). Master Plan for Artificial Recharge to Groundwater in India. Central Ground Water Board, Ministry of Water Resources, Government of India.

CPCB (2007). Guidelines for Water Quality Monitoring MINARS/27/2007-08. Central Pollution Control Board, Government of India. http://cpcb.nic.in/upload/NewItems/NewItem_116_Guidelinesof%20waterqualitymonitoring_31.07.08.pdf

Chadha, D.K. (2002). State of art of artificial recharge applied on village level schemes in India. p19-24 in Tuinhof, A. and Heederik, J.P. (eds) Management of aquifer recharge and subsurface storage: making better use of our largest reservoir. Netherlands National Committee –Intl Assoc. Hydrogeologists NNC-IAH Publication No 4.

Chadha, D.K. (2014). Overview Of MAR -Schemes In India. Report of Saph Pani project to European Commission. www.saphpani.eu/

Denison, A., Howard, G., Stevens, M., Callin, P., Fewtrell, L., Deere, D. and Bartram, J. (2005). Water Safety Plans: Managing drinking-water quality from catchment to consumer. World Health Organisation, Geneva. WHO/SDE/WSH/05.06. 235p

Dillon, P., Page, D., Vanderzalm, J., and Chadha, D. (2013). Water quality considerations in managed Aquifer Recharge: from Artificial Recharge to Managed Aquifer Recharge in India. J. Groundwater Research 2 (2) 8-15, Dec 2013.

Dillon, P., Vanderzalm, J., Page, D., Toze, S., Wolf, L., Pavelic, P., Cunliffe , D., Wang, W., Willardson, B., Tredoux, G., Jain R. and Raj, R. (2010). Australian Guidelines for Managed Aquifer Recharge and their International Relevance. Proc. ISMAR7, Abu Dhabi 9-13 Oct 2010. www.ismar7.org

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

Dillon, P.J. (2005). Future management of aquifer recharge. Hydrogeology Journal, 13 (1) 313-316.

Gale, I. N., Macdonald, D. M. J., Calow, R.. C., Neumann, I., Moench, M., Kulkarni, H., Mudrakartha, S. And Palanisami, K. (2006). Managed Aquifer Recharge: an assessment of its role and effectiveness in watershed management. British Geological Survey Commissioned report CR/06/107N. 80pp.

Government of India. Ministry of Water Resources (2012a). National Water Policy. Adopted by National Water Resources Council 28 Dec 2012. http://wrmin.nic.in/writereaddata/NationalWaterPolicy/NWP2012Eng6495132651.pdf

Government of India. Ministry of Water Resources (2012b). Compendium of Profiles of National Water Awardees and Ground Water Augmentation Awardees. India Water Week, April 2012.

Jain, R.C. (2010).Groundwater scenario in Gujarat with special reference to the scheme on artificial re-charge to ground water through dugwells. Proceedings of the Workshop on Dug well recharge-Efficiency and efficacy, 22 Feb 2010. Published by Central Ground Water Board, West Central Region, Ahmedabad, Gujarat, India.

Kazner, C., Wintgens, T. and Dillon, P. (eds) (2012). Water Reclamation Technologies for Safe Managed Aquifer Recharge. 429p. IWA Publishing, London, UK. http://www.iwapublishing.com/template.cfm?name=isbn9781843393443

Maheshwari, B. *et al* (2014). The role of transdisciplinary approach and community participation in village scale groundwater management: Insights from Gujarat and Rajasthan, India. J. Water. (in press) http://www.mdpi.com/journal/water/special_issues/MAR

Ministry of Environment & Forests (1992). Policy Statement for Abatement of Pollution. Government Of India, New Delhi http://envfor.nic.in/sites/default/files/annual_report/psap.pdf (accessed 9 Jul 2014)

National Safety Council of India (2014) Risk Assessments. http://www.nsc.org.in/index.php?option=com_content&view=article&id=93&Itemid=85

NRMMC–EPHC–AHMC (2006). Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1), Natural Resources Ministerial Management Council, Environment Protection and Heritage Council and Australian Health Ministers’ Conference, Canberra. www.ephc.gov.au/taxonomy/term/39

NRMMC–EPHC–NHMRC (2009). Australian Guidelines for Water Recycling (Phase 2): Managed Aquifer Recharge. (Natural Resource Ministerial Management Council, Environment Protection and Heritage Council and National Health and Medical Research Council), Canberra, www.ephc.gov.au/taxonomy/term/39

Page, D., Gonzalez, D. and Dillon, P. (2012). Microbiological risks of recycling urban stormwater via aquifers. Water Sci. Tech. 65(9) 1692-5.

Page, D., Dillon, P., Vanderzalm, J., Bekele, E., Barry, K., Miotlinski, K. and Levett, K. (2010). Managed aquifer recharge case study risk assessments. CSIRO: Water for a Healthy Country National Re-search Flagship Report, Dec 2010, 144p. http://www.clw.csiro.au/publications/waterforahealthycountry/2010/wfhc-MAR-case-study-risk-assessments.pdf

Paithankar, A. (2011). Hazard Identification and Risk Analysis in Mining Industry. B. Technology in Mining Engineering Thesis, National Institute of Technology, Rourkela.

http://ethesis.nitrkl.ac.in/2445/1/Amol_thesis_final.pdf (accessed 9 Jul 2014)
Parsons, S., Dillon, P., Irvine, E., Holland, G. and Kaufman, C. (2012). Progress in Managed Aquifer Recharge in Australia. National Water Commission Waterlines Report Series No 73, March 2012, SKM and CSIRO, 107p. http://archive.nwc.gov.au/library/waterlines/73
Pyne, R. D. G. (2005). Aquifer Storage Recovery: A Guide to Groundwater Recharge Through Wells 2nd edition. ASR Press.
Ward, J. and Dillon, P. (2011). Robust policy design for managed aquifer recharge. Water-lines Report Series No 38, January 2011, 28p. http://www.nwc.gov.au/www/html/2986-waterlines-38.asp?intSiteID=1
WHO (2011). Guidelines for Drinking Water quality 4th edition. World Health Organisation, Geneva.
WHO (2006). Protecting groundwater for health; Managing the quality of drinking-water sources available (O. Schmoll, G. Howard, J. Chiton, I. Chorus). World Health Organisation and IWA Publishing.
WHO (2012). Water safety planning for small community water supplies: step-by-step risk management guidance for drinking-water supplies in small communities.World Health Organisation, Geneva.
WHO (2014). Water safety plan: a field guide to improving drinking water safety in small communities (B. Rickett, O. Schmoll, A. Rinehold, E. Barrebberg). World Health Organisation, Regional Office for Europe, Copenhagen.

Appendix 1. World Health Organization Water Safety Plans

A1.1 Components of a water safety plan

The most effective way to ensure drinking water safety is to use a comprehensive risk assessment and risk management approach encompassing all steps in the water supply chain from catchment to consumer (WHO 2011). These approaches are termed water safety plans (WSPs). The WSPs represent an evolution of sanitary inspections or surveys and vulnerability assessments concept which encompass the entire water supply system. A WSP has three key components, including:

- *System assessment*-to determine whether the whole water supply chain can deliver water quality that meets identified health-based targets. This component also includes design criteria and assessment of new MAR systems;
- *Identifying control measures in MAR system*- that will control identified risks and ensure that the health-based targets are met. For each of the identified control measure, an appropriate means of operational monitoring should be defined that will ensure rapid detection of any deviation from required performance;
- *Management and communication plans*- outlining detailed action and system assessment and documentation plans to be followed during the normal operation or incident conditions. This also includes improvement planning, monitoring and communication plans.

The effective management of groundwater quality in recharge schemes requires a comprehensive understanding of the recharge system, hazards, hazardous events and their health and environmental implications. The assessment of the MAR scheme as outlined in the Stage 1 evaluation along with the sanitary survey supports subsequent steps in the WSP to develop and implemented effective strategies for control of hazards for drinking water systems. The assessment and evaluation process of MAR scheme could be enhanced through an accurate system description, including a simple flow diagram of the system. The system description should provide at least a basic level of characterization of the source water, identification of potential pollution sources in the catchment, measures for resource and source protection and potential treatment processes.

Effective risk management plan should be able to identify potential hazards, hazardous event and an assessment of the extent of health risks and environmental hazards presented by each event. In this context:

- a hazard is a chemical, biological, physical or radiological agent in the water that can potentially lead to health risks;
- a hazardous event is an incident which result in the presence of a hazard;
- risk is the likelihood of a particular hazards leading to populations exposure in a specified time frame leading to adverse health outcomes.

Site specific data on the occurrence of pathogens and chemicals in source waters and groundwater quality is essential along with the information on the effectiveness of existing controls. This information is essential for a proper assessment of a proposed scheme to check whether health-based targets could be achieved with the existing infrastructure.

A1.2 Collecting and evaluating available data

A structured approach in the collection and analysis of available data should be adopted to ensure that significant health and environmental issues are identified. The data collection and evaluation process should take historical water quality data in conjunction to recorded events into consideration which may assist in understanding source water characteristics and potential links to groundwater quality over time and following specific events

After identification of potential hazards and sources of contamination the risk associated with each hazard or hazardous event should be compared so that risk management priorities are established and the process is documented. The risk associated with each hazard or hazardous event should be described according to the likelihood of occurrence (e.g. certain, possible, rare) and the outcomes or the consequences if the hazard occurred should be classified as (e.g. insignificant, major or catastrophic). A risk assessment matrix could be developed for each hazard or hazardous event

A1.3 Operational monitoring and maintaining control

Operational monitoring includes a set of routine pre-planned activities used to determine if the existing WSPs continue to work effectively.

Determining system control measures

System-specific control measures are identified in the sanitary survey and aquifer assessment. The control measures also depend upon the nature of hazards and hazardous events as well as the magnitude of associated risks.

The operational requirements for control measures include:

- Measureable operational monitoring parameters for which limits can be set to define the operational effectiveness;
- Parameters that can be monitored routinely with sufficient frequency to promptly detect any system failures;
- Corrective action procedures which can be quickly implemented in response to deviation from the pre-set limits.

Selecting operational monitoring parameters

Operational monitoring can include both observation and monitoring activities which should reflect the effectiveness of control measures and provide a timely indication of system performance. The selected parameters should be readily measureable and provide a reasonable response time. Examples include observable factors such as algal bloom, vermin proof screens, the measurable variables include; turbidity, pH, and electrical conductivity. Further information on parameters is found in WHO (2006).

Establishing operational and critical limits

The control measures put in place need to have defined limits for operational acceptability which are termed as operational limits. These limits can be used for taking timely action for maintaining system integrity. Operational limits should be defined for each of the control parameter put in place. Operational and critical limits can be upper limits, lower limits, or a range of performance measures. If any deviation from the operational limit is detected during monitoring then predetermined corrective action could be taken. Deviations from critical limits will usually require urgent action, including immediate stopping of recharge and notification of the appropriate authority. For example, if turbidity of water reaches a pre-set limit the recharge operation for ASR well could be stopped until the turbidity falls back within normal limits.

A1.4 Water safety plan team

The water safety plan (WSP) team is responsible for developing, implementing and maintaining the water safety plan (WHO 2012). The team is assembled in consultation with community leaders and should include members from varying backgrounds, with one of more of the following characteristics (WHO 2012):

- is familiar with, and uses water from, the water supply
- is responsible for the operation of the water supply, or was involved in construction or maintenance of the water supply
- has authority to make decisions about allocating resources to the water supply
- has the knowledge and capacity to identify risks to the water supply and manage those risks
- is influential and interested, at both the community level and at least one administrative level up, in representing water quality concerns and investment needs at the district level or higher.

Appendix 2. Australian Guidelines for Managed Aquifer Recharge

The Australian Guidelines for Managed Aquifer Recharge (NRMMC-EPHC-NHMRC 2009) follow a structured risk management approach outlined in Fig A2.1.

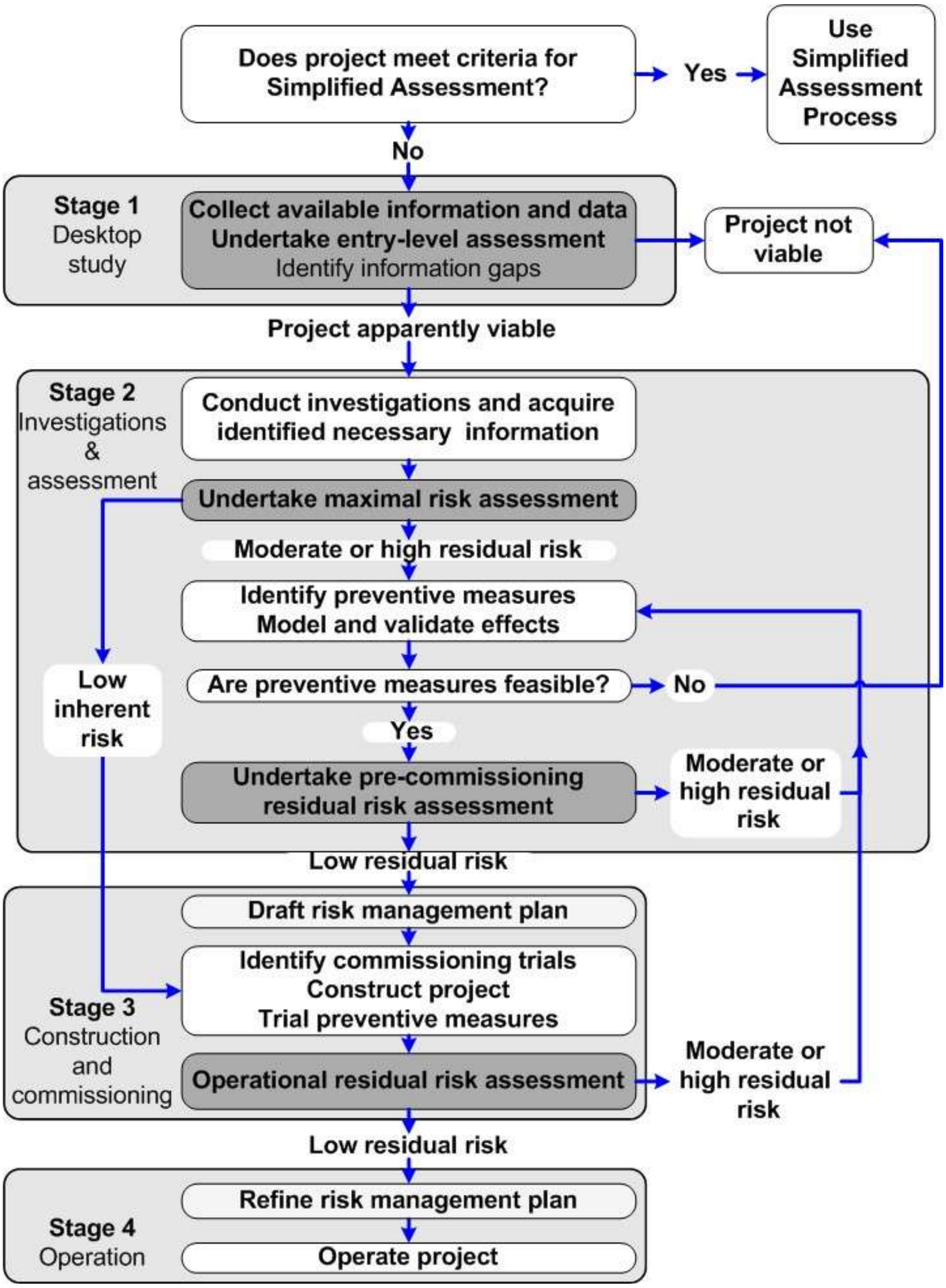


Figure A2.1 Risk assessment stages in managed aquifer recharge project development.

The stages of the assessment develop as information is accumulated (Table A.1). The Indian Guidelines are a simplification of the entry level assessment of the Australian Guidelines, that feeds a WHO –based water safety plan. The Australian guidelines go on to determine the types of data necessary to assess the project, and allow for assessment to become more focused on the key issues so that projects ensure that human health and the environment are protected to the levels required in other documents of the National Water Quality Management Strategy. In this way the Australian Guidelines are adaptable and deal with all source water types, recharge methods, aquifer types end uses of water.

Table A2.1 Assessment stages and objectives.

Assessment step	Information available	Objectives
Entry-level assessment	Existing information and regulations (Stage 1)	• To assess likely presence of a suitable aquifer • To assess conformity with catchment and aquifer management plans and local government requirements • To identify, using only rudimentary information, the likely degree of difficulty of the managed aquifer recharge project; this will inform the extent of investigations and level of operational expertise likely to be required at Stage 2
Maximal risk assessment	Investigations (Stage 2)	• To assess whether the project has low maximal (inherent) human health and environmental risks based on investigation data • In low maximal risk cases, planning for construction and commissioning is simplified. This avoids the requirement for additional preventive measures and precommissioning residual risk assessment • In moderate or high maximal risk cases, preventive measures must be identified
Residual risk assessment: pre-commissioning	Investigations (Stage 2)	• To assess whether proposed preventive measures and operational procedures ensure acceptably low residual risks to human health and the environment from constructing and commissioning the project • To inform on hazards or aspects that may require validation monitoring during commissioning trials
Residual risk assessment: operational	Validation data from commissioning (Stage 3)	• To assess whether ongoing operation of the project has acceptably low human health and environmental risks • To inform the management plan, including operational and verification monitoring for ongoing operation (Stage 4)

Entry-level assessments firstly address water allocation issues that are usually adequately determined without detailed site-specific information. Governance of these issues will generally be in the hands of a state or regional water resources management agency. A preliminary assessment of the effort likely to be required to demonstrate low risks to human health and the environment is also carried out at this stage. The entry-level assessment is intended to inform on the likely degree of difficulty of the managed aquifer recharge project, and hence inform proponents of the extent of field investigations needed in Stage 2.

Stage 1 is the most cost-effective stage at which to abandon projects for which the potential rewards do not justify the high degree of difficulty. If the potential value of recycled water or new resource generated is large, an investment in Stage 2 investigations can focus on the key issues affecting viability. Causes of the high degree of difficulty may be resolved with feasible preventive measures; if not, such projects will not be viable.

Risk is assessed at two levels — maximal risk and residual risk. Maximal risk (also referred to as unmitigated or inherent risk) is risk in the absence of preventive measures. A maximal risk assessment:

- identifies high-priority risks
- determines where attention should be focused
- prepares for emergencies and appropriate preventive measures
- determines the targets that preventive measures need to achieve.

Residual risk is risk after consideration of preventive measures. A residual risk assessment provides an indication of the safety and sustainability of the recycled water scheme. Residual risk needs to be less than the upper limits of tolerable risk.

Following investigations in Stage 2, maximal risk is determined for each hazard. If the responsible authority in the jurisdiction assesses the maximal risk to be low for all hazards, the project may proceed directly to construction. However, the more usual case is that the assessment will determine that some preventive measures are needed to reduce risk related to some hazards. This will be followed by reassessment of residual risk at the pre-commissioning stage, based on known or predicted effects of preventive measures on hazards. This step estimates the residual risk of commissioning the project. Preventive measures, operational procedures and incident and emergency management plans are intended to give confidence that the project will be safe during commissioning trials (Stage 3). If residual risks fail to reach acceptance criteria, preventive measures are added and residual risks reassessed until residual risks are determined to be low, or the project proponent determines that the expense of these measures makes the project unviable.

The risks for each project will depend on the quality of the source water, the intended uses of recovered water and the environmental values of the aquifer.While all projects follow the same risk assessment pathway, the level of effort required in risk assessment and management can vary markedly between projects, based on the specific risk profile of the project. For example, projects influencing drinking water supplies will generally require substantially more effort than those affecting only irrigation supplies.For many managed aquifer recharge projects, the level of some risks can only be estimated before full-scale implementation and validation monitoring occurs.

Following construction of the project, or at least a pilot or demonstration project, commissioning trials are run to enable validation of processes that could not be measured until recharge occurs, and to allow verification of the efficacy of the preventive measures. At this stage (Stage 3; Figure A2.1), it is possible to make an accurate calculation of residual risk; that is, an operational residual risk assessment. A low residual risk assessed at Stage 3 provides a basis for ongoing operation of the site and development of risk management plans (including verification and operational monitoring and reporting) (Stage 4). The risk management plans should be periodically reviewed, subject to monitoring results. In the event that the low impacts anticipated are not achieved, the proponent needs to identify and adopt additional preventive measures, and perform further commissioning trials if the project is to continue.

The major difference between Australian Guidelines and these Indian Guidelines is that the Australian Guidelines assume that water quality data obtained from water sampling and analysis programs are available to inform quantitative risk assessments. The Indian Guidelines do not assume any water quality data are available and primarily rely on visual observations to inform water safety plans that will enhance the safety of drinking water supplies likely to be affected by aquifer recharge projects.

Appendix 3. Overview of selected recharge sites in India

Case study information used to apply the Guidelines (Appendix 4) is provided below.

Box 3.2 provides an example assessment for a village check dam, Gujurat.

A3.1 Roof top rain water harvesting Indian Institute of Technology (IIT), New Delhi

Rain water is harvested from the IIT rooftop, by the Central Ground Water Board. Pre-treatment includes filtration through local porous media (sand). The total roof area is 1660 m^2 and the estimated mean annual recharge volume is 830 m^3.

Recharge to the alluvial, unconfined aquifer is under gravity via two vertical recharge wells that are slotted within the filter interval and wrapped with geotextile (Figure A3.1). Groundwater is harvested for drinking water supply via a tube well operated by Delhi Jal Board, located approximately 20 metres from the recharge wells (Figure A3.2). The depth to groundwater is approximately 30 m bgl, therefore water logging is not likely.

Bird droppings can be found on the roof surface. Filtered rain water harvested from the roof top is expected to be reasonable quality and similar to groundwater, which is the existing drinking water supply. High nitrate concentrations, up to 560 mg/L, have been reported in the groundwater.

Figure A3.1 Recharge well with slotted pipe in porous media filter after excavation for de-silting and installation of geo-textile around the slots.

Figure A3.2 Drinking water tube well of Delhi Jal Board, 20 m from the recharge site.

A3.2 Check dam Jawaharlal Nehru University (JNU) Campus, New Delhi

Semi-urban runoff is harvested using four check dams with a catchment area of 45 to 126 Ha, at JNU. The reservoir capacities range from 4,600-22,200 m^3 and the water spread area is 9,600-20,200 m^2. Approximately 75,700 m^3 captured stormwater has been recharged via infiltration to the alluvium, which overlies a hard rock aquifer. A sequence of impoundments improves water quality in the downstream check dam (Figure A3.3).

The catchment area consists mostly of vacant land and animals have access to the check dams. Industrial activities and waste stockpiles are also present in the catchment. The recharge source water can be turbid.

Groundwater is used for drinking water supply, but extraction is remote from the recharge site. Transit in the aquifer may provide natural treatment prior to recovery. There are no reported groundwater quality concerns.

Figure A3.3 Check dam on JNU campus, New Delhi.

A3.3 Stormwater recharge wells AIIMS crossing flyover , New Delhi

Central Ground Water Board in NCT, Delhi, has provided stormwater drainage technical designs for 33 flyovers. The intersection of Ring Road and Aurobindo Marg at the All India Institute of Medial Sciences (AIIMS) crossing is one of the most important flyovers in NCT, Delhi (Figure A3.4).

Urban runoff from this green flyover is utilized for recharge to the unconfined, alluvial aquifer, which overlies a hard rock aquifer. The total annual runoff available in this flyover is about 35,000 m^3, which is recharged through 10 recharge shafts constructed at different locations, each containing recharge tube-wells to a depth of 25 m.

The source water for recharge is mainly runoff from roads with heavy traffic loads; faecal sources are unlikely to impact on source water quality. The recharge source water can be turbid. Pre-treatment consists of an oil trap and sand filtration. Groundwater is used for drinking water supply, but extraction is remote from the recharge site. Transit in the aquifer may provide natural treatment prior to recovery. The depth to groundwater is approximately 24 m bgl. There are no reported groundwater quality concerns.

Figure A3.4 Artificial recharge at AIIMS fly-over (after CGWB, 2008).

A3.4 Bank filtration at Palla on Yamuna River, New Delhi

The Palla Well field is located in the North West district of NCT Delhi, which extends along the western bank of the river Yamuna from north of Burari village through Palla village to the Delhi/Haryana border. The well fields extend from the right marginal bund of river Yamuna to right up to the water mark of the river Yamuna. Recharge occurs through the river bed in response to extraction from wells adjacent to the river. Sandy soil is predominant in the floodplain, which slopes gently toward the south. Presently the area is characterised by agriculture fields where two to three crops are grown annually. The generalisation of the subsurface geology reveals that there are four formations mainly, the first and the topmost formation is characterized by medium to fine grained gray colored Yamuna sand with a few gravels, followed by a zone characterized by medium to coarse grained gray colored Yamuna sand with gravels and Kankars (Figure A3.5).

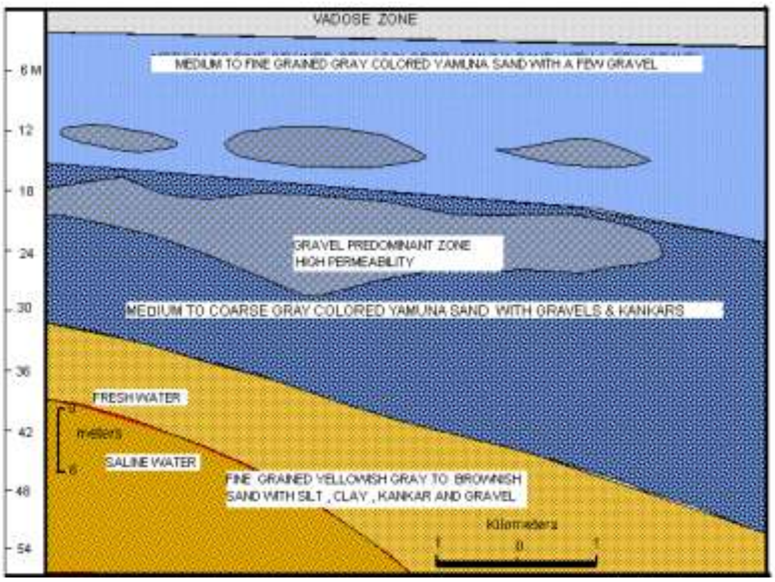


Figure A3.5 Longitudinal subsurface cross section of the Palla well field.

Latrines, fresh animal faecal material and stockpiles and animal manure are present and agricultural chemicals, such as fertilisers are used in the catchment area. The source water for recharge can be trubid, especially in high flows. Faeceal contamination sources are also present clost to the extraction wells. Groundwater is used for drinking water supply via around 90 tube wells in the Palla sector, extraction is adjacent to the river. Drinking water is treated by chlorination, but treatment can be interrupted by power failures. Recovery wells are housed to exclude livestock (Figure A3.6). The depth to groundwater is approximately 35-60 m bgl, but the floodplain can become waterlogged during flooding. There are no reported groundwater quality concerns.

Figure A3.6 Delhi Jal Board tube wells in Yamuna floodplain.

A3.5 Bank filtration at Haridwar on Ganga River, Uttarakhand

Bank filtration has been used in Haridwar since the 1980s as an alternative to surface water abstraction and to supplement groundwater resources. The alluvium is comprised of unconsolidated to semi-consolidated, coarse to fine sand, silt and clay. The Haridwar district aquifer system consists of four water bearing layers, separated by confining clay layers in the western part of the district.

The source water for recharge is largely rural runoff. Latrines, fresh animal faecal material and stockpiles and animal manure are present and agricultural chemicals, such as fertilisers are used in the catchment area. During religious festivals up to 5 million visitors may wash themselves in the Ganga in close proximity (<50 m) to the bank filtration wells. The source water for recharge can be turbid, especially in high flows. Filtration through the river bed provides water quality improvement, shown as a reduction in turbidity and coliform numbers.

Faeceal contamination sources are also present close to the extraction wells. Groundwater is used for drinking water supply, extraction is adjacent to the river (Figure A3.7). As of 2013, the toal drinking water production of >64,000 m^3/d is sourced from 22 large diameter, bottom entry caissson wells (>43,000 m^3/d) and 50 tube wells (21,000 m^3/d) receiving bank filtrate from the Ganga River. Drinking water is treated by chlorination, but this can be interrupted by power failures. Recovery wells are housed to exclude livestock, but well houses are occupied by families. Flood water can directly enter wells during high flow. Private wells are further from the recharge site.

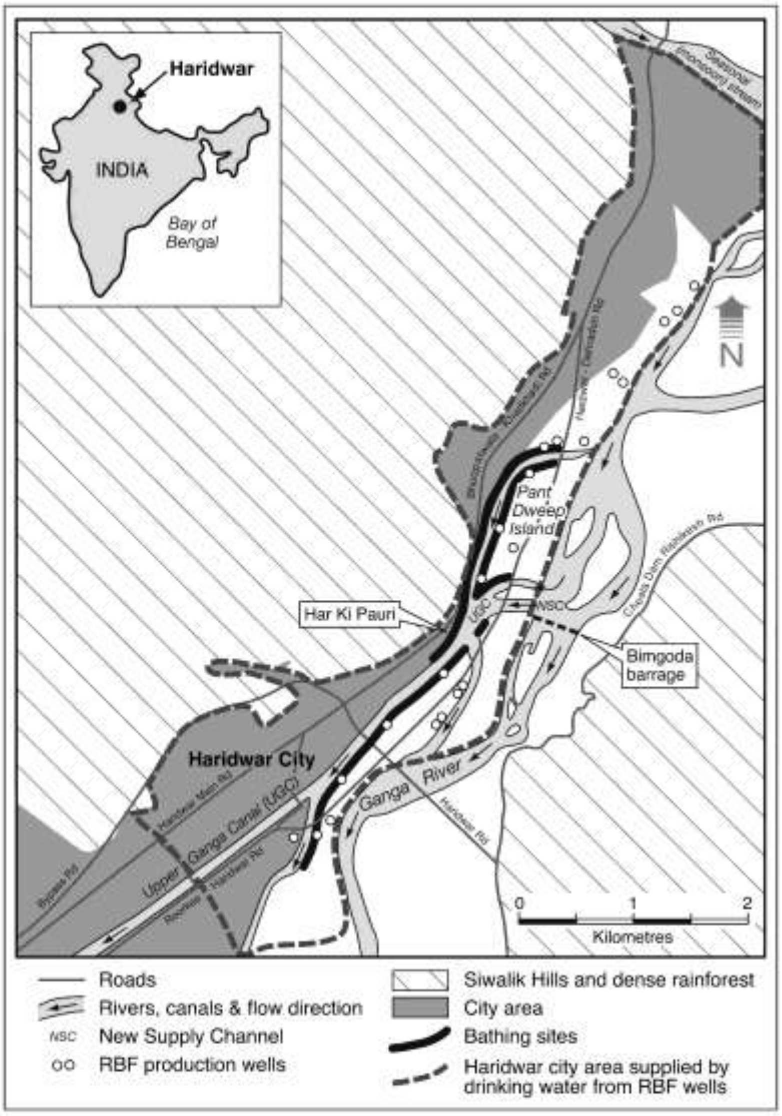


Figure A3.7 Haridwar bank filtration scheme including well locations.

Appendix 4. Example applications of these Guidelines to selected recharge sites in India

	Village check dam, Gujarat (Box 3.2)	**Roof top rain water harvesting IIT, New Delhi ** (A3.1)**	**Check dam JNU Campus, New Delhi (A3.2)**	**Stormwater recharge wells, AIIMS crossing flyover, New Delhi ** (A3.3)**	**Bank filtration, Palla on Yamuna River, New Delhi ** (A3.4)**	**Bank filtration, Haridwar on Ganga River, Uttarakhand ** (A3.5)**
Source water and treatment	rural runoff, infiltration through alluvium	Rainwater, sand filtration, recharge wells	Semi-urban runoff, infiltration through alluvium	Urban runoff, oil trap, sand filtration, recharge wells	Mainly rural sources, recharge through river bed	Mainly rural sources, recharge through river bed
Aquifer type	hard rock	alluvium	hard rock	alluvium/hard rock	alluvium	alluvium
1. Simple assessment						
	Yes/No	**Yes/No**	**Yes/No**	**Yes/No**	**Yes/No**	**Yes/No**
1. Is the aquifer being recharged used as a drinking water supply?	Y	Y	Y	Y	Y	Y
2. Is the scale of recharge larger than. domestic rainwater harvesting?	Y	Y	Y	Y	Y	Y
3. Does the water being recharged contact or contain human or animal excreta, industrial wastewater, or urban stormwater??	Y	Y	Y	Y	Y	Y
4. Is the area around the recharge area ever waterlogged?	N	N	N	N	Y River in flood.	Y River in flood.
Simple assessment is satisfied if all answers are No. No need to continue assessment. However if any answer is Yes proceed to viability assessment.	Proceed to viability assessment Y	Proceed to viability assessment Y	Proceed to viability assessment Y	Proceed to viability assessment Y	Proceed to viability assessment Y	Proceed to viability assessment Y

	Village check dam, Gujarat (Box 3.2)	**Roof top rain water harvesting IIT, New Delhi ** (A3.1)**	**Check dam JNU Campus, New Delhi (A3.2)**	**Stormwater recharge wells, AIIMS crossing flyover, New Delhi ** (A3.3)**	**Bank filtration, Palla on Yamuna River, New Delhi ** (A3.4)**	**Bank filtration, Haridwar on Ganga River, Uttarakhand ** (A3.5)**
2. Viability assessment						
	Yes/No	**Yes/No**	**Yes/No**	**Yes/No**	**Yes/No**	**Yes/No**
1. Is there a sufficient demand for water ?	Y	Y	Y	Y	Y	Y
2. Is there an adequate source of water available for allocation to recharge ?	Y	Y	Y	Y	Y	Y
3. Is there a suitable aquifer for storage and recovery of the required volume?	Y	Y	Y	Y	Y	Y
4. Is there sufficient space available for capture and treatment of the water?	Y	Y	Y	Y	Y	Y
If the answer to any question is **No**, *then the project is not viable or has a major constraint.*	Viable, proceed to Sanitary survey Y	Viable, proceed to Sanitary survey Y	Viable, proceed to Sanitary survey Y	Viable, proceed to Sanitary survey Y	Viable, proceed to Sanitary survey Y	Viable, proceed to Sanitary survey Y
3. Guidelines applicability assessment						
1. Is the source of water for recharge from a rooftop or a natural catchment ? (*ie* not sewage effluent, industrial wastewater, or urban stormwater)	Y	Y	Y Mostly from vacant land	N Mostly runoff from roads with heavy traffic load	Y Mostly rural runoff	Y Mostly rural runoff
2. Is the aquifer unconfined and not polluted?	Y	N Nitrate up to 560 ppm	Y	Y	Unknown	Unknown

	Village check dam, Gujarat (Box 3.2)	Roof top rain water harvesting IIT, New Delhi ** (A3.1)	Check dam JNU Campus, New Delhi (A3.2)	Stormwater recharge wells, AIIMS crossing flyover, New Delhi ** (A3.3)	Bank filtration, Palla on Yamuna River, New Delhi ** (A3.4)	Bank filtration, Haridwar on Ganga River, Uttarakhand ** (A3.5)
3. Is the proposed recharge area remote from public drinking water supply systems?	Y	N Only 20 m from public water supply well	Y	Y	N This is for public water supply	N This is for public water supply
These Guidelines are applicable if all answers above are Yes, if so proceed to Sanitary Survey. *Otherwise not applicable, use alternate Guidelines e.g. Australian MAR Guidelines.*	Applicable, proceed to Sanitary Survey Y	Not Applicable N	Applicable, proceed to Sanitary Survey Y	Not Applicable N	Not Applicable N	Not Applicable N
4. Sanitary Survey						
	Yes/No	**Yes/No**	**Yes/No**	**Yes/No**	**Yes/No**	**Yes/No**
1. Is there a latrine, open sewer or leaky sewer or human or animal faeces within the catchment area of the recharge facility?	Y Animal excreta	N	N	N Not visible	Y Latrines, fresh animal faecal material, stockpiles of animal manure	Y Latrines, fresh animal faecal material, stockpiles of animal manure
2. Is there a latrine, open sewer, leaky sewer or animal faeces in close proximity to the recharge structure or to the wells from which water will be recovered ?	Y Animal excreta	N	Y Animals have access to check dam	N	Y Latrines, fresh animal faecal material close to extraction wells	Y Open latrines, leaky sewers, fresh animal faecal material close to extraction wells

	Village check dam, Gujarat (Box 3.2)	**Roof top rain water harvesting IIT, New Delhi ** (A3.1)**	**Check dam JNU Campus, New Delhi (A3.2)**	**Stormwater recharge wells, AIIMS crossing flyover, New Delhi ** (A3.3)**	**Bank filtration, Palla on Yamuna River, New Delhi ** (A3.4)**	**Bank filtration, Haridwar on Ganga River, Uttarakhand ** (A3.5)**
3. Are there industrial, transport or agricultural activities generating stockpiles, wastes, spills, or emissions reaching the surface of the catchment area of the recharge facility?	Y Animal excreta	N	Y Industrial activities and waste stockpiles in catchment	Y Heavy traffic - oil, metals, chemicals spills and diffuse loadings expected	Y Agricultural chemicals and fertilisers used in the catchment	Y Agricultural chemicals and transport fuels and fertilisers used in the catchment
4. Are there industrial, transport or agricultural activities generating stockpiles, wastes, spills, or emissions in close proximity to the recharge structure or the wells from which water will be recovered?	Y Animal excreta	N	N Recovery wells remote	Y Heavy traffic - oil, metals, chemicals spills and diffuse loadings expected	Agricultural chemicals and fertilisers used close to extraction wells and need further evaluation	Agricultural chemicals, transport fuels and fertilisers used close to extraction wells and need further evaluation
5. Is there pre-treatment or means of preventing contaminated water to be recharged? – if so describe its design and resilience to power and mechanical failure, and any alarm systems?	N	Y Sand filter in infiltration system.	Y Sequence of impoundments improves water quality in downstream check dam.	Y Oil and sediment trap in place for road runoff. Does not depend on power supply.	Natural treatment by passage through aquifer before recovery	Natural treatment by passage through aquifer before recovery
6. Is there post-treatment of water to be recovered? – if so describe its design and resilience to power and mechanical failure, and any alarm systems?	Y (boiling water)	Unknown	Unknown Distance to recovery wells expected to improve water quality.	Unknown Any recovery would be from remote wells.	Chlorination. Pumps shut down when power fails.	Chlorination. Pumps shut down when power fails.

	Village check dam, Gujarat (Box 3.2)	**Roof top rain water harvesting IIT, New Delhi ** (A3.1)**	**Check dam JNU Campus, New Delhi (A3.2)**	**Stormwater recharge wells, AIIMS crossing flyover, New Delhi ** (A3.3)**	**Bank filtration, Palla on Yamuna River, New Delhi ** (A3.4)**	**Bank filtration, Haridwar on Ganga River, Uttarakhand ** (A3.5)**
7. Does the existence and condition of any barriers around of the recharge structure and recovery wells prevent short circuit of contaminated water?		Y Well wall excludes runoff from other surfaces.	N Fencing and water troughs to exclude livestock from vicinity of check dam suggested.	Unknown whether water can enter wells during floods	Wells have housing to exclude livestock.	Wells have housing to exclude livestock. However well houses occupied by families. Also flood water can directly enter wells during high flow.
*Any question answered by **Yes** or **unknown** needs to be taken into specific account in the Water Safety Plan below. Even if not observed, the possibility of these hazards occurring or barriers being breached also needs to be taken into account. Proceed to aquifer assessment.*	Account for these in MAR water safety plan	Account for these in MAR water safety plan	Account for these in MAR water safety plan	Account for these in MAR water safety plan	Account for these in MAR water safety plan	Account for these in MAR water safety plan
5. Aquifer assessment						
	Yes/No	**Yes/No**	**Yes/No**	**Yes/No**	**Yes/No**	**Yes/No**
1. Does source water have low quality; is water turbid, coloured, contains algae, has a surface slick or does it smell?	Y Turbid	Unknown	Y Turbid	Y Turbid	Y Turbid especially in high flows/	Y Turbid especially in high flows.
2. Does the unconfined aquifer have a shallow water table, say < 8m in urban area and say < 4m in rural area?	N	N	N	N	Water table <3m in places. The bank filtration will not raise groundwater	Shallow water table. The bank filtration will not raise groundwater levels but will

	Village check dam, Gujarat (Box 3.2)	**Roof top rain water harvesting IIT, New Delhi ** (A3.1)**	**Check dam JNU Campus, New Delhi (A3.2)**	**Stormwater recharge wells, AIIMS crossing flyover, New Delhi ** (A3.3)**	**Bank filtration, Palla on Yamuna River, New Delhi ** (A3.4)**	**Bank filtration, Haridwar on Ganga River, Uttarakhand ** (A3.5)**
					levels but will lower them near extraction wells	lower them near extraction wells
3. Are there other groundwater users, groundwater-connected ecosytem or a property boundary within 100m of the recharge site?	Y (private drinking water wells)	Public water supply well at 20m	N	N	Only DJB drinking water supply wells	Y Private wells located further from river than the bank filtration well.
4. Is the aquifer known to contain reactive minerals (e.g. fluoride, pyrite) or is groundwater in this area known to contain arsenic? Is the aquifer contains soluble minerals such as calcite and dolomite ?		N Not known, unlikely in this alluvium.	N Not known, unlikely in this alluvium.	N Nt known, unlikely in this alluvium.	N Alluvial aquifer sourced by natural recharge of same source. No new geochemical reactions expected.	N Alluvial aquifer sourced by natural recharge of same source. No new geochemical reactions expected.
5. Is the aquifer composed of fractured rock or karstic (fissured or cavernous) limestone or dolomite?	Y Fractured hard rock.	N	N	N	N	N
6. Is the proposed project of such a scale that it requires development approval? Is it in a built up area; built on public, flood-prone or steep land; or close to a property boundary? Does it contain open water storages or engineering structures; or is it likely to cause public health or	N	N	Existing project. Good use of flood prone land over deep water table. If remains unclogged will avoid mosquitoes.	Existing project (integrated with AIIMS Flyover as a means of flood mitigation)	Existing project Built on flood prone land.	Existing project. Built on flood prone land.

	Village check dam, Gujarat (Box 3.2)	Roof top rain water harvesting IIT, New Delhi ** (A3.1)	Check dam JNU Campus, New Delhi (A3.2)	Stormwater recharge wells, AIIMS crossing flyover, New Delhi ** (A3.3)	Bank filtration, Palla on Yamuna River, New Delhi ** (A3.4)	Bank filtration, Haridwar on Ganga River, Uttarakhand ** (A3.5)
safety issues (e.g. falling or drowning), nuisance from noise, dust, odour or insects (during construction or operation), or adverse environmental impacts (e.g. from waste products of treatment processes)?						
Any question answered by ***Yes*** *or* ***Unknown*** *needs to be taken into specific account in the Water Safety Plan below. Even if not observed, the possibility of these hazards occurring or barriers being breached also needs to be taken into account. Proceed to Water Safety Plan*	Account for possibility of these in MAR water safety plan	Account for possibility of these in MAR water safety plan	Account for possibility of these in MAR water safety plan	Account for possibility of these in MAR water safety plan	Account for possibility of these in MAR water safety plan	Account for possibility of these in MAR water safety plan
6. Managed Aquifer Recharge Water Safety Plan						
	Yes/No	**Yes/No**	**Yes/No**	**Yes/No**	**Yes/No**	**Yes/No**
Human sewage entrainment in source water						
1. Do latrine leakage, open sewers, sewer pipe leaks, open defecation occur in the catchment or close to recharge facilities or recovery wells?	Y Open defaecation.	N	N	N Not visible.	Y Latrines	Y Latrines, leaky sewers, open defaecation.
Animal faecal matter entrainment in source water						
2. Are there any animal manure accumulations or cess pits in the catchment or close to the recharge area or recovery well?	Y	N	Y Animals have access to check dam.	N	Y Stockpiles of animal manure, fresh animal faecal material	Y Stockpiles of animal manure, fresh animal faecal material

	Village check dam, Gujarat (Box 3.2)	**Roof top rain water harvesting IIT, New Delhi ** (A3.1)**	**Check dam JNU Campus, New Delhi (A3.2)**	**Stormwater recharge wells, AIIMS crossing flyover, New Delhi ** (A3.3)**	**Bank filtration, Palla on Yamuna River, New Delhi ** (A3.4)**	**Bank filtration, Haridwar on Ganga River, Uttarakhand ** (A3.5)**
					close to extraction wells.	close to extraction wells
Leaching of microbial contaminants into aquifer						
3. Can water infiltrate that has been in contact with human and animal wastes?	Y	N	Y	N	Y Floodplain is likely to contribute more contaminants to drinking water than bank-filtered river water.	Y Floodplain is likely to contribute more contaminants to drinking water than bank-filtered river water.
Entrainment of chemicals in source water for recharge						
4. Are there industry, transport and agricultural activities generating stockpiles, wastes, spills, or emissions reaching the catchment surface?	Y	Y Dry fall and wet fall of contaminants including bird faecal matter on roof.	Y Industrial activities and waste stockpiles in catchment.	Y Heavy traffic - oil, metals, chemicals spills and diffuse loadings expected.	Y Manures and agricultural chemicals.	Y Manures and agricultural chemicals.
Leaching of chemicals into groundwater .						
5. Can water infiltrate from landfills, waste dumps or industrial discharge?	Y	N	Y Iindustrial activities and waste stockpiles in catchment.	N	Y From manure stockpiles)	Y From manure stockpiles, possible spills of transport fuels, pesticides.

	Village check dam, Gujarat (Box 3.2)	Roof top rain water harvesting IIT, New Delhi ** (A3.1)	Check dam JNU Campus, New Delhi (A3.2)	Stormwater recharge wells, AIIMS crossing flyover, New Delhi ** (A3.3)	Bank filtration, Palla on Yamuna River, New Delhi ** (A3.4)	Bank filtration, Haridwar on Ganga River, Uttarakhand ** (A3.5)
Bypassing or failure of pre-treatment in recharge facility						
6. Can recharging water short-circuit existing barriers to protect groundwater quality? (for example caused by clogging of filters, power or mechanical failures, or treatment chemicals running out)	N No pretreatment or bypass.	N Water must pass through filter to reach recharge well. Excess flows overflow and do not enter wells.	N No pretreatment or bypass for infiltration to water table.	Y Oil and sediment trap in place for road runoff. Does not depend on power supply. Not known if floodwater enters wells directly.	N Bank filtration is robust, but unsaturated zone is thin. Well heads have livestock exclosures.	Y Bank filtration is robust, but families are living inside the well head houses defeating their protective purpose.
Bypassing or failure of post treatment at recovery well						
7. Can water used for drinking bypass existing barriers or treatments? (for example caused by clogging of filters, power or mechanical failures, lack of fuel for boiling water, or treatment chemicals running out).	N Water is boiled or used in family ceramic filters, so unlikely.	Unknown Depends on DJBs own water safety plans.	N Recovery wells are remote, gives opportunity for attenuation of some contaminants in aquifer.	No known drinking wells within vicinity.	Y Chlorination. Pumps shut down when power fails. Plan should include verifying chlorination level, and procedures during floods.	Y Chlorination. Pumps shut down when power fails. But leaky mains allow ingress of contaminated shallow groundwater when pipes are not pressurised. Plan should include verifying chlorination level, procedures during floods and repairing leaky pipes.

	Village check dam, Gujarat (Box 3.2)	**Roof top rain water harvesting IIT, New Delhi ** (A3.1)**	**Check dam JNU Campus, New Delhi (A3.2)**	**Stormwater recharge wells, AIIMS crossing flyover, New Delhi ** (A3.3)**	**Bank filtration, Palla on Yamuna River, New Delhi ** (A3.4)**	**Bank filtration, Haridwar on Ganga River, Uttarakhand ** (A3.5)**
See Table 3.4 to identify suitable control measures, critical limits, monitoring, corrective actions and verification. Insert site-specific measures in consultation with stakeholders and agree on whom is to take each action required.	Stakeholders capable of implementation to complete the MAR Water Safety Plan	Stakeholders capable of implementation to complete the MAR Water Safety Plan	Stakeholders capable of implementation to complete the MAR Water Safety Plan	Stakeholders capable of implementation to complete the MAR Water Safety Plan	Stakeholders capable of implementation to complete the MAR Water Safety Plan	Stakeholders capable of implementation to complete the MAR Water Safety Plan
Extra work is required to start monitoring at these sites (**) with higher risks to better assess risks and remedies.		**		**	**	**

** Three of these six aquifer recharge sites directly contribute to public drinking water supplies and one recharges urban stormwater from an area with high traffic and expected large contaminant load. Therefore these Indian Guidelines on their own are considered unable to confidently protect human health (i.e. not applicable because of the high potential risk to drinking water supplies). However, the guidelines were followed through regardless to help identify any other issues needing to be considered in a more rigorous assessment. These may have parallels with issues at other sites requiring assessment by readers.

Appendix 5. Water Quality Monitoring

CPCB (2007) provides detailed advice on water quality monitoring protocols, including sampling methods and sample preservation.

A basic water quality monitoring suite to support the water safety plan approach is provided below. Trend monitoring is recommended four times per year; once pre-monsoon and then thereafter at 3 monthly intervals (groundwater) or 3 evenly spaced times during the flow period (surface water).

Parameter group	**Parameters**
General	Colour, odour, temperature, pH, EC, TDS, turbidity
Nutrients	NO_2+NO_3, NH_3, total P
Organic matter	COD, BOD
Major ions	K^+, Na^+, Ca^{2+}, Mg^{2+}, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}
Other inorganics	F, B, any location-specific parameter of interest (e.g. Fe, As)
Microbial*	*E. Coli*
Organic chemicals (pesticides)	Site specific, necessary for protection of groundwater for drinking water supply

Appendix 6. Checklists Brochure

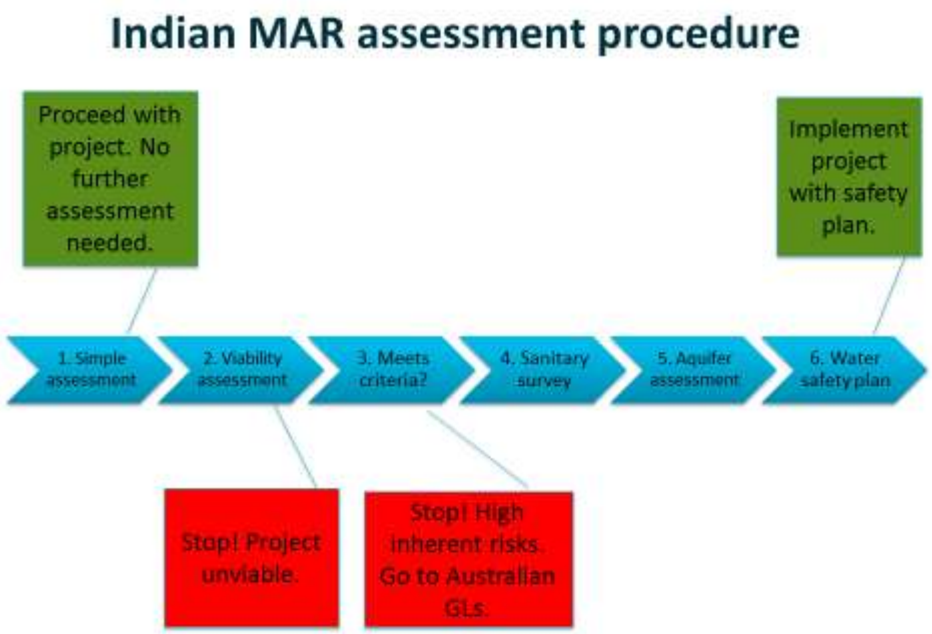
The following document captures the essentials of this guideline as stand-alone checklists that may be used at local level to help guide water quality improvement at new and existing recharge sites.

A Water Quality Guide to Managed Aquifer Recharge in India

Checklists Brochure

This brochure is intended for use to help managed aquifer recharge operations to protect the quality of nearby groundwater where it is a source of drinking water supplies. This is produced as a set of checklists that can be used by operators of recharge projects, or by local public health officers or water resources managers to developer safety plans. This is designed for situations where water quality data are sparse or not available and only visual observations are possible. This can be applied to new recharge projects, before they commence, and to existing artificial recharge operations. Taking action on the measures identified in these checklists will be needed to improve the health and safety of people who use nearby groundwater for drinking. For more comprehensive information and the rationale, please refer to the parent document (Dillon *et al* 2014).

Dillon, P., Vanderzalm, J., Sidhu, J., Page, D., Chadha, D. (2014). A Water Quality Guide to Managed Aquifer Recharge in India. CSIRO Land and Water Flagship and UNESCO. https://publications.csiro.au/rpr/pub?pid=csiro:EP149116



Water Quality Guide to Managed Aquifer Recharge in India - Checklists		
1. Simple assessment		
	Yes	**No**
1. Is the aquifer being recharged used as a drinking water supply?		
2. Is the scale of recharge larger than domestic rainwater harvesting?		
3. Does the water being recharged contain sewage effluent, industrial wastewater, or urban stormwater?		
4. Is the area around the recharge area ever waterlogged?		
Simple assessment is satisfied if all answers are No. No need to continue assessment. However if any answer is Yes proceed to Viability assessment.	Proceed to Viability assessment	Proceed with Project
2. Viability assessment		
	Yes	**No**
1. Is there a sufficient demand for water?		
2. Is there an adequate source of water available for allocation to recharge?		
3. Is there a suitable aquifer for storage and recovery of the required volume?		
4. Is there sufficient space available for capture and treatment of the water?		
If the answer to any question is no, then the project is not viable or has a major constraint. If all answers are Yes, proceed to Guidelines applicability assessment.	Viable, proceed to assessment	Not viable
3. Guidelines applicability assessment		
	Yes	**No**
1. Is the source of water for recharge from a rooftop or a natural catchment? (*ie* not sewage effluent, industrial wastewater, or urban stormwater)		
2. Is the aquifer unconfined and not polluted?		
3. Is the proposed recharge area remote from public drinking water supply systems?		
These Guidelines are applicable if all answers above are Yes, if so proceed to Sanitary Survey *Otherwise not applicable, use alternate Guidelines e.g. Australian MAR Guidelines.*	Applicable	Not Applicable

4. Sanitary Survey		
	Yes	**No**
1. Is there a latrine, open sewer or leaky sewer or human or animal faeces within the catchment area of the recharge facility?		
2. Is there a latrine, open sewer, leaky sewer or animal faeces in close proximity to the recharge structure or to the wells from which water will be recovered?		
3. Are there industrial, transport or agricultural activities generating stockpiles, wastes, spills, or emissions reaching the surface of the catchment area of the recharge facility?		
4. Are there industrial, transport or agricultural activities generating stockpiles, wastes, spills, or emissions in close proximity to the recharge structure or the wells from which water will be recovered?		
5. Is there pre-treatment or means of preventing contaminated water to be recharged? If so describe its design and resilience to power and mechanical failure, and any alarm systems.		
6. Is there post-treatment of water to be recovered? If so describe its design and resilience to power and mechanical failure, and any alarm systems.		
7. Does the existence and condition of any barriers around of the recharge structure and recovery wells prevent short circuit of contaminated water?		
*Any question answered by **Yes** needs to be taken into specific account in the Water Safety Plan below. Even if not observed, the possibility of these hazards occurring or barriers being breached also needs to be taken into account.*	Account for these specifically in MAR water safety plan	Account for possibility of these in MAR water safety plan
Proceed to aquifer assessment		

5. Aquifer assessment		
	Yes	**No**
1. Does source water have low quality; is water turbid, coloured, contains algae, has a surface slick or does it smell?		
2. Does the unconfined aquifer have a shallow water table, say < 8m in urban area and say < 4m in rural area?		
3. Are there other groundwater users, groundwater-connected ecosytems or a property boundary within 100m of the recharge site?		
4. Is the aquifer known to contain reactive minerals (e.g. pyrite) or is groundwater in this area known to contain arsenic? Is the aquifer contains soluble minerals such as calcite and dolomite?		
5. Is the aquifer composed of fractured rock or karstic (fissured or cavernous) limestone or dolomite?		
6. Is the proposed project of such a scale that it requires development approval? Is it in a built up area; built on public, flood-prone or steep land; or close to a property boundary? Does it contain open water storages or engineering structures; or is it likely to cause public health or safety issues (e.g. falling or drowning), nuisance from noise, dust, odour or insects (during construction or operation), or adverse environmental impacts (e.g. from waste products of treatment processes)?		
*Any question answered by **Yes** needs to be taken into specific account in the Water Safety Plan below. Even if not observed, the possibility of these hazards occurring or barriers being breached also needs to be taken into account.*	Account for these specifically in MAR water safety plan	Account for possibility of these in water safety plan
Proceed to Water Safety Plan		

6. Managed Aquifer Recharge Water Safety Plan		
	Yes	**No**
Human sewage entrainment in source water		
1. Do latrine leakage, open sewers, sewer pipe leaks, open defecation occur in the catchment or close to recharge facilities or recovery wells?		
Animal faecal matter entrainment in source water		
2. Are there any animal manure accumulations or cess pits in the catchment or close to the recharge area or recovery well?		
Leaching of microbial contaminants into aquifer		
3. Can water infiltrate that has been in contact with human and animal wastes?		
Entrainment of chemicals in source water for recharge		
4. Are there industry, transport and agricultural activities generating stockpiles, wastes, spills, or emissions reaching the catchment surface?		
Leaching of chemicals into groundwater		
5. Can water infiltrate from landfills, waste dumps or industrial discharge?		
Bypassing or failure of pre-treatment in recharge facility		
6. Can recharging water short-circuit existing barriers to protect groundwater quality? (for example caused by clogging of filters, power or mechanical failures, or treatment chemicals running out)		
Bypassing or failure of post treatment at recovery well		
7. Can water used for drinking bypass existing barriers or treatments? (for example caused by clogging of filters, power or mechanical failures, lack of fuel for boiling water, or treatment chemicals running out).		
See Table 3.4 to identify suitable control measures, critical limits, monitoring, corrective actions and verification. Insert site-specific measures in consultation with stakeholders and agree on whom is to take each action required.	Complete the MAR Water Safety Plan	Complete the MAR Water Safety Plan

Example water safety plans for managed aquifer recharge.

Hazardous event	Cause	Control Measure	Critical Limits		Monitoring			Corrective action	Verification
			Targets	Action	What	When	Who		
1.Human sewage entrainment in source water	Latrine leakage, open sewers, sewer pipe leaks, open defecation in catchment, and close to recharge facilities and recovery wells	More latrines with improved design, install separate sewage system from stormwater drains, or only harvest high wet weather flows, improve sewer capacity and response to chokes and leaks.	Control sewage leaks, regulate sewage discharge points in catchment	Identify sewage leaks sewage discharge points. Repair, rebuild, or implement overflow diversion. Boil drinking water.	Sanitary inspection	Monthly	Op	Remove pollutant sources, improve sanitation design, reduce sewer leakage or sewage discharge	Microbiological examination of water
2.Animal faecal matter entrainment in source water	Animal manure accumulation or cess pits in the catchment and close to recharge area and recovery well,	Exclude livestock from water harvesting and recovery structures, collect animal faeces and store in dry areas with setback distance from water infrastructure .	No overstocking in catchment, set back distances honoured, Dry storage of animal manures	Controls on animal husbandry in catchment, Repair fences, exclusion zones. Boil drinking water.	Sanitary inspection	Monthly	Op	Removing live stock out of catchment , repair or erect fencing, arrange collection and removal of faeces.	Microbiological examination of water
3.Leaching of microbial contaminants into aquifer	Infiltration of water that has been in contact with human and animal wastes	Provide adequate setback distances to drinking water wells or springs	No sources of faecal material within setback distance	Close any latrines, and enclose or seal open sewers within setback distance. Boil	Sanitary inspection	Monthly	Op	Remove sources of faecal material within setback distance, repair /erect fencing, improve sewerage.	Microbiological examination of water

Hazardous event	Cause	Control Measure	Critical Limits		Monitoring			Corrective action	Verification
			Targets	Action	What	When	Who		
				drinking water.					
4.Entrainment of chemicals in source water for recharge	Industry, transport and agricultural activities generating stockpiles, wastes, spills, and emissions reaching the catchment surface	Regulate industrial and agricultural activities in the catchment	No unauthorised sources of chemical contamination in catchment. All pollutants in wise use & management. Minimise spills through industry standards	Remove wastes from catchment. Install bunding around industrial sites to prevent runoff to recharge system. Traffic loading regulations enforced.	Sanitary inspection	Monthly	Op	Move or bund polluting industries, regulate industrial discharge and agricultural use of chemicals	Sanitary inspection Analysis of source water and groundwater quality for pollutants.
5.Leaching of chemicals into groundwater	Leaching from landfill, waste dumps and industrial discharge	Provide adequate set back distance, regulate industrial discharge	No source of chemicals within the set-back distance	Prevent pollutant discharge within set-back distance	Sanitary inspection	Monthly	Op	Improve containment and move or control pollution sources	Sanitary inspection Analysis of source water and groundwater quality for pollutants.
6. Bypassing or failure of pre-treatment in recharge facility	Short-circuit of recharge flow. Clogging of filters, power and mechanical failures, treatment chemicals run out.	Design treatment to avoid admitting untreated water into the well for each of these hazardous events.	No recharge of untreated water	Maintain treatment system regularly. Install system to shut-down recharge when alarm activated Boil drinking water.	Sanitary inspection	Monthly	Op	Maintain filter and any other treatment. Check alarm system operates correctly.	Sanitary inspection Analysis of source water and groundwater quality for pollutants.
7. Bypassing or failure of	Clogging of filters, power	Design treatment to avoid admitting	No distribution of	Maintain treatment	Sanitary inspection	Monthly	Op	Maintain filter and any other	Sanitary inspection

Hazardous event	Cause	Control Measure	Critical Limits		Monitoring			Corrective action	Verification
			Targets	Action	What	When	Who		
post treatment at recovery well	and mechanical failures, treatment chemicals run out.	untreated water into the water supply for each of these hazardous events.	untreated recovered water	system regularly. Install system to shut-down recovery when alarm activated. Boil drinking water.				treatment. Check alarm system operates correctly.	Analysis of groundwater &recovered water for pollutants.

Op= MAR scheme operator