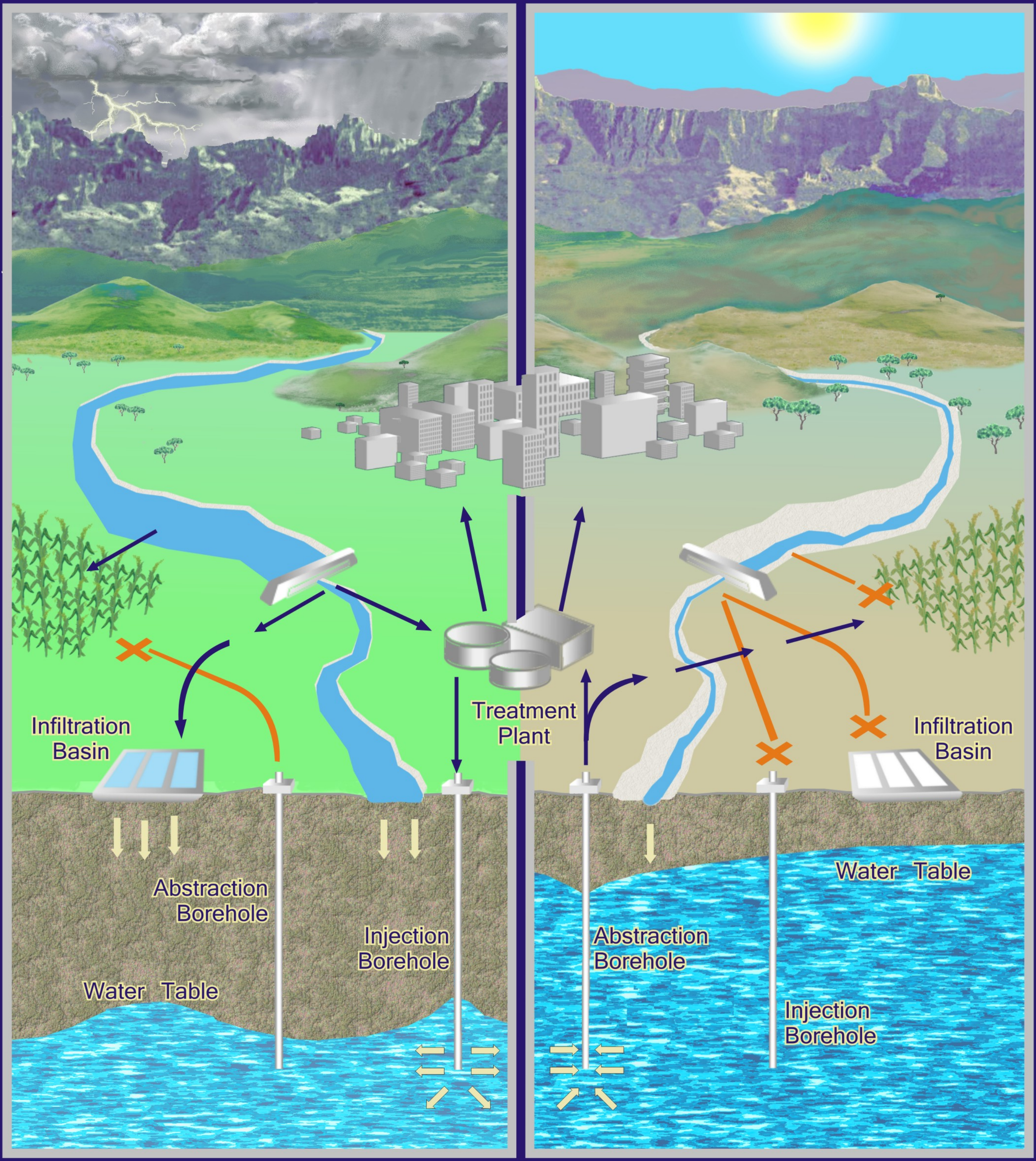
ARTIFICIAL RECHARGE STRATEGY

Version 1.3 - June 2007



water & forestry

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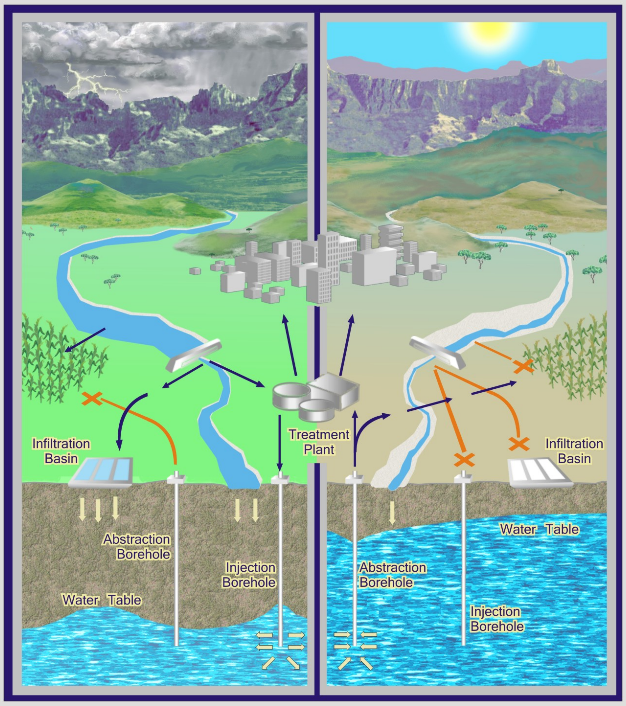
Research
Commission

When surplus water is available, it is transferred underground via infiltration basins or boreholes. The aquifers are rapidly replenished and the water is held in storage for later use.



In times of need, the stored water is pumped from the aquifer via boreholes to the users.

ARTIFICIAL RECHARGE STRATEGY

Version 1.3

June 2007

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Acronyms

AOC	Assimilable Organic Carbon
AR	Artificial Recharge
ARMS	Artificial Recharge Management and Storage
ASCE	American Society of Civil Engineers
ASR	Aquifer Storage and Recovery
ASTR	Aquifer Storage, Transfer and Recovery
AWWA	American Water Works Association
BCM	Billion Cubic Metres (1000 000 000 m^3)
CBA	Cost Benefit Analysis
CMA	Catchment Management Agency
CMS	Catchment Management Strategy
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
DBP	Disinfection By-Products
DEADP	Department of Environmental Affairs and Development Planning
DEAT	Department of Environmental Affairs and Tourism
DNDE	Department of National Development and Energy, Australia
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DWAF	Department of Water Affairs and Forestry
EAP	Environmental Assessment Practitioner
EC	Electrical Conductivity
Eh	Oxidation-reduction potential, mV
EIA	Environmental Impact Assessment
ENVES	Environmental Engineering Services
EPA	Environmental Protection Agency (USA)
GIS	Geographical Information System
GRA II	Groundwater Resource Assessment Phase II (DWAF)
HAA	Halo-Acetic Acids
HACCP	Hazard Analysis and Critical Control Point Plan
IDP	Integrated Development Plans
IMIESA	Institution of Municipal Engineering of South Africa
ISP	Internal Strategic Perspective
IWRM	Integrated Water Resource Management
MAR	Mean Annual Runoff
MAR	Managed Aquifer Recharge
MARS	Managed Aquifer Recharge and Storage
MFI	Membrane Filter Index
MHa	Million Hectares
Mm^3	Million cubic metres
NamWater	Namibia Water Corporation (Ltd)
NEMA	National Environmental Management Act (Act 107 of 1998)
NGDB	National Groundwater Data Base
NWA	National Water Act (Act 36 of 1998)
NWCDMS	National Water Conservation and Water Demand Strategy
NWP	National Water Policy (for South Africa)
NWRS	National Water Resource Strategy
SAT	Soil Aquifer Treatment
SWECO	SWECO International (Consulting Company)
TDS	Total Dissolved Solids
THM	Trihalomethanes
TOC	Total Organic Carbon
WB	Water Board
WC	Water Conservation
WDM	Water Demand Management
WMA	Water Management Area
WRC	Water Research Commission
WSA	Water Services Authority
WSDP	Water Services Development Plan
WSI	Water Services Institution
WSP	Water Services Provider
WSPF	Water Services Planning Framework
WUA	Water User Association

SECTION A: INTRODUCTION

A.1 INTRODUCTION

A.1.1 Purpose of a national strategy

Artificial recharge (AR) is the process whereby surface water is transferred underground to be stored in an aquifer. The most common methods used involve injecting water into boreholes and transferring water into spreading basins where it infiltrates the subsurface. Underground water storage is an efficient way to store water because it is not vulnerable to evaporation losses and it is relatively safe from contamination. Internationally, artificial recharge is becoming an increasingly recognised form of water storage and conservation. South Africa has one major established artificial recharge scheme, however, this technology is underutilised and together with proper groundwater management, artificial recharge can contribute significantly towards maximising the use and sustainability of available water resources.

The purpose of the national artificial recharge strategy is captured in the vision statement:

Vision

To use natural sub-surface storage as part of Integrated Water Resource Management wherever technologically, economically, environmentally and socially feasible.

In order to realise this vision, the Department of Water Affairs and Forestry (DWAF) has identified seven themes that require attention. These themes are listed below and described in Section D which presents the artificial recharge strategy.

Themes

1. Knowledge Theme
2. Legislation and Regulation Theme
3. Planning Theme
4. Implementation Theme
5. Management Theme
6. Research Theme
7. Strategy Implementation Theme

Artificial recharge or Managed Aquifer Recharge (an alternative term that is commonly used), has many purposes. The most common is to store water in the subsurface for later use, this usually being achieved by allowing water to infiltrate the subsurface via infiltration basins or by injecting water via boreholes into the aquifer. In this context, it is a form of water conservation, in that water that would otherwise be lost through evaporation and evapotranspiration from dams and rivers, or from outflows to the sea (fresh or waste water), would be captured and made available for later use. Other common uses are to prevent sea water intruding into coastal aquifers by creating hydraulic barriers at the coastline, and to use aquifer media for water treatment, like a large-scale sand filter. A potential use in South Africa may also be to maintain the Reserve, whereby surplus water (fresh or waste) would feed areas where the Reserve is considered to be under threat due to large-scale groundwater or surface water abstraction.

DWAF intends to incorporate artificial recharge as part of water resource planning - both at the Water Resource Level and at the Water Services Level. At the Water Resource Level, this will mean incorporating artificial recharge within Catchment Management Strategies (CMSs) and the National Water Resource Strategy (NWRS); and at the Water Services Level, it will mean including artificial recharge in Integrated Development Plans, in Water Services Development Plans and in the various Water Conservation and Water Demand Management Strategies.

The main aim of this document is to provide a national strategy on how to create an enabling environment for implementing artificial recharge.

For this strategy to be effective, that is, for it to enable authorities to include artificial recharge as a feasible option when assessing, planning and managing water resources, it will need to accomplish four critical objectives:

- It will need to promote awareness on artificial recharge
- It will need to pave the way for artificial recharge to be included in various levels of water resource planning
- It will need to provide basic information on the factors that affect the viability of artificial recharge schemes
- It will need to provide guidance on how to obtain approval from DWAF for implementing artificial recharge projects.

A.1.2 Introduction to the document

The Artificial Recharge Strategy has four main components (Table A.1):

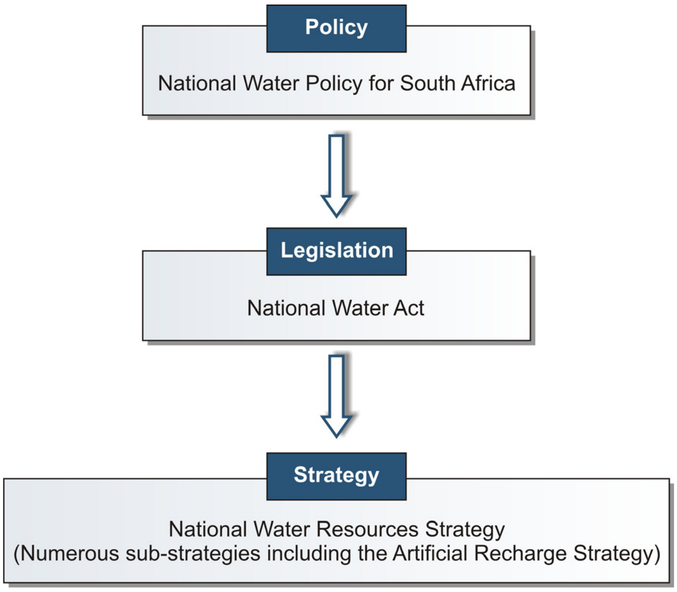
A: Introduction
B: The artificial recharge concept, its application and potential
C: Implementation and authorisation
D: The Artificial Recharge Strategy

Table A.1: Roadmap of the Artificial Recharge Strategy

SECTION	PURPOSE
A: Introduction	
Introduction This section describes the purpose of the Artificial Recharge Strategy, provides the artificial recharge vision and the seven objectives to realise the vision.	To provide a brief explanation of why the Artificial Recharge Strategy is necessary.
Legislative framework Artificial recharge is contextualised within existing national strategies and legislation.	To see where artificial recharge fits in the “big picture”.
B: The Artificial Recharge Concept, Its Application and Potential	
What is artificial recharge The types of artificial recharge schemes are described as well as their benefits.	To give the reader a rapid overview of what the artificial recharge concept entails.
International and Southern African experience Describes existing schemes internationally and within Southern Africa.	To highlight the role that artificial recharge plays in integrated water resource management and to illicit key lessons from operational schemes.
Artificial recharge potential in South Africa This section assesses the potential role of artificial recharge in South Africa and quantifies the volume of water per WMA that could be stored using the artificial recharge approach.	To provide an initial assessment of the potential of artificial recharge in relation to the country’s total water resources.
C: Implementation and Authorisation	
Criteria for successful implementation Lists and describes the criteria for assessing the viability of artificial recharge schemes.	To provide guidance on the factors that affects the implementation of a successful artificial recharge project.
Project stages, legislation and authorisation This section describes the process of assessing, implementing and authorising artificial recharge projects.	To provide guidance on the process of implementing an artificial recharge project and the legal requirements. This section is aimed at both implementing agents and regulatory authorities.
Guideline documents Provides an overview of artificial recharge guideline documents.	To provide awareness on existing support material.
D: The Artificial Recharge Strategy	
The Artificial Recharge strategy The Artificial Recharge Strategy includes the artificial recharge vision and seven themes. Each theme contains one objective and the actions required to meet the objective. The current status of each theme is described as well as the strategic approach to address each objective.	To describe in detail the Artificial Recharge Strategy
Approach to incorporate artificial recharge in water resource planning This section lists government documents into which artificial recharge should be incorporated.	To provides an initial approach to incorporate artificial recharge in water resource planning.

A.2 LEGISLATIVE FRAMEWORK

This section describes the foundation of this strategy document – the principles, the legislation and the overarching water resource strategy. The diagram below shows how the Artificial Recharge Strategy falls within the legislative framework.



A.2.1 Policy

The National Water Act, 1998 (No 36 of 1998), is based on the **National Water Policy for South Africa** (NWP), which in turn was guided by 28 Fundamental Principles and Objectives for a New South African Water Law. Three of these principles are pertinent to artificial recharge – Principles 7, 13 and 14:

Principle 7:	*The objective of managing the quantity, quality and reliability of the Nation's water resources is to achieve optimum, long-term, environmentally sustainable, social and economic benefit for society from their use.*
Principle 13:	*As custodian of the Nation's water resources, the National Government shall ensure that the development, apportionment, management and use of those resources is carried out using the criteria of public interest, sustainability, equity and efficiency of use in a manner which reflects its public trust obligations and the value of water to society while ensuring that basic domestic needs, the requirements of the environment and international obligations are met.*
Principle 14:	*Water resources shall be developed, apportioned and managed in such a manner as to enable all user sectors to gain equitable access to the desired quantity, quality and reliability of water. Conservation and other measures to manage demand shall be actively promoted as a preferred option to achieve these objectives.*

The terms reliability, sustainability and conservation, as contained in these Principles, provide the basis for pursuing artificial recharge as one of the means to meet the Nation's water supply and management objectives.

Three fundamental objectives for managing South Africa's water resources arise from these principles:

- To achieve equitable access to water, that is, equity of access to water services, to the use of water resources, and to the benefits from the use of water resources.
- To achieve sustainable use of water by making progressive adjustments to water use with the objective of striking a balance between water availability and legitimate water requirements, and by implementing measures to protect water resources.
- To achieve efficient and effective water use for optimum social and economic benefit.
- The concepts of sustainability and efficient and effective use are captured within these objectives. These are also fundamental principles for AR.

A.2.2 Legislation

The **National Water Act (NWA),** 1998 (No 36 of 1998), is the principal legal instrument relating to water resources management in South Africa and contains provisions for the protection, use, development, conservation, management and control of South Africa's water resources. In addition to the NWA, there are many other policies and laws administered by a number of Departments that affect water resources. Of particular relevance are:

- The **Water Services Act,** 1997 (No. 108 of 1997), which relates to the provision of water services by water services institutions including the safe disposal of effluent. The Water Services Act also requires that Water Services Authorities (WSA's) produce an annual water audit including details of water conservation measures.
- The **National Environmental Management Act,** 1998 (No. 107 of 1998) is relevant to the management of water resources within the context of national environmental principles and legislation.

The **National Environmental Management Act** (No. 107 of 1998) (NEMA) and as amended (No. 56 of 2002 and No. 8 of 2004) provides for the control of listed activities. The Government Notices R. 385, R. 386, and R. 387 published in Government Gazette No. 28753 on the 21st April 2006, and promulgated under Section 24(5) of NEMA, have replaced the environmental impact assessment (EIA) regulations that were promulgated in terms of the Environment Conservation Act, 1989 (Act No. 73 of 1989) in 1997 and introduce new provisions regarding environmental impact assessments.

The **Environment Conservation Act** (No. 73 of 1989) (ECA) previously provided for the control of certain listed activities that 'may have a detrimental effect on the environment'. These activities were listed in Government Notice R1182 of 5 September 1997 (as amended). The Act further prohibits such activities until written authorisation was obtained from the Minister or his delegated authority. The regulations published in terms of the National Environmental Management Act have replaced the ECA Environmental Impact Assessment regulations with effective from 3 July

2006. However the ECA remains in force as it relates to waste disposal, and the Outeniqua Sensitive Coastal Areas regulations.

While the NWA and the NEMA are the two primary acts that govern artificial recharge projects in South Africa, there is other legislation and local bylaws that may apply to specific projects. These include:

- Water Services Act (Act 108 of 1997)
- National Environmental Management: Biodiversity Act (Act 10 of 2004)
- National Environmental Management: Protected Areas Act (Act 57 of 2003)
- Mineral and Petroleum Resources Development Act (Act 28 of 2002)
- Dam Safety Regulations (published in Government Notice R. 1560 of 25 July 1986)
- Conservation of Agricultural Resources Act, 1983 (Act 43 of 1983)
- Promotion of Administrative Justice Amendment Act (Act 53 of 2002)
- National Heritage Resources Act (Act 25 of 1999).

A.2.3 Strategy

As required by the NWA, a **National Water Resource Strategy** (NWRS) has been developed (DWAF, 2004). The purpose of the NWRS as stated in the NWA (Part 1 – Sections 5 - 7) is to *"...provide the framework for the protection, use, development, conservation, management and control of water resources for the country as a whole"*. The final artificial recharge strategy will form part of the NWRS. Artificial recharge is one of the many ways in which water resources can be protected, used, conserved, managed and controlled.

The National Water Policy discusses the need for an integrated approach to water resource management, and the NWRS provides the context in which this should happen. Artificial recharge is a good example of an approach that integrates the use of surface and groundwater in an environmentally sustainable manner. Whether the source water is from rivers or dams, or whether it is recycled water (e.g. treated waste water), sub-surface storage and blending with groundwater is an effective way to integrate and optimise the use of various water sources.

Integrated water resources management (IWRM) is defined in the NWRS as more than just the joint management of surface and groundwater. It is seen as the holistic management of natural resources within the context of sustainable and equitable social, economic and environmental principles. The NWRS defines IWRM as "*...a process which promotes the co-ordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems"*. In this context, artificial recharge schemes generally fare favourably when compared with other water development options. A good example is the way in which artificial recharge combines the aspects of both natural water treatment and storage. This is a common goal in many parts of the world where the soils or aquifer media are suitable for both these purposes.

In most cases, artificial recharge schemes are cheaper or more cost-effective than the development of new surface water schemes (Pyne, 1995). This is usually because either they can be implemented incrementally (in phases) as the demand increases, or the capital costs are less, not requiring the construction of new water treatment works and reservoirs, and frequently being located near the point of use. Further, the environmental costs are usually favourable because the “foot print” on the landscape is relatively small compared with those of new surface water schemes.

The NWRS recognises that instituting IWRM is a complex and challenging process. In this regard, the Catchment Management Agencies (CMAs) will be tasked with, amongst other issues, ensuring that their water-related plans are consistent with the plans of all other role players in their particular catchments. This will require co-operation between all relevant institutions, organisations and individuals. Where groundwater resources (that have been artificially recharged) are accessible to a number of potential users who are located on or near the aquifer, such cooperation will be vital in order to prevent the misuse of the scheme.

At the local level, artificial recharge can be a significant tool in water conservation. Its advantages over dam development include smaller economic sizes and, in arid areas, significantly reduced evaporation losses and avoidance of the growth of blue-green algae that produce toxins. The concept of “wise use” and conservation is common to many internationally recognised goals. By creating an enabling environment for implementing artificial recharge schemes, South Africa is contributing to a number of international development goals and plans. Examples of these are:

Millennium Development Goals, which state among other goals that there should be environmental sustainability by 2015.

World Summit on Sustainable Development, Plan of Implementation, where it was agreed, among other issues, to develop IWRM plans by 2005 that would incorporate national/regional strategies, plans and programmes with regard to integrated river basin, watershed and groundwater management, and to introduce measures to improve the efficiency of water infrastructure to reduce losses and to increase recycling of water.

Southern African Vision for Water, Life and the Environment in the 21st Century, which strives towards, among other issues, a southern Africa where there is equitable and sustainable planning, use, development and management of water resources.

SECTION B:

THE ARTIFICIAL RECHARGE CONCEPT, ITS APPLICATION AND POTENTIAL

B.1 WHAT IS ARTIFICIAL RECHARGE?

B.1.1 Types of artificial recharge

A brief overview of terminology and descriptions of the major techniques is provided below (Dillon, 2005). These are represented in Figure B.1.

- **Aquifer storage and recovery (ASR)** – injection of water into a borehole for storage and recovery from the same borehole.
- **Aquifer storage transfer and recovery (ASTR)** – injection of water into a borehole for storage and recovery from a different borehole, generally to provide additional water treatment.
- **Bank filtration** – extraction of groundwater from a borehole, well or caisson near or under a river or lake to induce infiltration from the surface water body thereby improving and making more consistent the quality of water recovered.
- **Dune filtration** – infiltration of water from ponds constructed in dunes and extraction from boreholes, wells or ponds at lower elevation for water quality improvement and to balance supply and demand.
- **Infiltration ponds** - ponds constructed usually off-stream where surface water is diverted and allowed to infiltrate (generally through an unsaturated zone) to the underlying unconfined aquifer.
- **Percolation tanks** – a term used in India to describe harvesting of water in storages built in ephemeral streams where water is detained and infiltrates through the base to enhance storage in unconfined aquifers and is extracted down-valley for town water supply or irrigation.
- **Rainwater harvesting** – roof runoff is diverted into a borehole, well or a caisson filled with sand or gravel and allowed to percolate to the water-table where it is collected by pumping from a borehole or well.
- **Soil aquifer treatment (SAT)** – treated sewage effluent, known as reclaimed water, is intermittently infiltrated through infiltration ponds to facilitate nutrient and pathogen removal in passage through the unsaturated zone for recovery by boreholes after residence in the aquifer.
- **Sand dams** – built in ephemeral streams in arid areas on low permeability lithology, these trap sediment when flow occurs, and following successive floods, the sand dam is raised to create an “aquifer” which can be tapped by boreholes in dry seasons.
- **Underground dams** – in ephemeral streams where basement highs constrict flows, a trench is constructed across the streambed keyed to the basement and backfilled with low permeability material to help retain flood flows in saturated alluvium for stock and domestic use.
- **Recharge releases** – dams on ephemeral streams are used to detain flood water and uses may include slow release of water into the streambed downstream to match the capacity for infiltration into underlying aquifers, thereby significantly enhancing recharge.

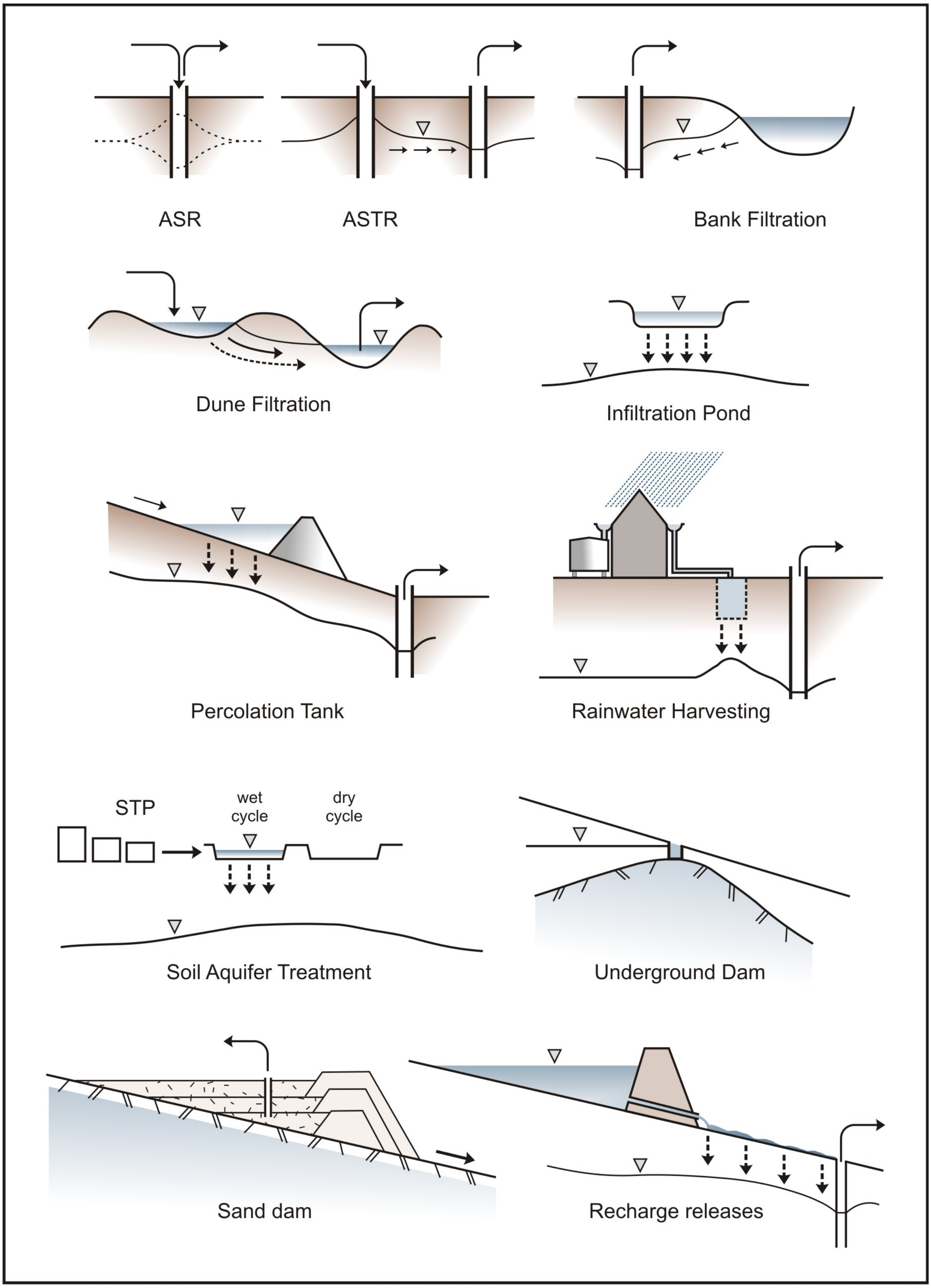


Figure B.1: Schematic of types of management of aquifer recharge

(After Dillon, 2005)

B.1.2 Aquifer and artificial recharge storage

For the purposes of quantifying groundwater and conceptualising the proportion that should be allocated for use, aquifer storage is divided into dynamic and static components. The dynamic part is that which naturally fluctuates as a result of inflows (natural recharge and lateral inflows) and outflows (discharge as springs, etc). The static part is the deeper and older water that lies below the dynamic component. The question that will need to be addressed in many artificial recharge schemes is what portion of the dynamic and static storage should be allocated for use? Should it only be a proportion of the dynamic storage? If so, the potential benefits may be limited. Or, should it also utilise a proportion of the static storage? In this case, the potential storage will be maximised, but the environmental costs may be prohibitive. Box B.1 adapted from DWAF's Groundwater Resource Assessment II Project (DWAF, 2005) provides an overview of the storage levels in an aquifer.

The proportion of aquifer storage available for use in artificial recharge schemes is a management choice based mostly on water volumes, environmental implications and economics.

Box B.1: Concepts of groundwater storage

Groundwater storage can be grouped into static and dynamic storage:

Static storage *Level 1* Bottom of the aquifer
Level 2 Bottom of the natural dynamic groundwater elevation
Dynamic storage *Level 3* Current groundwater elevation
Level 4 Average groundwater elevation
Level 5 - Top of the aquifer.

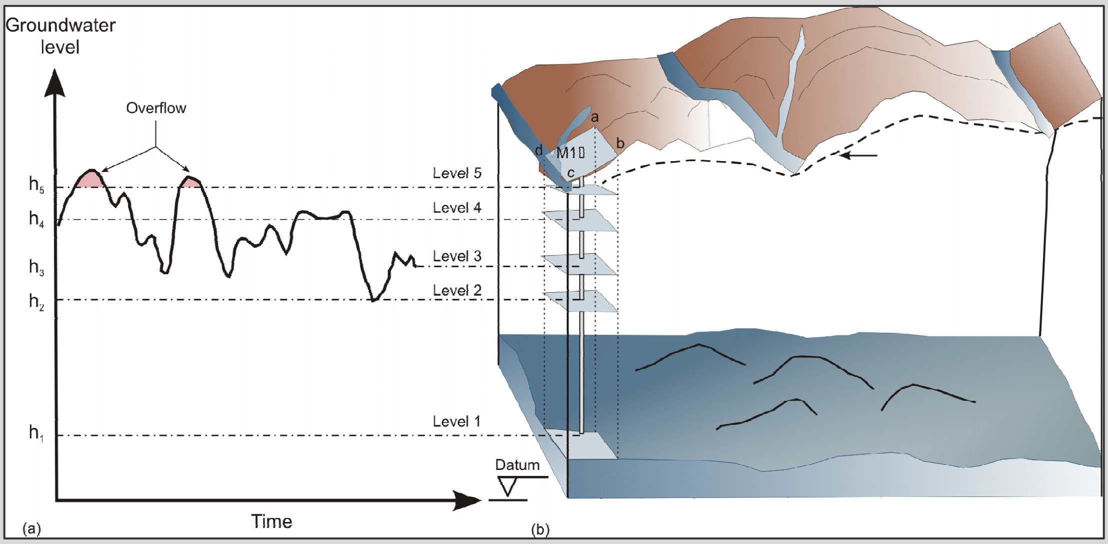
A schematic representation of these levels is presented below for an elementary grid, abcd, located around the monitoring borehole, M1. The elevations of the levels 1 to 5 vary spatially. The volume bound between the layers reduced by an appropriate storage coefficient gives groundwater storage (V). The mathematical expression for groundwater storage is:

$V = A\Delta hS$

where A is the area of the aquifer (m^2), Δh is the thickness between any two layers of interest and S is the coefficient of storage (dimensionless).

If:

(i) $\Delta h = h_5 - h_1$, gives the maximum groundwater storage;
(ii) $\Delta h = h_4 - h_1$, gives the average total groundwater storage;
(iii) $\Delta h = h_4 - h_2$, gives the average dynamic groundwater storage;
(iv) $\Delta h = h_3 - h_2$, gives the current dynamic groundwater storage;
(v) $\Delta h = h_2 - h_1$, gives the static storage.



(a) Hydrograph of monitoring borehole M1, and (b) Schematic presentation of the physical layers

(Source: DWAF, 2005)

B.1.3 Applications, benefits and constraints of artificial recharge

Water stored in the sub-surface can be used to meet domestic, agricultural, industrial and environmental needs. Although sizeable artificial recharge schemes exist that cater for large city and agricultural water supplies, artificial recharge has the advantage over dams in that its economic size can range as low as 1 000 m^3/a whereas dams may need to be several orders of magnitude larger to become economic (Dillon, 2005). In arid areas, dams have significant evaporation losses and may allow growth of blue-green algae that produce toxins. Desalination costs are decreasing, but desalination remains a relatively energy-intensive activity and needs a high level of technical support to maintain operations. Table B.1 summarises key comparative issues of various water supply sources.

Table B.1: Factors affecting technology choice for water supply

Method	Typical scale (m^3/a)	Limits	Relative capital costs	Relative investigation costs	Relative technical. knowledge needed	Relative regulation difficulty
Rainwater tanks	Family 10 –10^2	Fails in droughts	*	*	*	*
Springs	Family/village 10^3 –10^4	Can fail in droughts	**	*	*	*
Groundwater	Village/town 10^4 –10^6	Needs aquifer	***	**	**	**
AR	Village/town 10^3 –10^6	Needs aquifer	****	***	***	***
Dam and treatment plant	Region 10^7 –10^9	Needs dam site	*****	****	***	***
Desalination	Town/region 10^3 –10^7	Needs power and brine discharge	*****	**	****	**

(Adapted from Dillon, 2005)

The applications, benefits, constraints, risks and disadvantages listed below are primarily derived from Pyne (1995), Jones *et al* (1998) and Murray and Tredoux (1998).

B.1.3.1 Applications and benefits

Applications of artificial recharge are summarised in Table B.2 and are then briefly described. Depending on the water management goals or the severity of the problem, other water management measures may be required in addition to artificial recharge.

Table B.2: Applications and benefits of artificial recharge

Maximise natural storage	Water quality management
• Seasonal storage • Long-term storage ("water banking") • Emergency storage • Diurnal storage	• Water quality improvement • Disinfection by-products (DBPs) reduction • Nutrient reduction in agricultural runoff • Stabilization of aggressive water by storage in calcium carbonate aquifers
Physical management of the aquifer	**Ecological benefits**
• Restoration of groundwater levels • Reduction of land subsidence • Prevention of saltwater intrusion • Enhancement of wellfield production • Hydraulic control of contaminant plumes	• Reduce abstraction from rivers • Maintain the Reserve (maintain groundwater levels and in-stream flow requirements) • Minor environmental imprint • Minimal land use • Temperature control (e.g. for industry)
Management of water distribution systems	**Other benefits**
• Maintenance of distribution system flow & pressure • Storage of treated water	• Defer expansion of water facilities • Storage of reclaimed water • Utilise saline aquifers • Storage of huge quantities of water • Rapid implementation and staged development • Low capital cost • Mitigate effects of climate change • Savings on evaporation

B.1.3.1.1 Maximise natural storage

1) **Seasonal storage.** Water is stored during wet months when it is available and recovered during dry months.

2) **Long-term storage (water banking).** Water is stored during wet years, or during years when new supply, treatment and distribution facilities have spare capacity, and is recovered during dry years, or when the capacity of existing treatment facilities is inadequate to meet the demand. Water banking not only provides security against droughts, but it also provides security against uncertainty in future assurances of supply due to climate change.
3) **Emergency storage.** Water is stored locally to provide an emergency supply or strategic reserve when the primary source of supply is unavailable. This is appropriate for systems that rely on a single source and a long transmission pipeline.

4) **Diurnal storage.** Where daytime demands exceed supply capacity, night-time local storage is an option (similar to the operation of some hydroelectric plants).

B.1.3.1.2 Water quality management

1) **Improve water quality.** Certain artificial recharge schemes are designed specifically to improve water quality (e.g. soil aquifer treatment schemes and bank filtration schemes). In such cases and in schemes where the primary goal is storage, improvements in water quality can be significant. Examples include the reduction of nitrate, iron, manganese, hydrogen sulphide, pH stabilisation and softening.
2) **Disinfection by-products reduction.** A drawback of chlorinating water prior to recharge is the formation of carcinogenic disinfection by-products (DBPs) such as trihalomethanes (THMs) and haloacetic acids (HAAs). Recent research, however, has shown that DBPs do attenuate during aquifer storage (Gerges, 1996; Toze *et al*, 2001; Pyne, 1998).
3) **Nutrient reduction in agricultural runoff.** Sub-surface storage of agricultural runoff (causing eutrophication of lakes and reservoirs) can reduce nitrogen concentrations through bacterial denitrification. Some aquifers can reduce phosphorus concentrations through physical-chemical and bacteriological mechanisms.
4) **Stabilize aggressive water.** Aggressive water is frequently treated with calcium carbonate. This can be done naturally by storage in suitable limestone aquifers.

B.1.3.1.3 Physical management of the aquifer

1) **Restore groundwater levels.** Continuing trends in water level decline can be reversed.
2) **Reduce subsidence.** Restoring groundwater levels can reduce land subsidence.
3) **Prevent saltwater intrusion.** Placing recharge facilities between wellfields and the coast or saline aquifers can restrict the movement of the saltwater intrusion front.
4) **Enhance wellfield production.** By enhancing recharge, it is possible to abstract water at higher rates during peak demand months than the long-term sustainable yield of the aquifer.
5) **Hydraulic control of contaminant plumes.** Optimal placing of recharge facilities can create the necessary hydraulic conditions to prevent the migration of contaminant plumes.

B.1.3.1.4 Ecological benefits

1) **Reduce abstractions from rivers.** Surface water stored in aquifers during wet months would lead to lower stream diversions during the dry months.
2) **Maintain the Reserve.** The Reserve could be supported by maintaining groundwater levels and in-stream, low-flow requirements. For example, river water could be transferred to infiltration trenches parallel to rivers during wet months. The water would slowly return to the rivers thereby enhancing flow during the dry months.
3) **Minor environmental imprint.** Artificial recharge offers a means to store and abstract water with minimal environmental impact. Where confined aquifers are used (as is the case with many ASR schemes), there is minimal impact on surface water courses.
4) **Minimal land use.** Artificial recharge schemes, and in particular those that employ borehole injection, require relatively small surface areas. For borehole injection schemes, the land use is measured in square metres, whilst the size of equivalent reservoirs would

be tens of hectares. For example, a borehole injection scheme extending over a few square metres that stores 1Mm^3 is equivalent to a surface reservoir of 4 m depth by 500 m by 500 m. The cost, planning, engineering and environmental issues associated with the latter development are of a far greater scale than borehole injection schemes.

5) **Temperature control.** The relatively stable temperatures of the subsurface can be used to maintain water temperatures for industry (e.g. for fish hatcheries).

B.1.3.1.5 Management of water distribution systems

1) **Maintenance of distribution system flow and pressure.** Optimally located artificial recharge schemes (usually at the ends of long distribution pipelines) can be used to meet seasonal peak demands at maintain adequate pressures in the supply pipelines. They can also be used to maintain a disinfection residual.
2) **Storage of treated water.** Storing treated water allows for the supply of water at a rate greater than the capacity of the treatment plant. This allows for the sizing of water treatment works closer to the average needs rather than the peak requirements.

B.1.3.1.6 Other benefits

1) **Defer expansion of water facilities.** By optimising conjunctive use of surface and groundwater, and by using artificial recharge principles, expansion of surface water facilities can be deferred, with substantial cost savings. It may be possible to make more efficient use of existing investment in treatment and conveyance capacity by operating these facilities at full capacity throughout the year, and throughout the life of the facility (by incorporating artificial recharge into systems management).
2) **Storage of reclaimed water.** High quality reclaimed water can be stored in fresh or brackish aquifers for reuse. The stored water can be used for a variety of purposes, depending on its quality and post-treatment facilities.
3) **Utilise saline aquifers.** Many ASR schemes utilise saline aquifers that were previously not considered an asset. A fresh water bubble is created around the point of injection, and water quality is managed according to specific targets. The Marathon scheme in Florida, USA, is an example of an ASR scheme where drinking water is stored in a seawater aquifer.
4) **Storage of huge quantities of water.** Aquifers can store huge quantities of water. Table B.3 gives an indication of the orders of magnitude depending on aquifer type and extent.

Table B.3: Aquifer storage potential

Aquifer type	Aquifer size (thickness x length x breadth)	Storage coefficient	Volume of water stored (Mm^3)
Sand	20 m x 5 km x 5 km	0.1	50
Hard-rock		0.003	1.5
Sand	40 m x 10 km x 10 km	0.1	400
Hard-rock		0.003	12

5) **Rapid implementation and staged development.** Implementation of artificial recharge schemes is generally rapid in comparison with surface water schemes. Borehole injection schemes typically become operational within three years of scheme conceptualisation (Jones, *et al*, 1998). An additional advantage is that it is possible to develop schemes incrementally as the demand arises. Initially, one or two boreholes may be used in ASR or ASTR schemes, with expansion to wellfield scale as required.
6) **Low capital cost.** The **overall** costs of artificial recharge operations are invariably much less than the capital cost of conventional water supply alternatives, especially those involving the development of new reservoirs, treatment facilities or extensive pipelines (National Research Council, 1994; Pyne, 1995).
7) **Mitigate effects of climate change.** Groundwater recharge and storage is expected to decline over the semiarid and arid regions of Southern Africa under currently accepted climate change scenarios (Cave et al, 2003). These changes will require alternative groundwater management practices to control impacts, particularly in situations of groundwater dependency. Artificial recharge may become a useful technology under these conditions.
8) **Savings on evaporation.** Water stored in an aquifer is not subjected to same water losses through evaporation associated with water stored in dams, which can be significant depending on dam location and surface area.

B.1.3.2 Constraints, risks and disadvantages

It is not possible to implement artificial recharge schemes in all environments. The successful implementation of these schemes is based on a number of criteria that are discussed in Section C. If the necessary assessment of these criteria is undertaken to a sufficient level of confidence, then the risk of scheme failure is small. However, in some cases, the scale (and sometimes, the nature) of the drawbacks only become apparent during operation. In the feasibility stage of artificial recharge projects, most potential drawbacks are, however, identified and an assessment of their severity is made. The ability to deal with the drawbacks usually hinges on economic and management factors.

The drawbacks of implementing artificial recharge usually fall within the following concerns:

1) **Clogging.** Artificial recharge of groundwater generally results in an increased resistance to flow near the point of recharge. This is a result of clogging or plugging, which results in a decreasing rate of recharge or the need to continually increase the recharge head to maintain a constant recharge rate. Clogging can be caused by physical factors (such as air entrapment and suspended matter), bacteriological factors and chemical factors. Clogging also has a negative impact on the recovery of artificially recharged water, since it increases drawdown during pumping (if the recovery borehole is clogged).
2) **Uncertainty in aquifer hydraulics.** In the case of new artificial recharge schemes that involve deep-seated aquifers or saline aquifers, little will be known about the aquifers' hydraulic properties. This will either mean that intensive research should be conducted on the aquifer prior to implementation, or that an extensive monitoring system is installed, and that the project be commissioned with an acceptable level of risk.

3) **Recovery of stored water.** Where the characteristics and extent of the aquifer are known in sufficient detail, water levels can be managed to prevent losses of recharged water. *Recovery efficiency* is of concern in borehole injection schemes where the quality of the recharge water and the native groundwater are vastly different. In the case of ASR systems, recovery efficiency is defined as the percentage of water volume stored that is subsequently recovered, while meeting a target water quality criterion (Pyne, 1995). The water quality criteria are typically total dissolved solids (TDS), electrical conductivity (EC) or chloride concentration. Most schemes can be developed to 100 percent recovery efficiency, except those in very transmissive, highly saline aquifers which typically reach 70 to 80 percent efficiency (Pyne, 1995).

4) **Controlled recovery by different users.** The concept of whoever stores the water has the right to recover it is generally accepted throughout the world. It would be highly problematic if there was uncontrolled usage of the stored water.

5) **Regulatory constraints.** Storage of water in the sub-surface needs to comply with the country's water and environmental legislation. In certain circumstances, Departmental approval of a scheme may take a long time, or even be prevented, since implementation of new legislation is untested in relation to artificial recharge.

6) **Damage to aquifers.** This concern refers to the negative effects of recharge such as the precipitation of solids, the dissolution of aquifer material and of contaminants such as arsenic. Precipitation has been observed near ASR boreholes, evident as clogging, but has not been observed as widespread aquifer clogging. The dissolution of arsenic has been observed in a number of instances, and needs to be assessed in the feasibility stage of most projects. Aquifer collapse, due to large-scale dewatering during the recovery stage of the artificial recharge cycle, may be a concern for specific aquifer types (such as unconsolidated, unconfined aquifers). Most artificial recharge schemes around the world are in these types of aquifer, but this problem has not been widely observed.

7) **High outlay before feasibility of ASR can be established.** In certain circumstances (e.g. where there is a poor understanding of the hydraulic properties of the aquifer), it may require a high financial outlay in order to establish the feasibility of the scheme. This will need to be compared with the feasibility studies required for other options.

8) **Operational issues.** Lack of experience in South Africa is an obstacle to artificial recharge development.

9) **Environmental concerns relating fluctuating groundwater.** Artificial recharge could result in groundwater levels being raised above and below the norm, and this can have negative environmental consequences such as affecting groundwater level dependant ecosystems, increased aquifer vulnerability to contamination and sinkhole formation in dolomitic aquifers.

B.2 INTERNATIONAL EXPERIENCE

This section draws on international experience on the value of artificial recharge in water resource planning and management. Case studies are presented that include both site-specific examples, where artificial recharge schemes have been incorporated into the overall water management strategy for the area, town or city, and regional examples, where artificial recharge is considered on a national or regional scale as a water conservation measure.

There appears to be few official planning documents that incorporate artificial recharge within water resource management. This is probably because artificial recharge is largely considered as a localised solution to water problems and relevant documents are mostly artificial recharge feasibility studies that incorporate artificial recharge within the context of the broader water needs.

AR is not a new concept. For centuries, nomads of the Kara Kum Plain desert in Turkmenistan have enhanced recharge by diverting infrequent surface runoff from clay-rich areas to pits dug into porous sandy areas via long trenches. In Europe, artificial recharge schemes have been in operation for over a hundred years. At Mt Gambier in Australia, surface runoff has been diverted into limestone pits and wells for over a hundred years. The scheme is still an integral part of the city’s water supply system.

Although artificial recharge is practised throughout the world, much of the literature, research and guideline documents are sourced in Europe, the USA, Israel and Australia. Countries such as India, Pakistan, Kuwait, Japan, Namibia and many others, have contributed to the international pool of knowledge in various degrees, usually, but not exclusively, with well documented case studies. Experience, lessons and future artificial recharge plans from a few countries are described below to highlight points of relevance to South Africa.

B.2.1 ASR in the USA

B.2.1.1 Introduction

The USA has a long history of both infiltration and injection schemes. Text books, guideline documents, regulations and many case studies have emerged from the USA, particularly over the past two decades. This section focuses on ASR schemes in the USA, of which the oldest, a seasonal storage scheme in New Jersey, has been in operation since 1968. In most cases, the aquifers used for storage are confined, that is, they have a relatively impermeable layer above them, and the ASR boreholes are drilled through this layer into the most porous and permeable parts of the aquifer (Figure B.2).

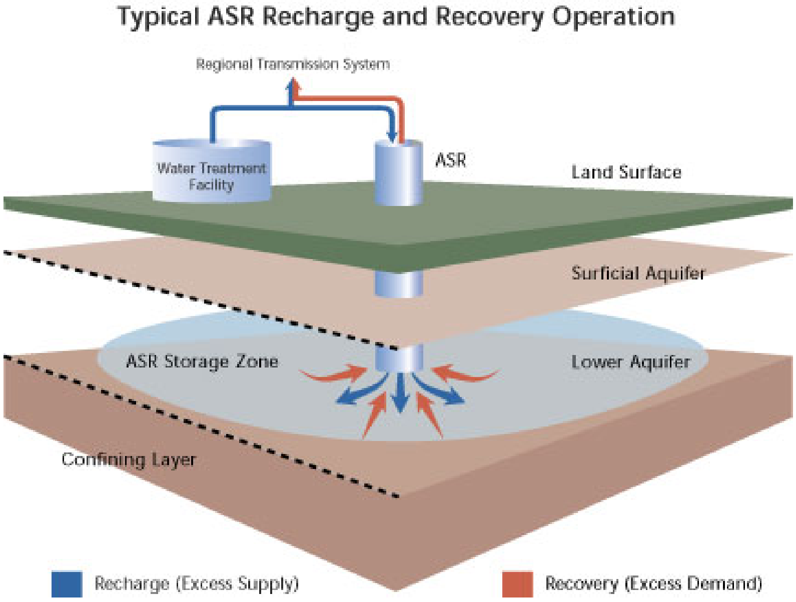


Figure B.2: Typical ASR recharge, storage and recovery operation

(Source: www.regionalwater.org)

There has been a noticeable increase in the number of ASR schemes during the past 20 years (Figure B.3). A recent survey shows that in 2001, there were 30 operational schemes and a further 10 pilot studies being conducted (AWWA, 2002). Most of the current ASR schemes involve potable water and are designed to increase the efficiency of water system operation.

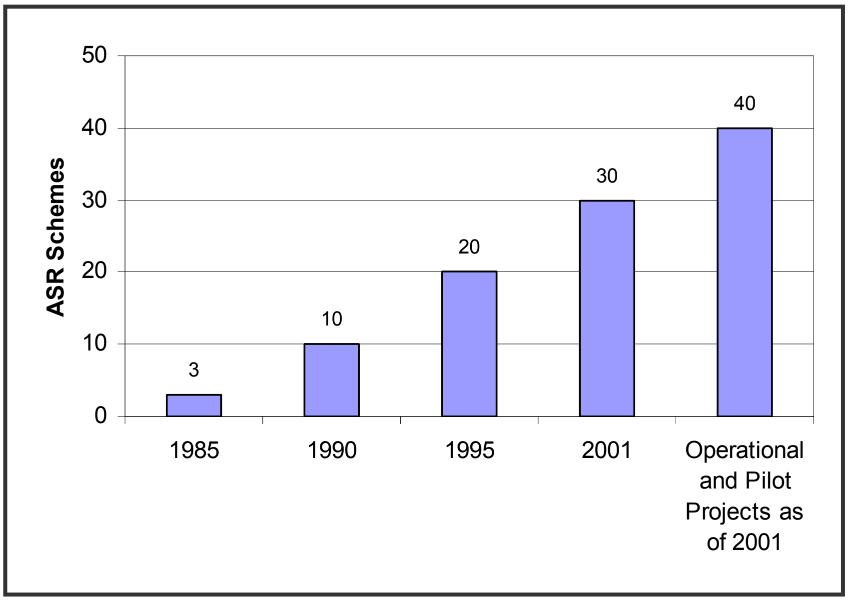


Figure B.3: Historical development of ASR schemes in the USA

(Source: AWWA, 2002)

Together with the increase in ASR schemes, there has been a recent shift toward incorporating ASR to meet larger, regional objectives rather than isolated boreholes here and there to meet local needs. Project plans are getting larger, as in the Florida Everglades restoration – 6.4 Mm^3/day with 330 boreholes; New York City – 0.85 Mm^3/day; Calleguas Metropolitan Water District, California - 0.23 Mm^3/day; and San Antonio Water System, Texas – 0.23 Mm^3/day (D. Pyne, *pers comm*). The largest existing ASR operation is in the Las Vegas Valley Water District. This has an ASR recovery capacity of 0.59 Mm^3/day (D. Pyne, *pers comm*).

The American Water Works Association (AWWA) survey shows that most schemes are used primarily for municipal supplies (Figure B.4) and for seasonal storage (Figure B.5). Many of the schemes have secondary benefits such as the recovery of groundwater levels, prevention of saltwater intrusion, protection of endangered species habitat, improvement of groundwater quality and use of surface water allocations.

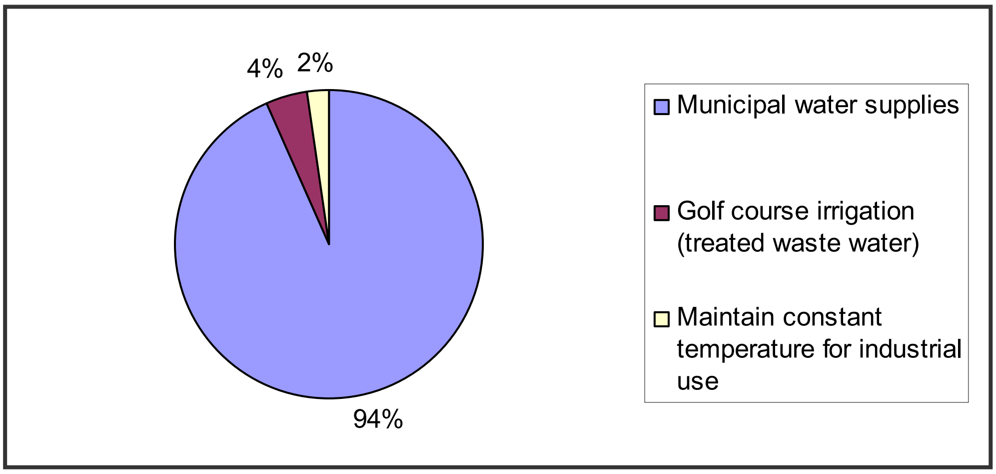


Figure B.4: Uses of ASR schemes

(Source: AWWA, 2002)

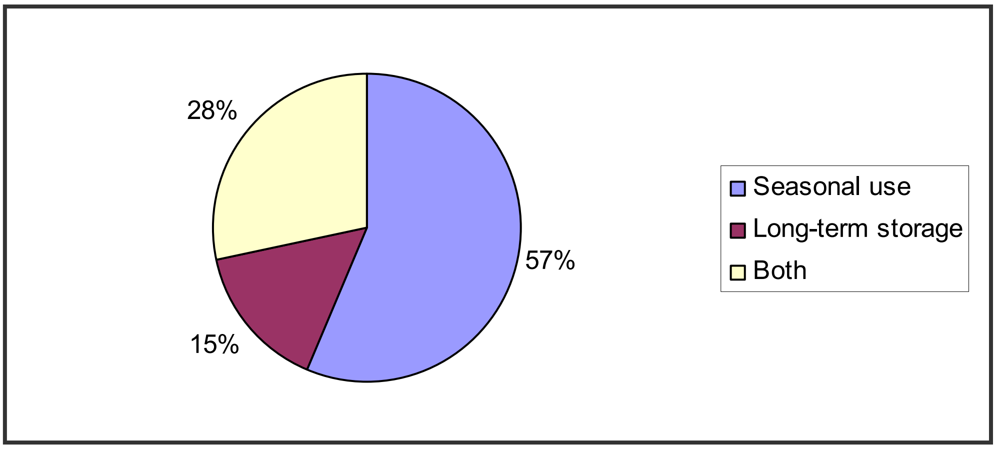


Figure B.5: Use of ASR schemes in relation to duration of storage

(Source: AWWA, 2002)

The survey indicated that, in most cases, the water source is surface water (Figure B.6). Interestingly, a number of schemes involve transferring groundwater from one aquifer to another. Presumably, this is a form of balancing storage or creating fresh water storage in a saline aquifer.

Of the water sources that have already been treated to meet drinking water standards, only a few are further treated prior to injection (Figure B.7).

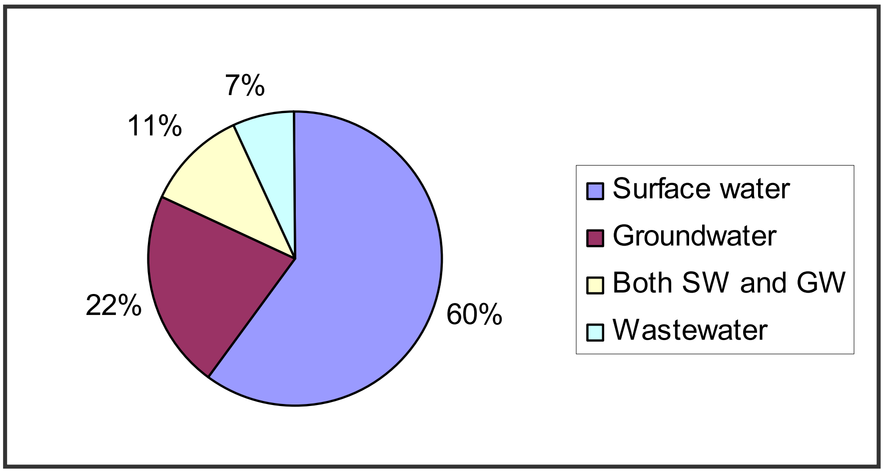


Figure B.6: Source water for ASR schemes

(Source: AWWA, 2002)

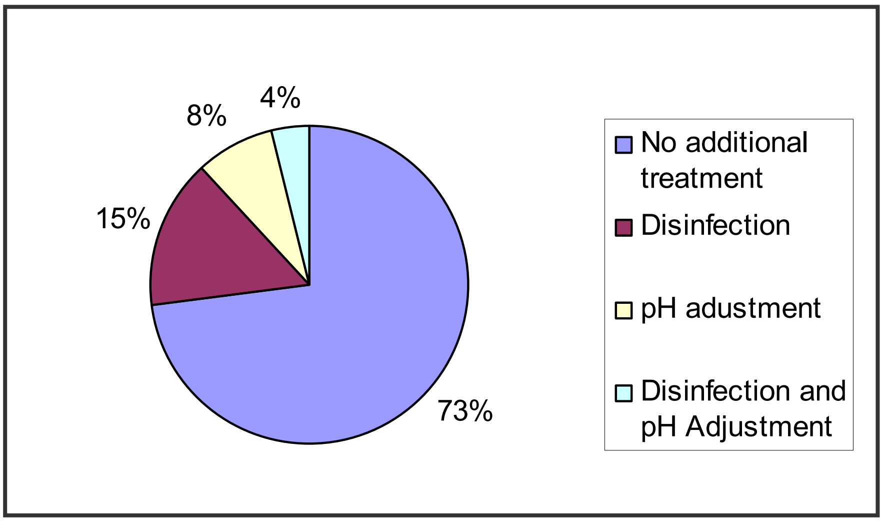


Figure B.7: Pre-injection treatment methods at potable water ASR schemes (beyond existing treatment)

(Source: AWWA, 2002)

Most of the potable ASR schemes do not require post-treatment prior to supply (Figure B.8).

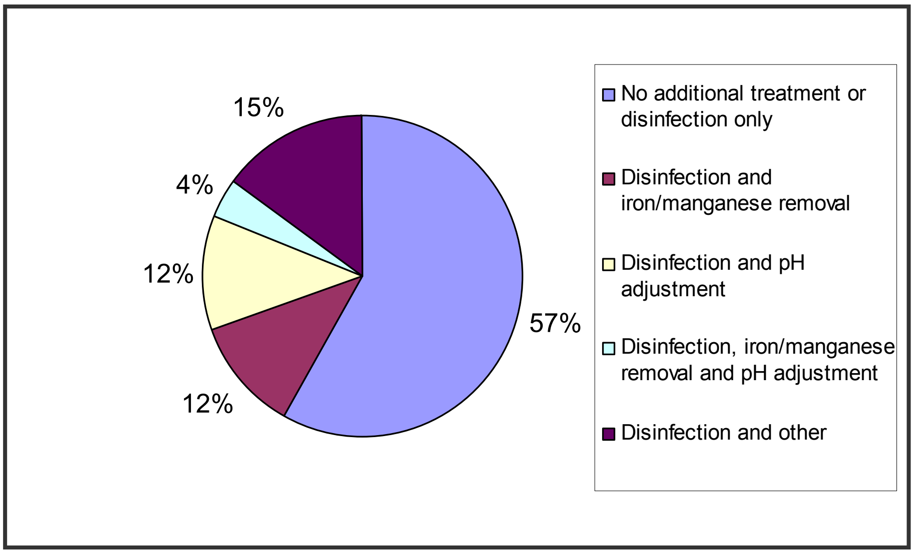


Figure B.8: Post-injection treatment methods at potable water ASR schemes

(Source: AWWA, 2002)

Sources of information:

- AWWA, 2002
- www.regionalwater.org
- D. Pyne, *personal communication*

B.2.1.2 Peace River, Florida: Large scale ASR in a limestone aquifer

The Peace River ASR scheme is described because it is an example of a large-scale water conservation measure that uses artificial recharge principles and a brackish aquifer. It is in a limestone aquifer with some similarities to the dolomites that are fairly extensive in the Gauteng and North West Provinces. Both its aquifer geochemistry and hydraulic parameters are comparable to some South African dolomitic aquifers, although the Peace River limestones are deep-seated and confined by overlying low-permeability formations. A schematic diagram of the water transmission and storage process is shown in Figure B.9 and described in Table B.4.

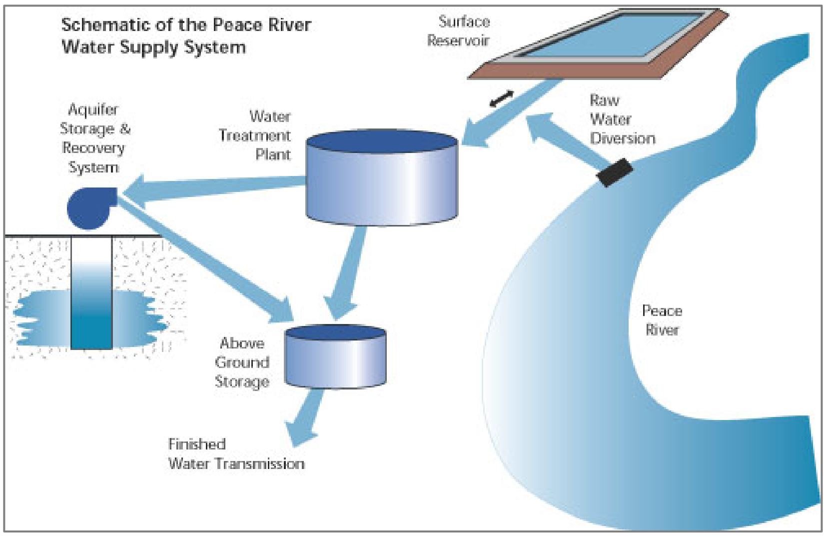


Figure B.9: Peace River Water Supply System Model

(Source: www.regionalwater.org)

Table B.4: Key features of the Peace River Water Supply System

Scheme	Peace River
Purpose	Primary: Seasonal storage Secondary: Water banking
Aquifer	Two limestone aquifers: Upper: 122 – 152 m deep (30 m thick) Transmissivity: 450 m^2/day; storativity: 0.0004 Lower: 174 – 274 m deep (100 m thick) Transmissivity: 560 m^2/day; storativity: 0.0001
Source water	Peace River. The variable flows and quality mean no diversions are allowed for periods of up to 7 months. Water is stored in the aquifer to cover these periods.
Pre-treatment	Water is treated to domestic standards prior to injection
Water quality	Recharge water (average): Conductivity: 47 mS/m Alkalinity (as $CaCO_3$, mg/L): 50 Groundwater: Conductivity: 122 mS/m Alkalinity (as $CaCO_3$, mg/L): 143
Post treatment	None
Injection/recovery capacity	Injection and recovery capacities per borehole: 2000 – 4000 m^3/day
Injection/recovery history	In the main ASR area, a storage volume of 6 400 Mm^3 has been developed during the past 19 years (81 percent of the target storage volume).
Clogging management	Seasonal back-flushing of boreholes
Recovery efficiency	100%
Implementation stages	1985: 2 ASR boreholes (~6 000 m^3/day) 1988: Additional 4 ASR boreholes (~18 000 m^3/day) 2005: 21 ASR boreholes in total with a combined recovery capacity of 68 000 m^3/day.
Key opportunities and challenges	By deferring or eliminating the need for surface reservoir expansion and relying instead on sub-surface storage, this system is expected to meet regional water demands at less than half the capital cost of other water supply alternatives. Recent elevated arsenic concentrations (in some areas) have led to post treatment, and research into assessing ways of minimising these concentrations. In other areas, the arsenic concentrations have decreased.
Planning process	Planning through the Regional Water Supply Authority has resulted in a comprehensive and phased approach to ensuring the long-term sustainability of water supplies (including the implementation of water conservation measures) and the needs of the environment. A major part of the water supply augmentation plans is to maximise sub-surface storage. The aim is to store excess water during high river flow and withdraw less water from the river during the dry months. By expanding the ASR facilities, they will maximise existing capital investments and enable the Peace River Facility to operate at full capacity.

Sources of information:

- Pyne, 1995
- Pyne, 2005
- www.regionalwater.org

B.2.1.3 Kerrville, Texas: ASR in a sandstone and conglomerate aquifer

The Kerrville ASR scheme is an effective and financially attractive approach to meeting seasonal and long-term water security needs. Prior to implementing artificial recharge, groundwater levels dropped by 100 m due to over-abstraction from this sandstone and conglomerate aquifer. The hydraulic parameters of the aquifer are comparable with some South African sandstone aquifers, although the Kerrville sandstones have primary porosity, whereas most South African sandstones only have secondary (fracture) porosity.

Table B.5: Key features of the Kerrville, Texas, ASR Scheme

Scheme	Kerrville
Purpose	Primary: Seasonal storage Secondary: Water banking
Aquifer	Sandstone and conglomerate aquifers Transmissivity: 90 m^2/day; storativity: 0.0007
Source water	Treated surface water
Pre-treatment	Water is treated to domestic standards prior to injection
Water quality	Groundwater and injectant are of similar quality
Post treatment	None
Injection/recovery capacity	Injection and recovery capacities per borehole: 3000 – 6000 m^3/day
Injection/recovery history	Currently the ASR wellfield has 1.6 Mm^3 in storage, with a peak day combined recovery capacity of about 9 500 m^3/day. System peak day demand is typically about 11 300 m^3/day, so the ASR capacity provides substantial water supply reliability.
Recovery efficiency	N/A (Recovery efficiency percentages are only relevant when the two waters are of different quality; here they are similar)
Implementation stages	The current target storage volume is 5.7 Mm^3 to achieve drought security and to meet the projected 2040 demand. The implementation cost of the scheme to meet this target is ~US $3M, compared with $30M for off-stream reservoir construction.
Planning process	In 2002, the City of Kerrville, Texas adopted the *Kerrville Comprehensive Plan – A Link to the Future* as a statement of the City's vision for the future. As part of meeting the city's long-term water security goals, it has adopted water conservation measures and the expansion of the ASR scheme.

Sources of information:

- Pyne, 1995
- Pyne, 2005

B.2.1.4 Main lessons from the USA

Probably the best “judge” of ASR schemes are the operators themselves – the agencies responsible for day-to-day operations and scheme maintenance. Many of these agencies also operate other schemes, including surface water schemes, and they are thus well-placed to have a good perspective of a range of different schemes. Key perceptions, issues and concerns raised by 46 operators in the AWWA ASR survey (AWWA, 2002) are summarised below.

Satisfaction with ASR schemes

One of the 46 respondents stated that his scheme would not use ASR again, as there were geological constraints that had prevented the system from operating as planned. In this case, it is presumed that either the permeability or storage capacity of the aquifer is not suitable for ASR; or that the recovery of the water is problematic due to steep hydraulic gradients or uncertainty in groundwater flow characteristics; or that there are problem constituents in the aquifer such as arsenic. Three respondents had reservations due to cost-benefit ratios and lower than expected pressure heads in the aquifers. The remaining respondents were satisfied, although three respondents stated that they would make changes to how they would develop their systems. Figure B.10 shows that 89 percent of ASR operators were satisfied with the ASR schemes.

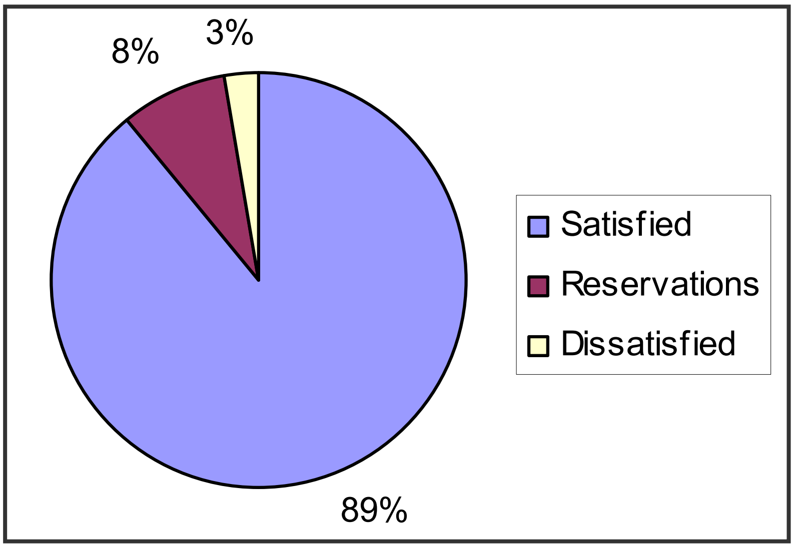


Figure B.10: Satisfaction with ASR schemes

(Source: AWWA, 2002)

Benefits of ASR

The benefits relating to the importance of ASR and specifically emphasised by ASR operating agencies are:

- Water conservation and reuse (especially in states that allow treated effluent ASR)
- Recovery of groundwater levels
- Prevention of saltwater intrusion

- Increasing the capacity to meet water demands while minimising impacts on the environment and protected species habitat (particularly in comparison with surface reservoir development)

Challenges

The most common challenges identified are:

- Permitting issues
- Geochemical problems
- Geological constraints (e.g. low permeability, low storage capacity, poorly understood groundwater flow characteristics)
- Water rights issues (ownership of injected water)
- Public relations.

Some agencies reported problems with:

- Clogging (which is more common when the recharge water is not of drinking quality)
- Lower than expected yields.

All these challenges are likely to apply to the South African situation. In many instances, ASR agencies indicated that there would have been value in extending the pilot test stage of the projects (particularly where geochemical problems were anticipated), as this would have affected the design of the schemes, and ultimately made the operation and maintenance more efficient and cost-effective. A key lesson from this is that feasibility studies need to be sufficiently comprehensive to allow a good indication of the viability of the schemes.

Regulatory issues

A key concern causing much frustration among ASR operators is the issue of regulation and permitting. Each state has different regulations, and those states where ASR is being introduced need to develop their own regulations. One Californian ASR facility requires permits from 14 separate agencies for that facility (including the US Environmental Protection Agency and the state Department of Health).

Because artificial recharge is relatively new in South Africa, and because of the new water and environmental legislation, the challenge will be to strike a balance between maintaining the impetus for implementing artificial recharge schemes and meeting water and environmental legal requirements.

Sources of information:

- AWWA, 2002
- Pyne, 1995
- Pyne, 2005

B.2.2 USA: Conjunctive Management of Surface and Ground Water in Utah

This is a very informative document on artificial recharge, and on Utah's strategies for incorporating artificial recharge into conjunctive management. Examples of topics covered are:

- Consequences of declining groundwater levels (including economic, environmental and water quality costs)
- Examples of past and present conjunctive management experiences
- Project implementation stages
- Utah Ground Water Recharge and Recovery Act

Utah has a history of investigating conjunctive management and aquifer storage and recovery (ASR) technology. Starting in 1936 and continuing intermittently to the present, numerous experiments and studies have been conducted. Conjunctive management strategies were employed in some areas simply because it made sense to do so. Despite this history only three specific projects involving managed aquifer recharge have been put into operation. This can probably be explained by over a century of steady implementation of surface water development projects. Further, conjunctive management and managed aquifer recharge require an understanding of groundwater conditions, which can be difficult.

Groundwater is out of sight, out of mind, and can be hard to define and understand. In the past, this complexity has been something of an impediment to ground water development. It is reasonable that surface water development would come first and groundwater development would come later. However, continuous development over time has brought improved pumping and underground investigation technology, expanded geologic exploration throughout the state, and the introduction of managed aquifer recharge technology. These have all made conjunctive management much easier to implement. It has also been demonstrated to be very cost effective compared to surface water development alternatives. Moreover, the possible overdraft of aquifers has created concern. Yet the demand for water increases and will continue to increase. Action today is needed to be ready for tomorrow.

Conjunctive management is a proven technology employed throughout the world, including about 70 ASR projects, with over 290 ASR wells, operating in the United States. Many more are in various stages of development. Conjunctive management strategies are among the next logical steps to more fully develop Utah's water resources.

The document concludes with two recommendations:

1) Take Immediate Action to Facilitate Conjunctive Management
2) Develop an Internet-Based, Consolidated Ground Water Information List

The details of the first recommendation have been reproduced below. This recommendation is a collection of suggested actions to be taken by leaders in cities and towns, counties, water conservancy districts and water suppliers. It includes:

- Investigate the applicability of conjunctive management strategies to increase the water supply in your location.

- Visit existing aquifer recharge sites in Utah, and surrounding states to learn from their experiences.
- Set aside lands that are uniquely situated for storing water underground. These are valuable and cannot be used after the land is put to other uses. This especially includes gravel pits located above the unconfined aquifer at the mouth of canyons. If subsequent study determines aquifer recharge cannot be accomplished, the lands can then be developed otherwise. These areas are typically well suited for temporary or permanent multiple uses such as parks and recreation.
- Investigate the status of aquifers. This includes declining ground water levels and potential contamination risks. Take action based on what is found.
- When agricultural land is converted to urban use, investigate the options of directly putting former irrigation waters into the community water supply or developing a conjunctive management project to store those waters in aquifers.
- Require new subdivisions, annexations, or additions to provide the water needed by those entities.
- Require urban developers to install storm water recharge basins with every new development.
- Flood retention reservoirs are routinely installed on mountain streams to reduce the peak runoff. Investigate and locate the aquifer recharge sections of the stream and build the flood retention reservoirs at these locations.
- Locate debris collection basins as described above for flood retention reservoirs.

Source of information:

- Utah Division of Water Resources, 2005

B.2.3 India: Master Plan for Artificial Recharge to Ground Water in India

B.2.3.1 Overview of the Master Plan

The preparation of India’s Master Plan for artificial recharge to groundwater aims at providing area specific artificial recharge techniques to augment groundwater resources. It is based on the two important requirements of source water availability and the capability of aquifers to accommodate this water. The specific problems in different areas in the states, like excessive groundwater development resulting in groundwater decline, water scarcity due to inadequate recharge in arid areas, low groundwater retention in hilly areas despite substantial rainfall, urban areas with limited groundwater recharge and related problems of urban pollution, were considered in the preparation of the master plan.

To fully utilise the available surplus monsoon runoff in rural areas, the techniques emphasised include surface spreading such as percolation tanks, and sub surface techniques such as artificial recharge wells. In urban areas, hilly areas and coastal regions, the emphasis is on rain water conservation measures through roof top rainwater harvesting techniques. The Master Plan identifies areas suitable for artificial recharge and it prioritises areas where schemes should be implemented as a first priority to ameliorate the water scarcity problems.

Master Plan Summary:

Area identified for AR:	448 760 km^2
Volume to be recharged:	36 453 Mm^3
Total number of structures proposed (including roof top rain water harvesting):	3.9 million
Estimated cost:	R33 billion

The cost of implementing the Master Plan is given in more detail in Table B.6. It is recommended that this plan be implemented in a phased manner over a time period of 10 years as this would take care of availabilty of funds for implementation and it would enable the implementing agencies to review and modify the schemes based on data generated and experience gained in the initial stages.

Table B.6: Cost of implementing artificial recharge on a national scale

	Number of structures	Billion rand	Cost per structure (R)
Artificial recharge structures proposed	225,000	27	120,000
Roof top rainwater harvesting structures	3.7M	6.3	1,700
Total number of artificial recharge and water conservation structures	3.9M	33	-
Annual cost over a recommended 10-year implementation period	-	3.3/annum	-

Note: M = million (10^6); B = billion (10^9)

The contents of the Master Plan include:

1) National scenario for groundwater
2) Concepts of artificial recharge to groundwater
3) Need for artificial recharge to groundwater
4) Methodology for preparation of the master plan
5) Design of artificial recharge structures
6) Monitoring mechanism
7) State wise master plan for artificial recharge

The bulk of the Master Plan is in the last section: State wise master plan for artificial recharge. Typical items are discussed and quantified include:

- Identification of artificial recharge areas (this includes for example, mapping areas with declining trends in water levels, areas with relatively deep water levels, and areas with suitable geology for AR)
- Subsurface storage water requirements
- Source water availability
- Recharge structures
- Rooftop rainwater harvesting in urban areas
- Cost estimates

B.2.3.2 Background and the need for artificial recharge

Due to the diverse geological, climatological and topographic conditions in India, hydrogeological conditions vary considerably. Two-thirds of the country is occupied by hard rock formations and one-third by semi-consolidated sediments. By comparison, South Africa consists of about 90 percent of the less porous and permeable, hard-rock formations.

Over the past four decades, Indian government policies have encouraged the rapid development of groundwater resources, to the extent that groundwater is now considered the preferred source for irrigation, domestic and industrial water supplies. This development is a result of both the advancement of drilling and pumping technologies and the need for assured water supplies. The introduction of high yielding crops and the adoption of multi-cropping patterns of agriculture is one of the key factors underlying the need for dependable water supplies.

The number of groundwater wells and boreholes has increased from about 4 million in 1951 to more than 17 million in 1997. Consequently, the irrigation potential created from groundwater has increased from 6.5 million hectares (Mha) in 1951 to 45.73 Mha in 1997. It has, however, resulted in a significant depletion of groundwater resources, particularly in the hard rock areas covering the southern states. A total of about 200 000 km^2 of the country are over-exploited and show a continuous decline in groundwater levels. In many parts of the country, water levels have declined by more than 4 m, and this has led to the failure of wells and tubewells, shortages in water supplies, increasing pumping costs and higher energy consumption.

The unscientific development of groundwater in some coastal areas of the country has led to landward movement of the seawater-fresh water interface, resulting in the contamination of fresh water aquifers. In some areas, this interface has moved up to 6 km inland. The problems associated with this movement have been widespread and a number of tubewells have been rendered unusable. Even many shallow wells, which were previously yielding fresh water, have started to yield saline water due to seawater ingress.

In addition to its already extensive use, groundwater resources are placed under further stress during periods of drought. The preference for using this resource is not only due to declining storage levels in surface reservoirs, but also because the impact of erratic weather on groundwater resources has a delayed response.

Artificial recharge has been identified as playing a major role in water conservation in India. A number of pilot studies have been undertaken using various artificial recharge techniques and in a variety of hydrogeological environments. Both the technical viability and economic value of the schemes have been demonstrated, and this has led to a large-scale launching of artificial recharge schemes in the country. Emphasis on creating awareness among groundwater users stresses the need for conservation and augmentation of groundwater resources, and involves them in the implementation of artificial recharge schemes.

B.2.3.3 Areas suitable for artificial recharge

A number of hydrogeological environments located in various parts of the country provide scope for artificial recharge. These include:

- Various unconsolidated deposits in the valleys of the mountainous areas. These are suitable for artificially recharging groundwater by adopting various spreading techniques.
- Areas with steep slopes and fan deposits are considered favourable for slowing down the sub-surface drainage by constructing water retention structures.
- Alluvial aquifers are suitable for recharge through the construction of spreading basins and check dams in the recharge zone.
- Dolomitic environments can be favourable for both injection boreholes/wells and recharge structures such as spreading basins, check dams and percolation ponds.
- Depending upon the topography, thickness of the weathered/ fractured zones, continuity of fractures and climate, hard-rock areas are suitable for the construction of recharge structures, such as check dams, percolation tanks and injection wells and boreholes.

In addition to these areas of artificial recharge potential, roof-top rainwater harvesting is being made mandatory (by amending the building by-laws) in urban areas with groundwater levels deeper that 8 metres. This water is fed through various recharge structures to infiltrate the subsurface.

B.2.3.4 Case study: The basalts of Warud Taluka

The watershed covers an area of nearly 500 km^2 in Warud Taluka and represents a typical basaltic terrain. The area has been subjected to intensive groundwater development for the irrigation of orange orchards. This practice has led to a decline in groundwater levels of up to 0.4 m/year during the post-monsoon season. Wells in the area went dry and a number of boreholes were drilled to meet water requirements. Three percolation dams were constructed in natural depressions, and ten cement wells were constructed in stream beds.

Some 81 to 97 percent of the water collected and stored in the dams made its way into and recharged the aquifer. The remaining water was lost to evapotranspiration. Groundwater levels rose between 1 and 10 m. The rising groundwater levels not only resulted in dependable drinking water supplies from the wells, but the orange orchards were revitalised and new plantations, irrigation wells and additional greenery were established in these areas.

Sources of information:

- Central Ground Water Board, 2002
- Unpublished paper by Dr D. K. Chadha, Chairman, Central Ground Water Board, Ministry of Water Resources, India. Paper presented at a workshop at the 4th International Symposium on Artificial Recharge of Groundwater, Adelaide, Australia, 2002
- Chadha, 2002

B.2.4 The Netherlands

Artificial recharge started on a small scale in 1940 with the infiltration of surface water into unconfined aquifers to counteract declining water levels. Large-scale projects were initiated in the 1950s to supply the densely populated areas along the North Sea coast. Groundwater abstraction is restricted in these areas due to salt water intrusion and lowering of the water table.

The volume of artificial recharge water in 1990 was 180 Mm^3 and the withdrawal of recharged water met 22 percent of the country's total water demand. Amsterdam receives 60 percent of its drinking water from artificial recharge in the Dune Area. This artificial recharge scheme involves spreading treated river water over 40 recharge ponds covering 86 ha. The infiltration rates are in the order of 20 cm/day, and travel time in the sub-surface is 90 days on average. The water is recaptured through drains and open canals located about 60 m from the infiltration basins.

Borehole injection is also being used to transfer water to the deeper aquifers. Clogging problems have arisen and a considerable amount of research has gone into the design of boreholes and operational procedures to minimise and manage this problem. The banning of chlorine and similar products for the disinfection of source waters has added to the deep borehole injection and ASR challenge.

- The main purposes of artificial recharge in the Netherlands are:
- To maintain continuity of drinking water supply
- To prevent salt water intrusion after extensive groundwater extraction
- To treat surface water during infiltration
- To reverse ecological damage due to the lowering of groundwater levels.

Sources of information:

- Stuyfzand and Doomen, 2004
- Duijvenbode and Olsthoon, 2002

B.2.5 Australia

Artificial recharge is not a new concept in Australia. It has been practised for more than a century at Mt Gambier in Southern Australia. This small city disposes all of its stormwater into an underlying karst aquifer using more than 300 drainage wells that are dispersed throughout the city. The annual recharge of between 3.6 and 6.2 Mm^3 makes its way to a nearby lake from where it is abstracted for reuse.

Considerable research into ASR has recently been undertaken in Australia. This has focussed on water quality and microbiological changes that occur due to blending and sub-surface storage. A major part of this research is related to the use of poorer quality water such as stormwater, stream water and reclaimed water. In 2002, 25 ASR projects were in operation, under development or being investigated, with the intention, in most cases, of using storm water and/or reclaimed water for irrigation. Some deterioration of the aquifer due to the injection of non-potable water appears to be acceptable in Australia.

An example of surface infiltration is the Burdekin Delta scheme, which is the oldest and largest infiltration scheme in Australia. The scheme has been operating since the mid 1960s and is largely responsible for supporting the Australian sugarcane area. It is also used to prevent salt waster intrusion into the aquifer. The artificial recharge scheme is managed by Water Boards and consists of natural and artificial channels and recharge pits supplied with water drawn from the

Burdekin River. The irrigated agricultural land is served by 2 000 production boreholes that are abstracting 210 to 530 Mm^3/a.

Australia is not only implementing innovative ASR schemes but also conducting valuable research. Some of the impressive schemes include those in Adelaide, where urban runoff is diverted to newly-developed wetlands which serve to treat the runoff prior to injection. The water is then abstracted for irrigation purposes in the dry months. In this way, they ensure that the fully treated drinking water is not used for irrigation.

Sources of information:

- Charlesworth, *et al*. 2002
- Gerges, *et al*. 1996

B.2.6 Germany

Berlin has been supplied with artificial recharge water since 1916; Wiesbaden since 1921; and Hamburg since 1928. Most schemes involve bank filtration along the Rhine, Main, Elbe and Ruhr rivers. Approximately 15 percent of Germany's drinking water is produced through artificial recharge.

The purpose of artificial recharge is mostly for drinking water (54 percent of applications) (Figure B.11), but there are also several schemes (less than 2 percent of applications) that are used for the preservation of wetlands, the raising of lake water levels and groundwater rehabilitation.

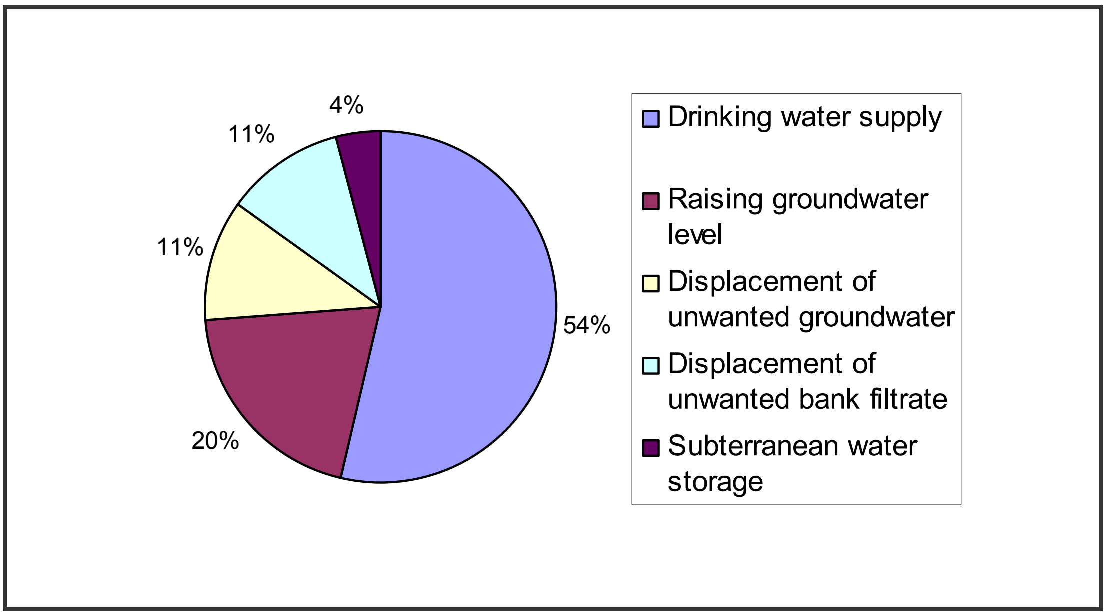


Figure B.11: Uses of artificial recharge in Germany

(Source: Schottler, 1996)

Source of information:

- Schottler, 1996

B.2.7 Israel

Israel has been one of the leading countries in the research and implementation of surface and injection schemes. The Yarkon-Taninim Aquifer, a dolomite-limestone aquifer, is one of Israel's three principal water sources, the others being the Coastal Aquifer and Lake Kinneret. The aquifer is recharged by borehole injection using water from Lake Kinneret. Artificial recharge serves a number of purposes:

- It increases the water reserves for use during the summer months and during other periods of high demand
- It reduces hydrological deficits
- It prevents saline water intrusion from peripheral areas
- It affords efficient utilisation of surplus water from Lake Kinneret.

High volumes of groundwater abstraction caused groundwater levels to drop and, as a result, spring flow was dramatically affected. For example, the Yarkon spring dried up after previously flowing at 220 Mm^3/a, and the flow of the Taninim spring declined from 110 Mm^3/a to 30 Mm^3/a. Artificial recharge volumes have ranged from a maximum of 62 Mm^3/a to a minimum of 4 Mm^3/a, depending on the availability of source water. On average, 26 Mm^3/a, or 7.5 percent over and above the average natural replenishment, was recharged over the 23 year period to 1993. Clogging in recharge boreholes occurs due to silt build-up and algae in the source water, but this is adequately managed by back-flushing (pumping) the injection boreholes.

The largest artificial recharge scheme in Israel is the Dan Region Project that uses the aquifer media for treating reclaimed wastewater from Tel Aviv. The recovered water is used for unrestricted irrigation and over the five year period, 1991 to 1996, a total of 400 Mm^3 was supplied for this purpose.

There are a number of other artificial recharge schemes in Israel, including the Nahaley Menashe project north of Tel Aviv. This is a river runoff scheme where runoff from a three-river system is captured and channelled into a sedimentation basin and then released into recharge basins in the coastal dunes. Similar projects exist in the southern desert area.

Sources of information:

- Guttman, 1995
- Kanarek and Michail, 1996

B.2.8 Palestine

Artificial recharge using stormwater and treated wastewater is considered a viable means of reducing Palestine's water deficit. Over-abstraction of groundwater in coastal aquifers has led to an increase in water salinity and seawater intrusion. In the Gaza Strip, groundwater recharge is about 98 Mm^3/a, of which 46 Mm^3/a is supplied by rainfall using direct infiltration, the balance being obtained from irrigation return flow, leakage from wastewater and brackish transboundary flow. The total amount of groundwater abstraction is 145 Mm^3/a. This results in a deficit of 47 Mm^3/a.

The effect of this over-abstraction has been a water level decline of 20 cm/a and, as a consequence, sea water intrusion and water quality deterioration. Artificial recharge is not only expected to provide 56 Mm^3 of water to offset the deficit by the year 2020 (Table B.7), but it is also considered a means to limit sea water intrusion.

Table B.7: Expected water demand and supply in Mm^3

Target Year	2000	2005	2010	2015	2020
Recharged stormwater	*10*	*12*	*13*	*15*	*18*
Recharged treated wastewater	*5*	*10*	*14*	*29*	*38*
Natural supply	99	97	79	78	77
Total supply	**114**	**119**	**106**	**122**	**133**
Municipal demand	63.1	83.9	111	147	182
Agricultural demand	91	92.2	88.3	83.6	79.7
Total demand	**154**	**176**	**200**	**230**	**262**
Total deficit	**40**	**57**	**94**	**108**	**129**

Source of information:

- El Sheikh and Hamdan, 2002

B.2.9 Sweden

Infiltration basins have been operational since 1898. There are 1 800 artificial recharge schemes in the country and 80 of the 284 municipalities use this technology. Artificial recharge provides about 50 percent of total groundwater use, which is more than 20 percent of total water use. Recharge is mostly by infiltration basins using partially treated surface water derived from lakes.

Sources of information:

- Hjort and Ericsson, 1996
- Connorton and McIntosh, 1994

B.2.10 Switzerland

The cities of Zurich, Geneva and Basel rely on sophisticated artificial recharge schemes that use high quality (pre-treated) river water. Artificial recharge was motivated by declining groundwater yields, increasing demands, deteriorating groundwater quality and the need for security of supply. Recharge methods include infiltration basins, ditches and borehole injection.

Source of information:

- Connorton and McIntosh, 1994

B.2.11 United Kingdom

Pilot studies were conducted north of London in the 1890s and the 1950s, but it was not until the 1970s that permanent artificial recharge facilities using wells and boreholes were constructed. Surplus winter water from the Lee River is pre-treated to drinking water quality and injected into the aquifer. A high level of treatment is adopted so as to avoid clogging and to protect the groundwater resource.

The Lee Valley and Enfield-Haringey schemes are currently the only artificial recharge projects operating in the UK. Both make use of surplus potable mains water (derived from the Thames and Lee Rivers) that is injected into the deeply confined chalk aquifer of the London basin. When fully developed, the two schemes will provide a strategic drought resource of 60 Mm^3/a for the London area that has a current water deficit of 10 percent.

Feasibility studies to develop similar artificial recharge schemes have been undertaken in south London, and projects in the Anglia, Severn-Trent and Yorkshire regions are in the planning stage. All artificial recharge schemes require approval from the National Rivers Authority which regulates abstraction licences and consents to recharge (quantity and quality) into aquifers.

Source of information:

- Connorton and McIntosh, 1994

B.3 SOUTHERN AFRICAN EXPERIENCE

Artificial recharge is not a new concept in Southern Africa. The Atlantis scheme near Cape Town has been operational for over 20 years, and farmers throughout the region have built numerous earth dams for the purpose of enhancing groundwater recharge. In Namibia, sand storage dams were constructed in stages for the storage of water in artificial "aquifers" (Wipplinger, 1953). Recently, the Water Research Commission (WRC), DWAF and municipalities have supported research and implementation of artificial recharge schemes in fractured aquifers. This initiative this has resulted in two research reports and a booklet (Murray & Tredoux, 1998; Murray & Tredoux, 2002; Murray, 2004). Southern African artificial recharge sites are summarised in Table B.8 and Figure B.12.

In addition to the artificial recharge sites listed below, feasibility studies are being conducted in three other areas, namely Langebaan, Plettenberg Bay and Prince Albert. These are briefly described after descriptions of the operational sites.

Table B.8: Artificial recharge sites in Southern Africa

Site	Operational Status
Atlantis	Over 20 years of operation
Polokwane	Over 20 years of operation
Omdel, Namibia	Over 5 years of operation
Karkams	Over 5 years of operation
Windhoek	Recently constructed
Calvinia	Recently tested
Sand dams, Namibia, etc.	Up to 50 years

Figure B.12: Southern Africa's artificial recharge sites

B.3.1 Atlantis: Urban stormwater and treated domestic wastewater recharge

The Atlantis Water Resource Management Scheme was designed to optimise the use of water in the town of Atlantis situated along the arid west coast of southern Africa. The town has a population of approximately 245 000. Artificial recharge forms an integral part of the water management scheme.

The stormwater collection and recharge system was constructed in the latter part of the 1970s and it was decided to add treated wastewater from the town of Atlantis to the system. In 1979 it received its first recharge water. At that stage, it resorted under the authority of the Cape Divisional Council but was handed from one local authority to the following until eventually it became part of the Cape Metropolitan area. Since 1997 it resorts under the jurisdiction the City of Cape Town. Initially the system was equipped with various recorders for determining the water level, the rate of inflow into the recharge facility, electrical conductivity and pH. This equipment has been vandalised and is in the process of being replaced. In 1990 the recharge basin was cleaned and the top 250 to 300 mm of soil and sludge removed. The cleaning operation will have to be repeated in the near future and will need attention every 12 to 15 years. Several hundred boreholes and well points were installed for monitoring groundwater levels and water quality. At the first recharge basin some 50 monitoring points were installed and another 30 are located down gradient of the second recharge basin. Groundwater levels were measured monthly or even more frequently in the vicinity of the basins and wellfields.

Figure B.13: One of Atlantis' infiltration basins

Refurbishment of all systems is presently taking place and more automated readings are being planned for providing better feedback for operation and management. The City is presently carrying out the water level and water quality monitoring which was previously contracted out and in-house management is gradually evolving. This is important as the City has shown that it is taking ownership of the AWRMS. Further training of staff is required to ensure the success of the operation. The presence of iron has caused clogging of production wells and after several rehabilitation runs detailed monitoring of flow rates and water levels is being introduced for all production wells.

The upgrading of the operation is presently receiving due attention and an operation manual is being planned for supporting the Atlantis staff with decision-making. As various City Departments are responsible for the different components of the AWRMS it needs commitment from all of these to ensure that the wastewater plants are functioning optimally, the stormwater and drainage systems are maintained, the catchment cleaned regularly, while industries are controlled to prevent spillages and pollution. As the recharge system accepts both treated domestic effluent and urban stormwater runoff, these sources need regular monitoring and control. Alternatives exist for diverting substandard treated wastewater and poor quality runoff. However, further upgrading is needed for continuous monitoring of these components. Groundwater quality management is also a key part of the operation as the natural groundwater salinity is relatively high in some areas. Hardness is controlled by partial softening of the water supply. The possibility to introduce low salinity surface water into the system was fully utilised and improved the overall salinity of the water supply. However, surplus surface water will not always be available and therefore the operation of the Atlantis system itself needs to be optimised for controlling salinity levels.

As set out above, the system is presently being refurbished but this task and the associated management present an extensive series of challenges for ensuring product water of optimal quality on a sustainable basis. Presently the scheme runs slightly above half its capacity and the deficit is made up with imported surface water. While this is beneficial for lowering the overall salinity the importation of water is not possible continuously over the longer term and the management of the AWRMS will have to be stepped up to cope with the demands for water quantity and quality.

Table B.9: Key features of the Atlantis artificial recharge scheme

Town	**ATLANTIS**
Population	~245 000
Water demand	6.23×10^6 m^3/a (2004)
Town's water sources	Groundwater (since 1976) and partly surface water (since 2000) In 2004: Groundwater 2.87×10^6 m^3; Surface water 3.36×10^6 m^3 (Wellfields being rested while surface water available)
Water source for AR	Treated waste water and storm runoff. Good quality stormwater and treated domestic wastewater is used to recharge to the wellfields that supply the town. Inferior quality storm runoff and treated industrial wastewater is diverted for recharge near the coast to prevent seawater intrusion (by creating a hydraulic mound near the shoreline).
Purpose of AR	Augment local groundwater supplies. Prevent seawater intrusion into the aquifer. Sensible stormwater and treated wastewater disposal, obviating need for costly marine discharge.
Type of aquifer	Coastal dune sands overlying calcrete and fluvial sand deposits with peat lenses (~45 m thick). Bedrock consisting of shale or granite.
Type of AR	Spreading basins: 2 large spreading basins up-gradient of the main wellfield; 3 smaller basins down-gradient near the coast.
First AR activity	1979
Recharge rate/volume	Infiltration rate: 0.01 – 0.16 m/day 1.5×10^6 to 2.5×10^6 m^3/a (main basin only)
Recharge rate/volume as percent of current requirement	25 – 40 %

Town	ATLANTIS
Proportion of water conserved through AR	At least 40 %
Quality of water source	Source for main basins: EC 60 – 95 mS/m; DOC 8 – 10 mg/L Source for coastal basin: EC 100 – 150 mS/m; DOC > 10 mg/L
Quality of water abstracted from the aquifer	Recovered water from main basins: *(blended with groundwater)*: EC 60 – 100 mS/m; DOC 2 – 7 mg/L Recovered water from coastal basin: Not relevant, discharged into the sea via the sub-surface
Comments on the scheme	Artificial recharge has ensured the sustainability of the AWRMS since the early 1980s, and will continue to play a key role. A major component of the scheme has been the separation of the source water into different fractions, as this has allowed recharge of the highest quality water in the areas of greatest importance. The Atlantis groundwater scheme provides a cost-effective water supply option when coupled with careful management of the water sources and the aquifer. Augmentation of the water supply with low salinity surface water since 2000 has decreased salinity and increased the viability of the scheme.
Key lessons	***AR-related:*** 1. Artificial recharge is a reliable hydrogeological proposition when coupled with cautious engineering design and control 2. Water quality monitoring and management remains the key issue for the AWRMS. 3. For optimal artificial recharge implementation, infrastructure planning for urban stormwater runoff and wastewater collection should form part of urban planning design 4. Separation of domestic and industrial wastewater is essential as domestic wastewater can be treated and recycled indirectly 5. Quality of stormwater runoff from industrial areas needs extensive monitoring if used as an artificial recharge source 6. Environmental protection of the recharge zone and general catchment management is needed to maintain water quality 7. Regular and scheme-specific monitoring must be undertaken for effective artificial recharge management 8. Borehole clogging was experienced in both wellfields. Artificial recharge is only practised at Witzand, and thus artificial recharge cannot be the only or main cause of the problem. ***General hydrogeological:*** 1. Production borehole design, construction and materials must be such that borehole rehabilitation can be applied successfully 2. Borehole logging records must be accurate and complete, important for understanding the aquifer and to assist rehabilitation planning 3. Staff training is vital for understanding borehole management for optimum yields 4. Accurate production and monitoring records must be kept 5. Erratic and over-pumping is more likely to promote clogging, while steady pumping at a fixed rate is likely to limit clogging 6. Regular test-pumping of individual boreholes is important to ensure that production yield does not exceed the borehole optimum 7. Pumps and equipment must be carefully selected and regularly maintained.

Sources of information:

- Bishop & Killick, 2002
- Tredoux & Cavé, 2002
- Tredoux, *et al*, 2002

B.3.2 Polokwane: Wastewater recharge since the 1970s

With a population in excess of 400 000 and water requirements of about 12 million m^3/a, Polokwane is largely dependent on surface water. However, the city also has an elaborate groundwater abstraction infrastructure that supplies domestic water to meet daily peak demand, and serves as a back-up during periods of surface water shortage. For example, during the 1992–1994 drought, groundwater accounted for a large proportion of the city's needs (3.7 Mm^3/a). The reliability of this source is largely due to the infiltration of Polokwane municipal treated wastewater into the alluvial and gneissic aquifers. The water is used both by the municipality and by farmers for large-scale irrigation.

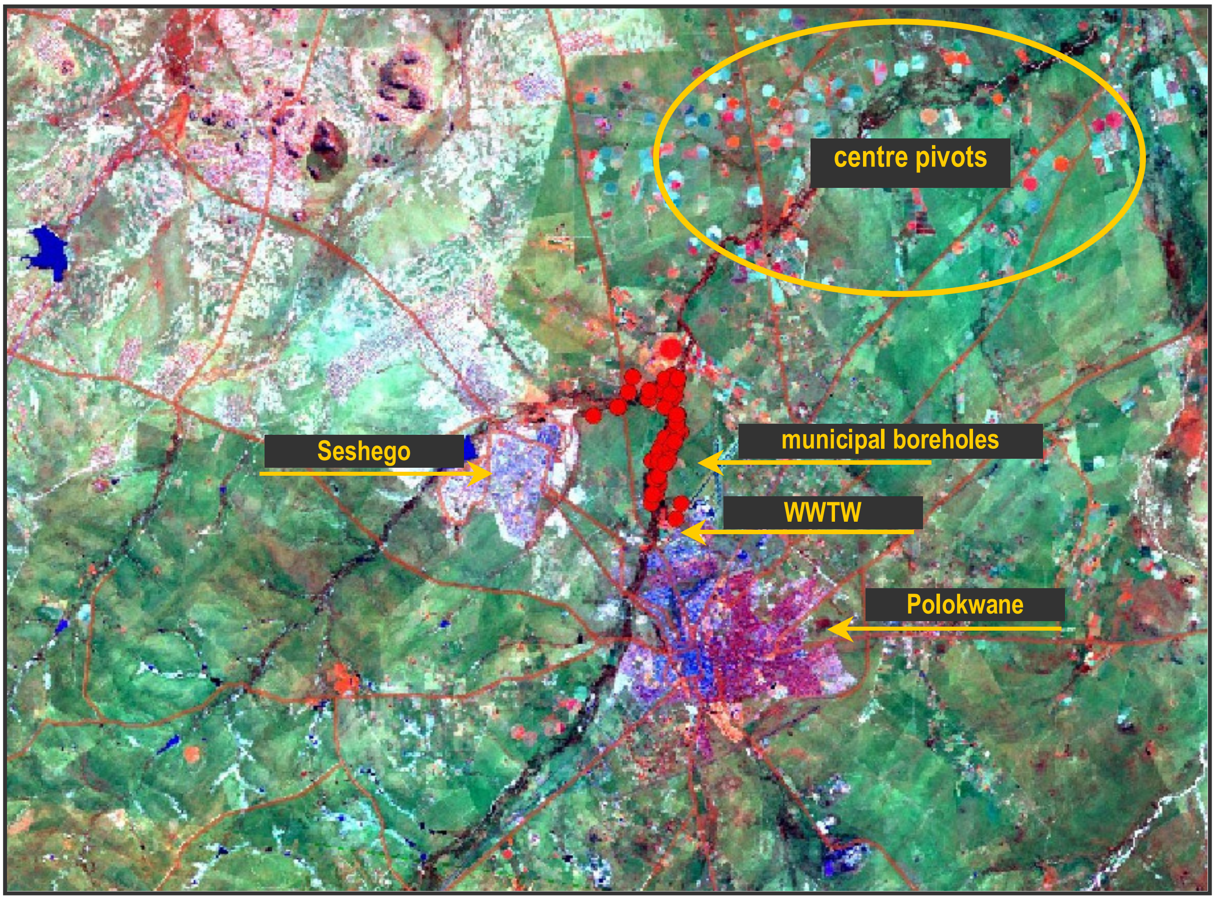


Figure B.14: Satellite image showing large-scale centre-pivot irrigation down-stream from the Polokwane Waste Water Treatment Works (This water is abstracted from the hard-rock aquifer that is recharged with waste water)

Table B.10: Key features of the Polokwane wastewater recharge scheme

Town	**POLOKWANE**
Population	~400 000
Water requirements	12 Mm^3/a
Town's water sources	Surface water; supported by groundwater when needed
Water source for AR	Treated municipal wastewater
Purpose of AR	Artificial recharge was not planned. Recharge to the aquifer takes place as a result of discharging waste water to the ephemeral Polokwane River
Type of aquifer	Sand: ~20 m thick alluvium that absorbs the waste water. Fractured granite/gneiss: ~60 m thick aquifer that is fed by the overlying saturated alluvium
Type of AR	Infiltration into fractured aquifer from river bed and surrounding alluvium
First AR activity	
Recharge rate/volume	Recharge potential: 3-4 million m^3/a (of the 6 million m^3/a discharged by the waste water treatment works)
Recharge rate/volume as percent of current requirement	25-30%
Proportion of water conserved through AR	Conservation potential: 50 - 65% of discharged waste water. So that the municipality can recycle as much of this water as possible, it needs to abstract continuously from the gneissic aquifer. In this way, space is created in the aquifer and the recycling process is made possible.
Quality of water source	Treated waste water: EC: 60-120 mS/m NO_3: <1 – 12 mg/L
Quality of water abstracted from the aquifer	Water from granites/gneisses: EC: 100 mS/m* NO_3: <1 mg/L* * Single sample (Note: There is a lack of historical data to assess discharged nutrients and organics, and the effect of subsurface storage on water quality)
Comments on the scheme	This scheme shows that a large proportion of treated waste water can be stored and recycled using sub-surface media. If this water was not recycled through artificial recharge and subsequent abstraction, it would either be lost to evapotranspiration or it would be pumped from the river or aquifer by other users downstream of the discharge point. When recycled, after abstraction from the deep production boreholes, the water is treated and blended with surface water prior to distribution into the supply network.
Key lessons	1. This form of water conservation is highly effective and is cheap. It should be implemented wherever possible. 2. Because of this scheme, the city has not needed to construct additional surface storage facilities, and can rely on groundwater to meet peak and drought demands. 3. The value of recycling water in this manner can only be realised if groundwater is abstracted from the deep-seated fractured aquifer. If not, the aquifer remains full, and the treated waste water is lost to evaporation, evapotranspiration, or abstracted directly from the river by other users. 4. Additional water quality determinands need to be monitored and analysed for artificial recharge schemes that utilise treated waste water. These should include indicators for potassium, discharged nutrients and organics.

Source of information:

- Murray and Tredoux, 2002

B.3.3 Omaruru River Delta (Omdel), Namibia: River runoff

The artificial recharge concept has found great acceptance in Namibia over the past decade, or even longer. The Omdel artificial recharge scheme was constructed in the Omaruru River Delta, in the Namib Desert 35 km from the coast. It consists of the Omdel Dam with a capacity of 40 Mm^3 constructed in 1993, and a series of infiltration basins in the riverbed 6 km down-stream where the present channel crosses paleo river channels (Zeelie, 2002). The main impoundment serves as a silt trap and, after settling, the water is allowed to flow along the river bed to the infiltration basins constructed of alluvial material in the river bed. The aquifer provides water to the coastal towns of Walvis Bay, Swakopmund and Henties Bay, and a large open pit mine at Rössing.

Figure B.15: Infiltration basins at Omdel

Table B.11: Key features of the Omdel artificial recharge scheme

Town	**WALVIS BAY, SWAKOPMUND, HENTIES BAY, RÖSSING MINE**
Water demand	$5.5x10^6$ Mm^3/a (2002)
Town's water sources	Groundwater from Omaruru River Delta and Kuiseb River alluvium
Water source for AR	Omaruru River floodwater collected in the Omdel Dam (constructed 1993)
Purpose of AR	Recharge to the ephemeral Omaruru River's alluvial aquifer. This water is used for town water supplies
Type of aquifer	Sand and gravel
Type of AR	Direct seepage from Omdel Dam into river alluvium. Seepage into river bed while released water flows to recharge basins. Infiltration of released dam water via recharge basins into alluvial aquifer in paleo channels in river delta
First AR activity	April 1997
Recharge rate/volume	Event driven, 1997-1998, total inflow Omdel Dam: $18x10^6m^3$

Town	**WALVIS BAY, SWAKOPMUND, HENTIES BAY, RÖSSING MINE**
	Seepage from dam plus basin recharge: 9.6x10^6 m^3 In 2000: Inflow of 18x10^6 m^3 of which 9.3x10^6 m^3 was recharged
Proportion of water conserved through AR	46 to 48 % of floodwater conserved of total inflow of 18x10^{6}m^3 (subtracting natural recharge in river bed before dam was constructed).
Quality of water source	EC ~57 mS/m in Omdel Dam (1997). EC ~110 mS/m at Recharge Site I (6 km down-stream) (1997)
Quality of water abstracted from the aquifer	EC: ~190 mS/m (average of three production boreholes) (1997)
Comments on the scheme	Flood event driven, but conserves more water by seepage and artificial recharge than would be possible by natural infiltration during flood events
Key lessons	1. A considerable volume of water, which would otherwise be lost as runoff to the sea or evaporation, can be captured and stored in the subsurface where evaporation losses are minimal. 2. The surfaces of the basins need to be scraped from time-to-time in order to maximise infiltration.

Source of information:

- Zeelie, 2002

B.3.4 Kharkams: Capturing runoff for borehole injection since 1995

Kharkams is a small village in the semi-arid Namaqualand region that depends solely on groundwater. The lowest yielding of the village's three production boreholes is artificially recharged whenever surface runoff is available. This action significantly increases the borehole's yield and water quality. This scheme demonstrates the value of opportunistic artificial recharge in semi-arid areas, even if it is only practised on a small scale.

Figure B.16: Sand filter with injection and abstraction borehole (pump house) in the background

Table B.12: Key features of Kharkams artificial recharge scheme

Town	**KHARKAMS**
Population	1 700
Water requirements	80 000 m^3/a
Town's water sources	Groundwater (3 boreholes)
Water source for AR	Ephemeral stream
Purpose of AR	Maximise recharge after rainfall events
Type of aquifer	Fractured granite/gneiss
Type of AR	Borehole injection (1 borehole)
First AR activity	1995 (1st injection run)
Recharge rate/volume	40 m^3/day. Maximum volume injected to date is 6 570 m^3 (2001).
Recharge rate/volume as percent of current requirement	The injection borehole's sustainable yield is 2 400 m^3/a. The injection run of 2001 resulted in a near three times increase in the borehole's annual yield. The daily injection volume amounts to 18% of the town's daily requirements. The volume injected in 2001 was 8% of the town's annual requirements.
Proportion of water conserved through AR	Surface runoff not artificially recharged would otherwise be lost through evaporation and evapotranspiration.
Quality of water source	EC: 20 mS/m
Quality of water abstracted from the aquifer	Without AR: EC: 300 mS/m With AR: EC: 40-100 mS/m
Comments on the scheme	This small-scale, village scheme demonstrates the value of opportunistic artificial recharge in semi-arid areas. Both the borehole's yield and water quality can improve significantly through artificial recharge. If the other two higher yielding boreholes that supply the village were also equipped for injection, then the artificial recharge benefits would be substantial.
Key lessons	Small-scale artificial recharge can substantially improve the quality and quantity of water supplies. Even the most robust artificial recharge systems need maintenance. This may require minimal work, but without basic maintenance, the efficiency of a scheme will drop.

Source of information:

- Murray and Tredoux, 2002

B.3.5 Windhoek: Water banking and integrating artificial recharge into bulk supplies

The City of Windhoek has opted for large-scale artificial recharge before introducing other supply options such as transferring water from aquifers in the northern parts of the country and the Okavango River. This decision was based on artificial recharge being the cheapest and most cost-effective option for the city, providing water supply security at accepted assurance levels. These were the conclusions from three recent options analyses and feasibility studies (SWECO, 2002; ENVES, 2003; NamWater, 2004).

The risk of losing injected water is negligible, as the aquifer is bounded by geological formations with low permeability, and the City of Windhoek is the only user of the aquifer.

As part of the NamWater study (2004), modelling was undertaken to optimise the use of water sources that supply water to the Central Areas of Namibia. These results were analysed statistically to provide an indication of required injection and abstraction capacities for the Windhoek Artificial Recharge Scheme. The frequencies of recharge and abstraction were analysed to provide more insight into what can be expected in respect to the reliability of the aquifer. Aquifer storage volumes, as affected by the staged artificial recharge implementation strategy and linked to a range of probabilities of occurrence, are depicted in Figure B.17.

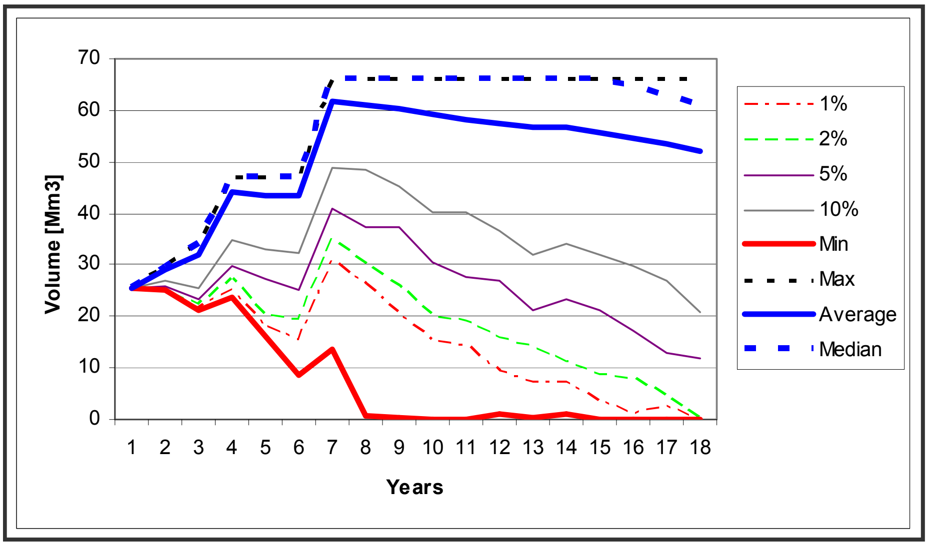


Figure B.17: Probabilities of the volume of storage in the aquifer

(Source: NamWater, 2004)

The worst case scenario, with a probability of less than 1 percent, is that the Windhoek Aquifer may be empty by year 8. There is a 5 percent probability that there will be approximately 12 Mm^3 in the aquifer after 18 years and a probability of 50 percent that the aquifer may hold 60 Mm^3 at that time. This equates to three years of the current demand. Water conservation, primarily through savings on evaporation, was calculated to be 13 Mm^3 after the completion of the final implementation stage in year 10 (ENVES, 2003).

A financial Cost Benefit Analysis (CBA) was undertaken for each water augmentation option, based on the expected average water supply over 18 years sold at an assumed bulk water price. The results are presented in Table B.13.

Table B.13: Results of Financial Cost Benefit Analyses of Augmentation Options

Indicator	Windhoek AR Scheme	Tsumeb & Karst III	Okavango Emergency	Okavango & Windhoek AR
Net Present Value (8%) N$ mil.	-36.59	-95.62	-673.32	-399.59
Internal Rate of Return IRR including inflation	-2.8% 5.0%	-4.0% 3.7%	-4.2% 3.5%	-5.6% 2.0%
Profitability Index (8%)	0.78	0.60	0.17	0.26

(Source: NamWater, 2004)

It is evident from the CBA analysis that none of the options are financially viable, the reasons being that a new scheme will only improve the security of supply and that additional water sales would only be realised during periods of shortfall. Statistically, there is a 55 percent probability that the scheme may not be required to supply any water to the Central Areas of Namibia over the 18-year planning period. The Windhoek Artificial Recharge Scheme has the least negative financial implications, and hence it is the preferred option. The need to go ahead with the scheme is based on a strategic decision that acknowledges the necessity for increased security of supply.

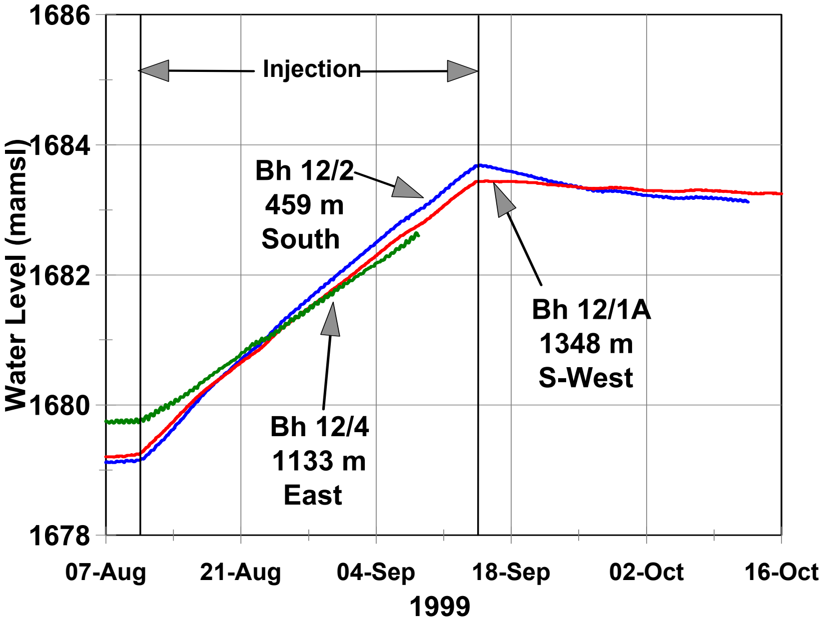


Figure B.18: Windhoek, the rise in groundwater level due to borehole injection (Observation borehole number, location and distance from the injection borehole is indicated)

(Source: Murray & Tredoux, 2002)

Table B.14: Key features of the Windhoek artificial recharge scheme

Town	WINDHOEK
Population	230 000
Water requirements	20 Mm^3/a
Town's water sources	Dams; groundwater from the Karst area in northern Namibia and the Windhoek aquifer; reclaimed water
Water source for AR	Mainly dam water
Purpose of AR	Water banking to provide security of supply during droughts; seasonal peak demands; and emergency supplies in case of problems with the other bulk supplies or the treatment works (recharged water can be supplied directly into the distribution system without treatment).
Type of aquifer	Fractured quartzite
Type of AR	Borehole injection
First AR activity	1996 – 1st injection test
Recharge rate/volume	Current: 2 Mm^3/a Planned: 8 Mm^3/a
Recharge rate/volume as percent of current	Current: 10% Planned: 40%

Town	**WINDHOEK**
requirement	
Proportion of water conserved through AR	The volume conserved is the evaporation volume saved from the dams; this is difficult to quantify. The value of the scheme lies in the assurance of supply during droughts, seasonal peak demand periods and in emergencies.
Quality of water source	EC: ~50 mS/m Dissolved Organic Carbon (DOC): ~4 mg/L

Town	**WINDHOEK**
Quality of water abstracted from the aquifer	Without AR: EC: ~60 mS/m; DOC: <2 mg/L With AR: At this stage, figures are not available, as long-term, large-scale sub-surface storage has not yet taken place. However, since the injectant has better quality than the groundwater, and because the aquifer medium is not highly mineralised, the recovered water should be a good quality blend of the two waters.
Comments on the scheme	The City of Windhoek has opted to implement artificial recharge prior to other options, such as transferring water from the Okavango River. This is because artificial recharge is the most cost-effective option for the city, and it will provide the water supply security needed. It is the first of its kind in the world – large-scale injection in a fractured aquifer, and it should pave the way for similar schemes in highly complex geological settings.
Key lessons	1. Complex, fractured aquifers can be used for AR 2. Detailed hydrogeological assessments are required to understand the groundwater flow system in such aquifers 3. Artificial Recharge can be the most cost-effective option for enhancing a city's water security and supply system.

Sources of information:

- ENVES, 2003
- Murray & Tredoux, 2002
- NamWater, 2004
- SWECO, 2002
- Van der Merwe, B, Tredoux, G, Johansson, P-O, & Jacks, G, 2003

B.3.6 Calvinia: Dam water recharge and storage for emergency supplies

The Calvinia artificial recharge scheme provides a back-up source for emergency situations in droughts. Treated surface water from the Karee dam is stored in a highly mineralised and permeable sub-surface compartment (similar in shape to Kimberlite pipes). The stored water cannot be lost, since the permeability of the surrounding formations is very low and only the municipality has an abstraction borehole that penetrates the aquifer. Because of the mineralised nature of the host rock, the recharged and abstracted water is unfit for human consumption and needs to be blended with the dam water prior to consumption. A similar water quality problem would result from storing fresh water in certain disused mines.

Figure B.19: Injection and abstraction boreholes in Calvinia

Table B.15: Key features of the Calvinia artificial recharge scheme

Town	**CALVINIA**
Population	8 500
Water requirements	~0.4 Mm^3/a
Town's water sources	Dam and groundwater
Water source for AR	Treated dam water
Purpose of AR	Water banking for emergency, drought supplies
Type of aquifer	Fractured, cylindrical, breccia pipe
Type of AR	Borehole injection
First AR activity	2001 (1st injection run)
Recharge rate/volume	7 L/s; Maximum storage potential ~80 000 m^3
Recharge rate/volume as percent of current requirement	Calvinia uses ~40 000 m^3/month during summer. The artificial recharge scheme could provide 2 months' emergency supply during the critical summer months. The town's annual use is ~400 000 m^3 (i.e. 20% of this can be stored using artificial recharge in the one equipped breccia pipe)
Proportion of water conserved through AR	It is difficult to quantify the volume of conserved water. The volume conserved would equal the volume stored in the sub-surface if the dam dried up. It is more useful to view this in terms of the value of security of supply that the artificial recharge back-up system provides, should there be a water shortage.
Quality of water source	pH: 7; EC: 20 mS/m; F: 0.1 mg/L; As: <0.001 mg/L.
Quality of water abstracted from the aquifer	Without AR: pH: 10; EC: 90 mS/m; F: 10.6 mg/L; As: 0.3 mg/L. With AR: pH: 9; EC: 95 mS/m; F: 7 mg/L; As: 0.4 mg/L.
Comments on the scheme	The scheme provides a valuable back-up emergency supply that can provide two months supply for the town. However, because the sub-surface medium is highly mineralised, the quality of the natural and recharged/stored water is unsuitable for human consumption unless blended with dam water at a ratio of at least 1:8. A similar water quality problem to this would result from storing fresh water in certain disused mines.
Key lessons	1. With 1-3 artificial recharge boreholes, it is possible to have a marked impact on the security of a small town's water supplies 2. Storage of fresh water in mineralised aquifers (and mines) can result in significant water quality deterioration 3. It is not always possible to predict the final water quality through laboratory analyses and modelling.

Source of information:

- Murray and Tredoux, 2002

B.3.7 Sand storage dams: Artificial aquifers created in river beds (Namibia)

In the more arid parts of the subcontinent, farmers are largely dependent on groundwater, and the more enterprising farmers have considered ways and means to extend their water supplies. Constructing dams in riverbeds above boreholes have largely solved this problem. However, the dams silted up quickly and, in view of the excessive evaporation, the idea originated that a dam filled with sand, that is, a "sand storage dam", could serve as a reservoir from which little or no evaporation would occur.

Wipplinger (1953) made an extensive study of the subsurface storage of water in such artificial sand aquifers in Namibia, and particularly the construction and efficiency of such systems to serve as water supply sources (see Figure B.20). His early work can have an important bearing on the use of artificial recharge as a means to reach sustainability in community water supply. Presently, extensive efforts are underway in Kenya to promote the building of sand dams for the subsurface storage of floodwater for drinking water supply, livestock watering, and sometimes agriculture (Mutiso, 2003). The Kenya initiative is supported by the World Bank.

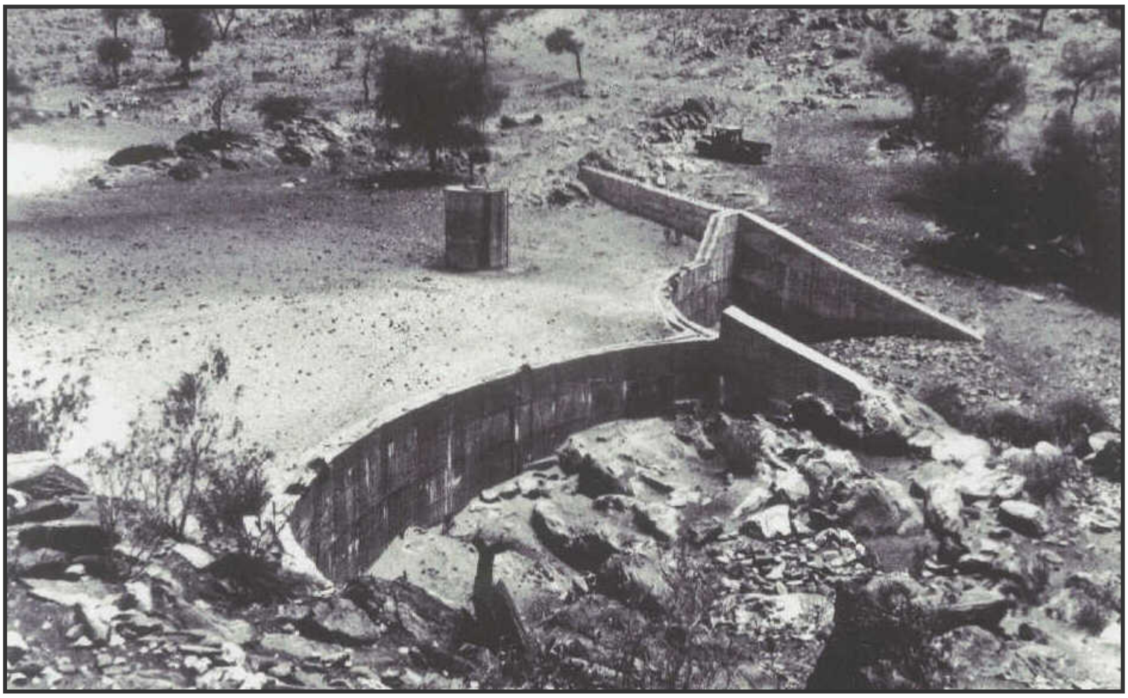


Figure B.20: Sand storage dam, Namibia

(Photo: Wipplinger, 1953)

The three case studies described below are currently being investigated to establish whether artificial recharge is a viable option to augment existing water supplies.

B.3.8 Langebaan: Is borehole injection feasible in a confined sandy aquifer?

The West Coast District Municipality gets its water supply from the Berg River and the Langebaan Road Aquifer. With increasing industrialisation at the strategic port of Saldana Bay, and the rapidly growing holiday and residential status of Langebaan lagoon area, the water supplies to these areas have become stretched to the point where additional supplies are necessary. Recharging the over utilised Langebaan Road Aquifer is currently being investigated.

Table B.16: Key features of the Langebaan Artificial Recharge Feasibility Study

Town	**WEST COAST DISTRICT MUNICIPALITY**
Water requirements	45 000 – 52 000 m^3/d in summer; 30 000 – 35 000 m^3/d winter
Town's water sources	Berg River and groundwater (4 boreholes)
Water source for AR	Treated water from the Berg River
Purpose of AR	Aquifer protection against mining of resource
Type of aquifer	Confined, primary
Type of AR	Borehole injection
First AR activity	2007 (1st pilot injection test)
Recharge rate/volume	Target recharge rate: 4000 m^3/day. Target recharge volume: 0.36 Mm^3/annum.
Recharge rate/volume as percent of current requirement	Approximately 3 months supply, i.e. 25%
Proportion of water conserved through AR	Surface runoff not artificially recharged would otherwise flow into the Altantic Ocean if not pumped for treatment for direct supply.
Quality of water source	EC: ~25 mS/m DOC: ~3 mg/L
Quality of water abstracted from the aquifer	Without AR: EC: 65 mS/m With AR: EC: 60 mS/m (target)
Comments on the scheme	The key technical factor affecting the viability of this scheme is whether the quality of the injection and aquifer waters are compatible. Microbiological and geochemical studies are being carried out to establish pre-treatment requirements to address this concern.
Key lessons	Future key lessons will be drawn from the authorisation process, the feasibility study and if commissioned, the operation and management of the scheme.

B.3.9 Plettenberg Bay: Can natural subsurface storage be used to augment the summer peak demand?

Every summer the holiday town of Plettenberg Bay on the south coast of South Africa experiences a huge inflow of people and the water use increases from about 200 000 m^3/month to over 300 000 m^3/month. Artificial recharge is being considered as one of the means to augment the summer supplies. The suburb in which existing boreholes are located requires an additional 48 000 m^3 to meet its summer requirements, and the initial aim of the project is to establish whether artificial recharge can meet this need. The source water is surplus winter surface water that will be treated prior to borehole injection. If this is a viable option, the next step will be to establish the full capacity of the artificial recharge scheme, as it may be possible to meet a far greater portion of the the summer requirements by applying artificial recharge.

Figure B.21 shows the water levels in an abstraction borehole that is being considered for recharge (prior to the installation of data loggers). During periods of high demand, the water levels are dropped by tens of metres (in 2004 the water levels are 40 m below those of 2006). If artificial recharge is a feasible, the aquifer in this area will be fully recharged on an annual basis prior to the December peak-demand period.

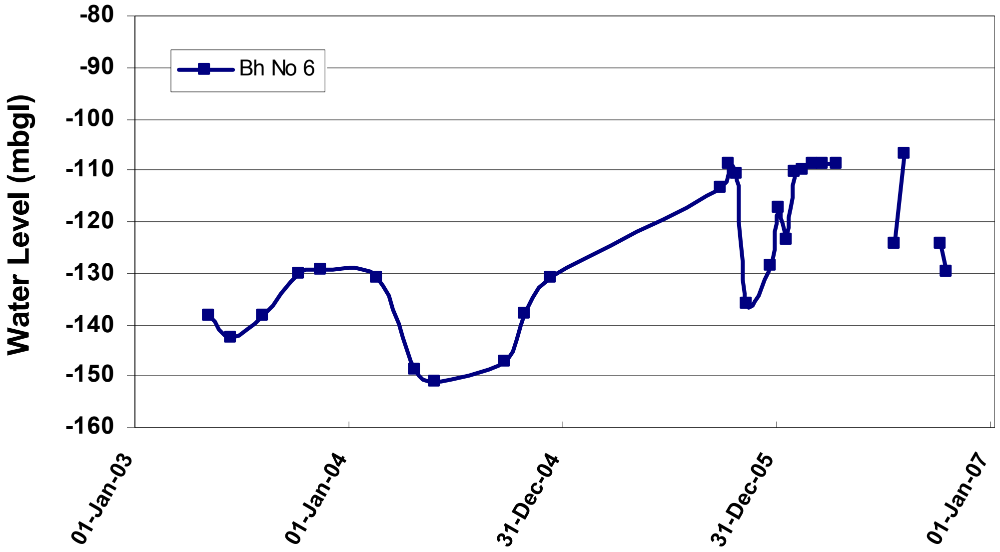


Figure B.21: Borehole water levels in Plettenberg Bay

Table B.17: Key features of the Plettenberg Bay Artificial Recharge Feasibility Study

Town	**PLETTENBERG BAY**
Water requirements	~3 Mm^3/a
Town's water sources	Keurbooms River and groundwater
Water source for AR	Treated river water
Purpose of AR	Augment summer peak demand
Type of aquifer	Fractures sandstones
Type of AR	Borehole injection
First AR activity	Test injection is planned for 2007
Recharge rate/volume	Planned injection rates: 10 – 20 L/s; Minimum injection volume: 50 000 m^3
Recharge rate/volume as percent of current requirement	50 000 m^3 is equivalent to 3 months of supply for the suburb in which the boreholes are located. The artificial recharge storage capacity in this area is estimated to be 750 000 m^3.
Proportion of water conserved through AR	Surface runoff not artificially recharged would otherwise flow into the Indian Ocean.
Quality of water source	pH: ~7; EC: ~10 mS/m; DOC: ~4.0 mg/L.
Quality of water abstracted from the aquifer	Without AR: pH: ~6; EC: ~120 mS/m. With AR: To be established
Comments on the scheme	The water table in the aquifer at the planned recharge site sits over 100 m below ground level. The potential for large-scale artificial recharge exists if the recharged water remains within the borehole capture zone after injection.
Key lessons	Sufficient borehole water level data was not available to rapidly establish whether artificial recharge could be a viable water augmentation option. It is recommended that as soon as an artificial recharge scheme is conceptualised, or as soon as it is identified as a water supply option), data loggers should be installed in boreholes to measure water levels and preferably EC, pH and temperature.

B.3.10 Prince Albert: Can the the aquifer be filled during the single month when surface water is available for recharge?

Prince Albert, like Plettenberg Bay experiences a large increase in water demand over summer. The daily water use increases from about 1 000 to 3 000 m^3/day, and all boreholes are used to capacity to bridge this period. A small portion of the town's water comes from an old furrow that is fed with excellent quality mountain runoff, and this is shared with local residents and farmers. Every winter, and over a four week period, the furrow is cleaned, and this provides a potential source for artificial recharge. The towns' boreholes are reasonably high yielding (~10 L/s) but natural recharge to the nothern wellfields is limited, and it is this area that hs been identified for potential artificial recharge. As with Plettenberg Bay, the intention would be to replenish the aquifer before the onset of the summer months. If the full flow of the furrow could be recharged, it would amount to ~120 000 m^3 which is equivalent to about one-and-a-half months of the summer requirements, and a welcome security system for a Karoo town.

Historical data from one of the boreholes targetted for recharge shows that water levels drop by tens of meters during high abstraction times. After the floods in the winter of 2006, the water levels rose to near-surface, showing the aquifer-full levels and the artificial recharge target. The recent installation of data loggers has shown how the water levels in certain boreholes steadily decline over the summer months.

Figure B.22: Prince Albert

Table B.18: Key features of the Prince Albert Artificial Recharge Feasibility Study

Town	**PRINCE ALBERT**
Water requirements	~0.4 Mm^3/a
Town's water sources	Groundwater and surface water from the Dorpsrivier
Water source for AR	Either treated or untreated river water (the water is sourced in the upper catchment in a nature reserve).
Purpose of AR	Augment summer peak demand
Type of aquifer	Fractures sandstones
Type of AR	Borehole injection
First AR activity	Test injection is planned for 2007
Recharge rate/volume	Planned injection rates: 10 – 20 L/s; Minimum injection volume: 50 000 m^3; Maximum injection volume: ~100 000 m^3. Injection volume will depend on individual borehole injection capacities, the aquifer's available space during the 1 month injection period; and the availability of surface water (estimated to be ~120 000 m^3 for the planned injection month).
Recharge rate/volume as percent of current requirement	The town uses ~90 000 m^3/month during the peak summer period. Artificial recharge could potentially supply one full month of the town's summer requirements (or about a quarter of the town's annual requirements).
Proportion of water conserved through AR	~120 000 m^3/a.
Quality of water source	pH: ~7; EC: ~5 mS/m; DOC: ~1 mg/L.
Quality of water abstracted from the aquifer	Without AR: pH: ~7; EC: ~60 mS/m. With AR: To be established
Comments on the scheme	Like Plettenberg Bay, borehole water levels were insufficient to establish whether artificial recharge is needed. The borehole capacities dropped significantly during summer months, and the limited data showed that water levels in certain boreholes are drawn down to pump intakes. Artificial recharge would be an effective measure to ensure the aquifers are full prior to the onset of the summer months.
Key lessons	The key lesson is the same as that of Plettenberg Bay – borehole water level and abstraction data are vital to establish whether artificial recharge is a feasible water supply option.

B.4 ARTIFICIAL RECHARGE POTENTIAL IN SOUTH AFRICA

B.4.1 Potential users and role players

Current and future role players involved in artificial recharge can be divided into institutions with responsibility for the regulation, licensing and monitoring of artificial recharge schemes and the potential users of artificial recharge schemes.

State institutions that have a role in the regulation, licensing and monitoring of artificial recharge schemes are:

- DWAF
- Catchment Management Agencies (CMA)
- Department of Environmental Affairs and Tourism (DEAT).

Users of artificial recharge schemes include:

- Water Services Institutions (WSI)
- Any institution involved in the provision of water services to households. This would include:
  - Water Services Authorities (WSA) and the following institutions that are contracted by a WSA to provide water services
  - Water Services Providers (WSP)
  - Water Services Intermediaries
  - Water Boards (WB)
- Water User Associations (WUA). A Water User Association represents the interests of a group of users. This would normally be made up of individual users and could include WSIs
- DWAF. Where DWAF is operating as a bulk water provider and where the bulk water supply includes an artificial recharge scheme.

Joint users of artificial recharge schemes: Where the supplier of water for an artificial recharge scheme is not the same institution as the user of the aquifer, special regulations need to be put in place to cover the rights of all involved parties.

B.4.2 Artificial recharge's potential role in water use

Artificial recharge can contribute to the quantity of water available for water use by providing storage for water that is normally not available or is lost. This includes:

- Storage of water intercepted from river flow to the sea
- Minimising evaporation
- Storage and final treatment of wastewater effluent (return flows).

In addition, artificial recharge can provide for emergency or reserve storage. An aquifer can be kept full and "saved" for droughts or other emergencies. This reduces the level of reserve storage that needs to be retained in surface storage dams. The uses of artificial recharge technologies are summarised in Section B.1.

B.4.3 Artificial recharge's potential role in water conservation

The National Water Conservation and Demand Management Strategy (NWCDMS) (August 2004) defines water conservation as follows:

> *"Water Conservation is the minimisation of loss or waste, care and protection of water resources and the efficient and effective use of water."*

The strategy further states that: Water Conservation (WC) should be considered as both an objective in water resource management and a strategy for Water Services Institutions (WSI).

This implies that, irrespective of the water demand management (WDM) objectives, it is necessary to have a long-term WC objective that acknowledges that South Africa is a water-scarce and water-stressed country.

The NWCDMS framework has eight objectives with linked strategic outputs defined per water sector institution. These are listed in Table B.19, together with the links to artificial recharge. The role of artificial recharge in Water Conservation is listed in Table B.20.

Table B.19: National Water Conservation/Water Demand Management Strategy framework objectives and the role of artificial recharge

Objective	Description of Objectives	Potential for AR contribution to objective	Need for AR to be included in outputs linked to objective
Objective 1	To facilitate and ensure the role of WC/WDM in achieving sustainable efficient and affordable management of water resources and water services	✓	✓
Objective 2	To contribute to the protection of the environment, ecology and water resources	✓	✓
Objective 3	To create a culture of WC/WDM within all water management and water services institutions		✓
Objective 4	To create a culture of WC/WDM for all consumers and users		✓
Objective 5	To support water management and water services institutions to implement water WC/WDM		✓
Objective 6	To promote the allocation of adequate capacity and resources by water institutions for WC/WDM		✓
Objective 7	To enable water management and water services institutions to adopt integrated planning		✓
Objective 8	To promote international co-operation and participate with other Southern African countries, particularly basin-sharing countries, in developing joint WC/WDM strategies.		✓

Table B.20: The role of artificial recharge in the spheres of water conservation

	Spheres of Water Conservation		
AR Purpose *(Refer to Section B.1 for description of each)*	**Minimisation of loss or waste**	**Care and protection of water resources**	**Efficient and effective use of water**
Seasonal storage	✓Evaporation		✓
Long-term storage (water banking)	✓Evaporation		✓
Emergency storage	✓Evaporation		✓
Enhance wellfield production		✓	✓
Restore groundwater levels		✓	✓
Reduce subsidence		✓	✓
Improve water quality		✓	✓
Prevent saltwater intrusion	✓	✓	✓
Hydraulic control of contaminant plumes		✓	
Reduce environmental effects of streamflow diversions and maintain the Reserve	✓	✓	✓
Defer expansion of water facilities			✓
Storage of treated water	✓		✓
Storage of reclaimed water	✓		✓
Utilise saline aquifers			✓
Nutrient reduction in agricultural runoff		✓	✓
Stabilise aggressive water			✓
Diurnal storage			✓
Temperature control			✓

B.4.4 Regional scale artificial recharge planning potential

B.4.4.1 Criteria for site selection

For the purpose of generating generalised national maps indicating the potential for artificial recharge, the factors listed in Table B.21 have been used.

Table B.21: Factors for identifying potential areas for artificial recharge application

Factor	Description	Comment
Hydraulic conductivity	The rate at which the aquifer can receive and supply artificially recharged water.	Intergranular aquifers and high-yielding fractured aquifers (See Section B.4.4.2).
Aquifer storage	The volume of aquifer storage available for AR.	Calculated using 50% of the available storage above the average water level, and mapped for the areas identified by hydraulic conductivity (See Section B.4.4.3).
Need	The need for artificial recharge should relate to all groundwater users, including the Reserve.	Municipal and agricultural users have been considered (See Section B.4.4.4). In Appendix 1 the AR potential is related to the total water requirements per sub-WMA.
Water source	Availability of a source water for AR.	In Appendix 1 the total local yield per sub-WMA is given.
Infrastructure	The location of major dams, water transfer infrastructure and water treatment facilities.	Major dams are mapped for each WMA in Appendix 1. Major inter basin transfers are shown in the NWRS but not captured in Appendix 1.

B.4.4.2 Aquifer type and hydraulic conductivity

The feasibility of successful artificial recharge implementation depends on numerous factors that are relevant at a local level. However, in order to provide a rough indication of suitable areas on a regional scale, areas of high hydraulic conductivity have been identified. These include the following:

- **Primary aquifers.** Primarily alluvium, coastal aquifers and localised riverbed alluvium. The zones identified as intergranular with borehole yields more than 0.5 L/s on the 1:500 000 hydrogeological maps have been used for this purpose. artificial recharge by means of surface infiltration may be appropriate in such areas.

- **Fractured and weathered aquifers with high borehole yields.** Two criteria have been used to identify these hard-rock aquifers: those with borehole yields more than 5 L/s and those with yields of more than 10 L/s. A 1 km^2 grid with borehole yields recorded in the National Groundwater Data Base (NGDB) has been used to identify the areas of high borehole yield. Those that fall into the Fractured and Weathered sections on the 1:500 000 hydrogeological maps were used to identify the prime artificial recharge areas. Artificial recharge by means of borehole injection may be appropriate in such areas.

Figure B.23 shows the areas of artificial recharge potential based on the above criteria for aquifer suitability.

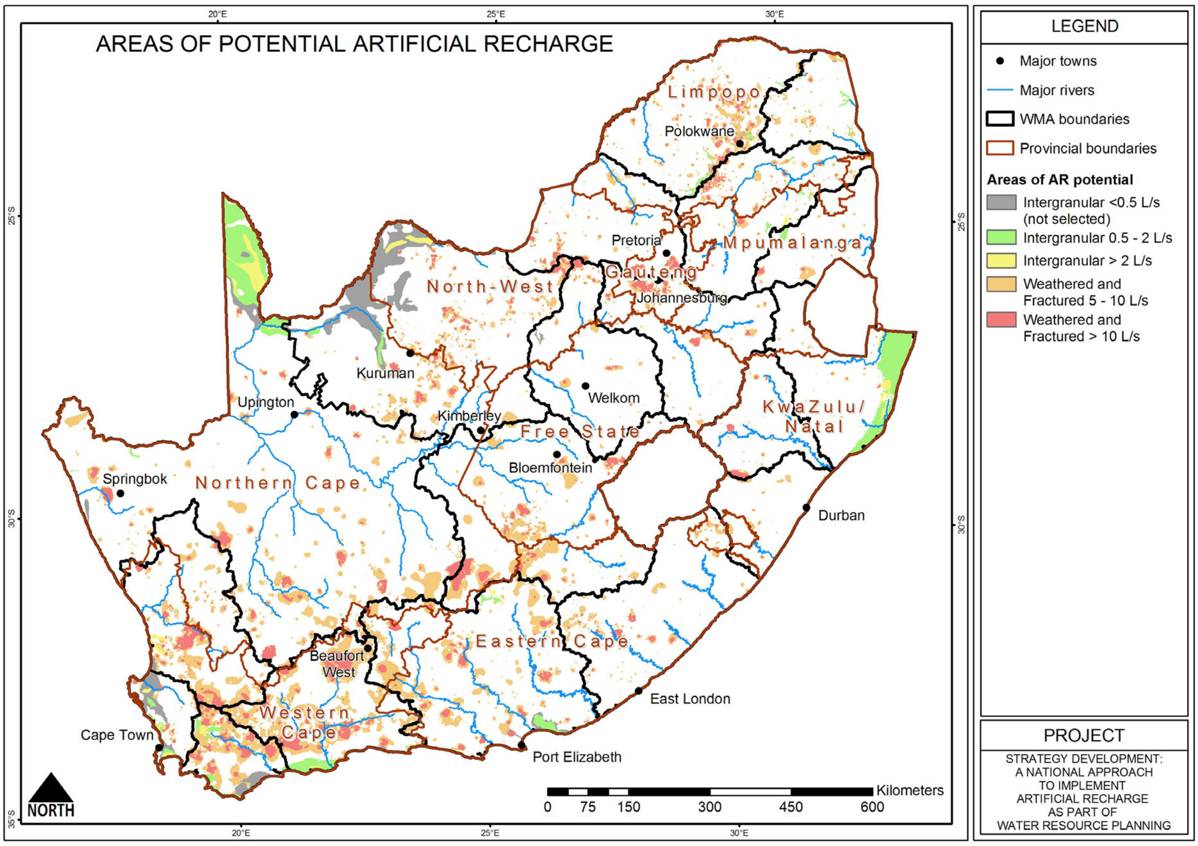


Figure B.23: Areas of artificial recharge potential based on aquifer type and areas of high hydraulic conductivity (borehole yields)

B.4.4.3 Aquifer storage

Aquifer storage available for artificial recharge has been calculated based on the approach adopted by, and the data used in, DWAF's GRA II project. Storage is obtained by multiplying: Surface area x Aquifer thickness x Coefficient of storage.

In order to obtain aquifer thickness for artificial recharge purposes, the following surfaces were calculated on a 1km^2 grid:

- Top of the aquifer (a). This level has been taken from the GRA II project, and is represented by a surface connecting the valley floors as shown in Figure B.24.

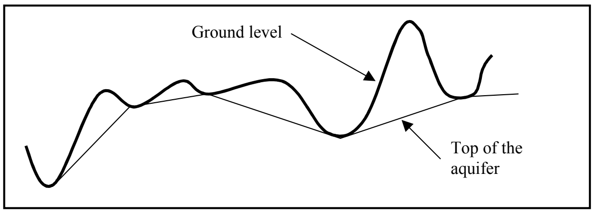


Figure B.24:Top of the aquifer

- Average water level (b). This level has been created from the NGDB recorded water levels.
- Base of weathered storage (c) has been developed under the GRA II project.
- Base of fractured storage (d) has been developed under the GRA II project.
- 5 m drawdown water level (f) – 5 m below the average water level (b)

An additional water level grid was developed, relative to these levels:

- Artificial Recharge Top level (e) is 50 percent of the difference between the average water level and the top of the aquifer.
  i.e. AR top level (e) = (b+0.5(a-b))
  Measured in metres above mean sea level (mamsl)

The values for the average specific yield of the weathered zone and the average storativity of the fractured zone used to calculate the storage volumes are based upon GRA II values for the sixty four hydrogeological regions.

Based on these water levels, the theoretical artificial recharge storage volumes have been calculated as the volume of water stored between the artificial recharge top level and the average water level.

The different aquifer and water levels used in the calculation of the artificial recharge storage volumes are illustrated in Figure B.25.

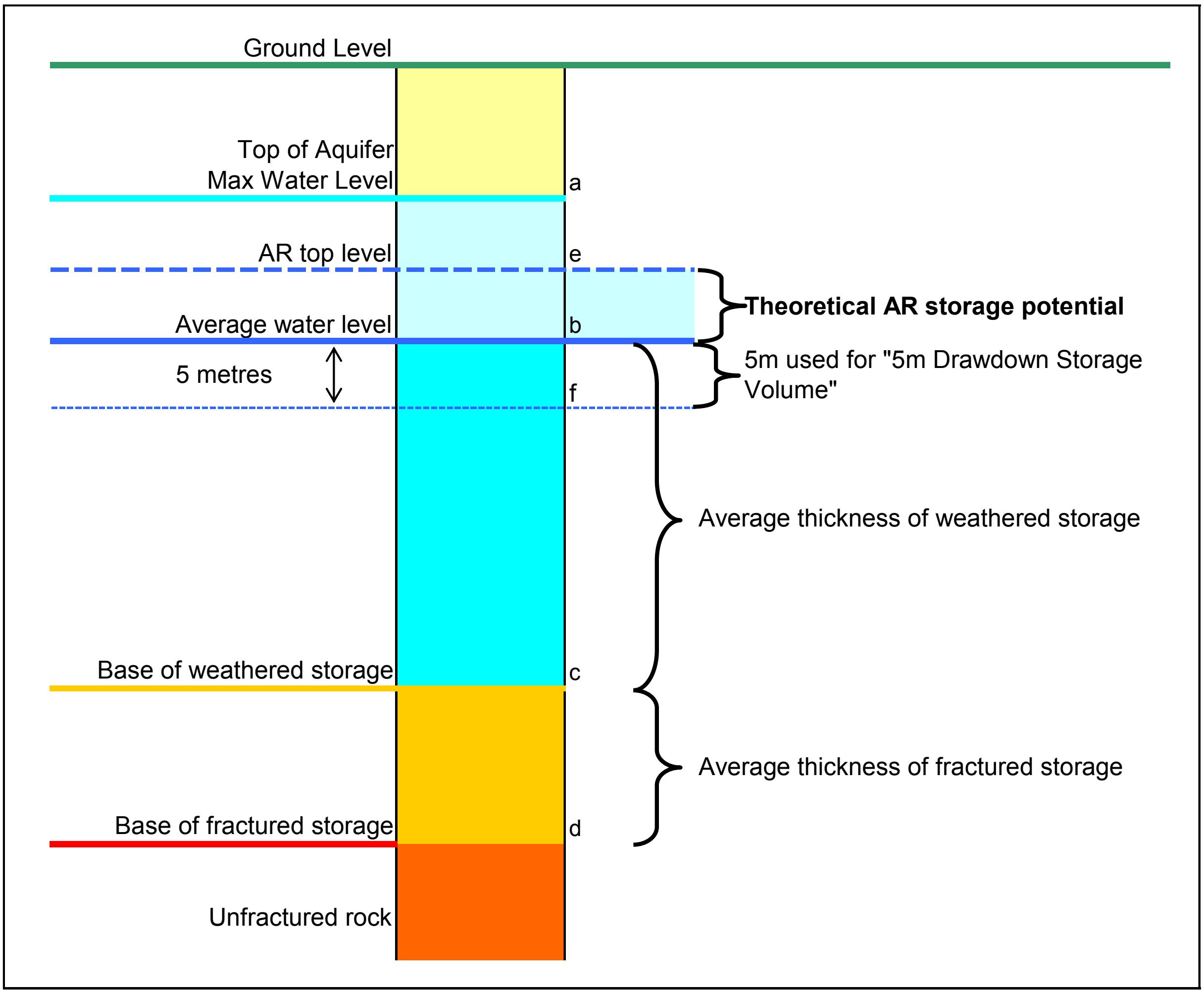


Figure B.25: Water levels and surfaces used for the calculation of artificial recharge storage potential

The calculated theoretical artificial recharge storage potential is illustrated in Figure B.26 and summarised by Water Management Area (WMA) in Table B.22.

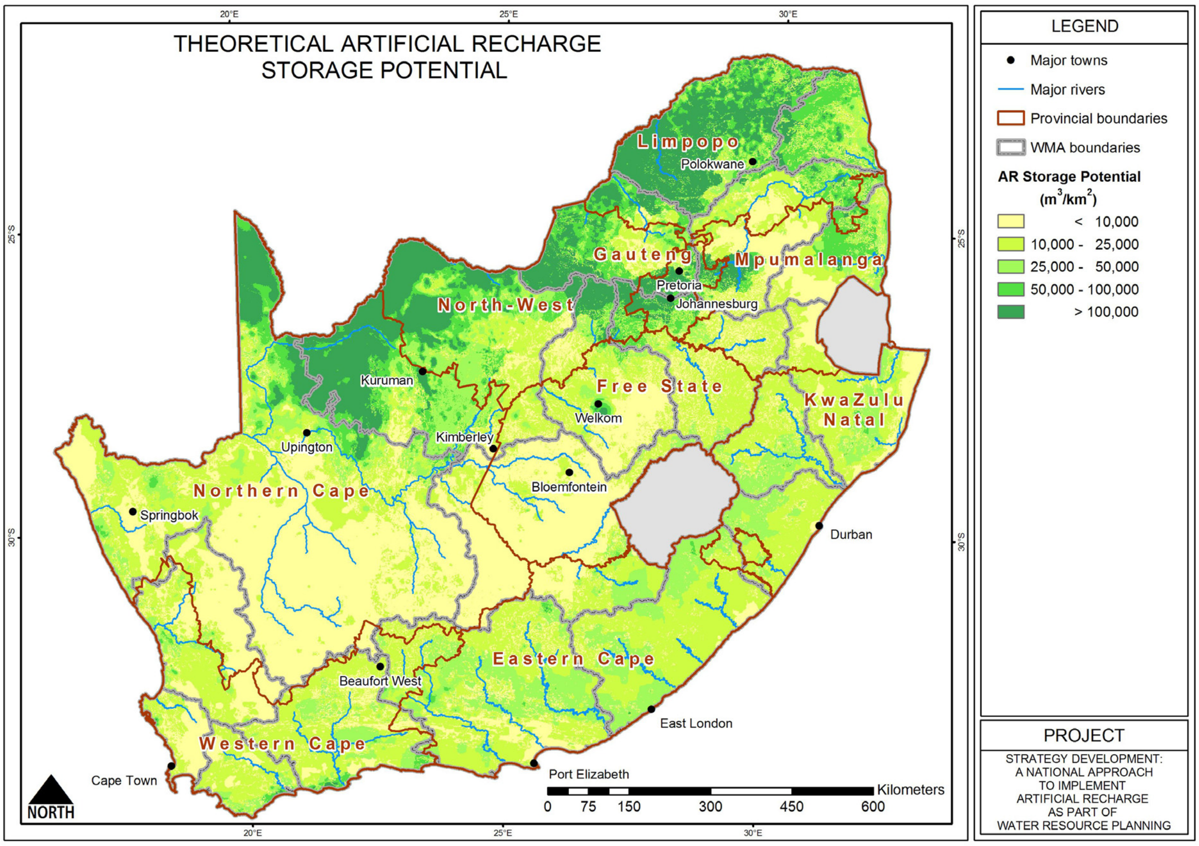


Figure B.26: Theoretical artificial recharge storage potential in m^3/km^2

The high groundwater storage potential shown in the northern and north-western parts of the country is explained by the fact that the data sets used from the GRA II Project placed the top of the aquifer surface far above the average water level. In many of these areas it may be unrealistic to assume that such large thicknesses are available for artificial recharge. In order to obtain more realistic storage capacities in these areas, the levels should be adjusted using localised data sets.

All areas are not suitable for artificial recharge because of aquifer hydraulic conductivity limitations. In order to reduce the country-wide storage potential to areas where artificial recharge is more likely to be feasible, the high potential areas identified in paragraph B.4.4.2 have been selected. In this way, the area is reduced to crudely accommodate hydraulic conductivity. Figure B.27 and Table B.22 are based upon the storage in this reduced area.

A more realistic quantification of artificial recharge storage potential could be made per WMA Sub-Area using detailed information for the area and by:

- Using a grid size smaller than the $1km^2$ grid
- Re-assessing the storage layers
- Re-assessing the coefficients of storage
- Re-assessing the extent of the artificial recharge areas
- Mapping the location of water sources, existing infrastructure and areas of need.

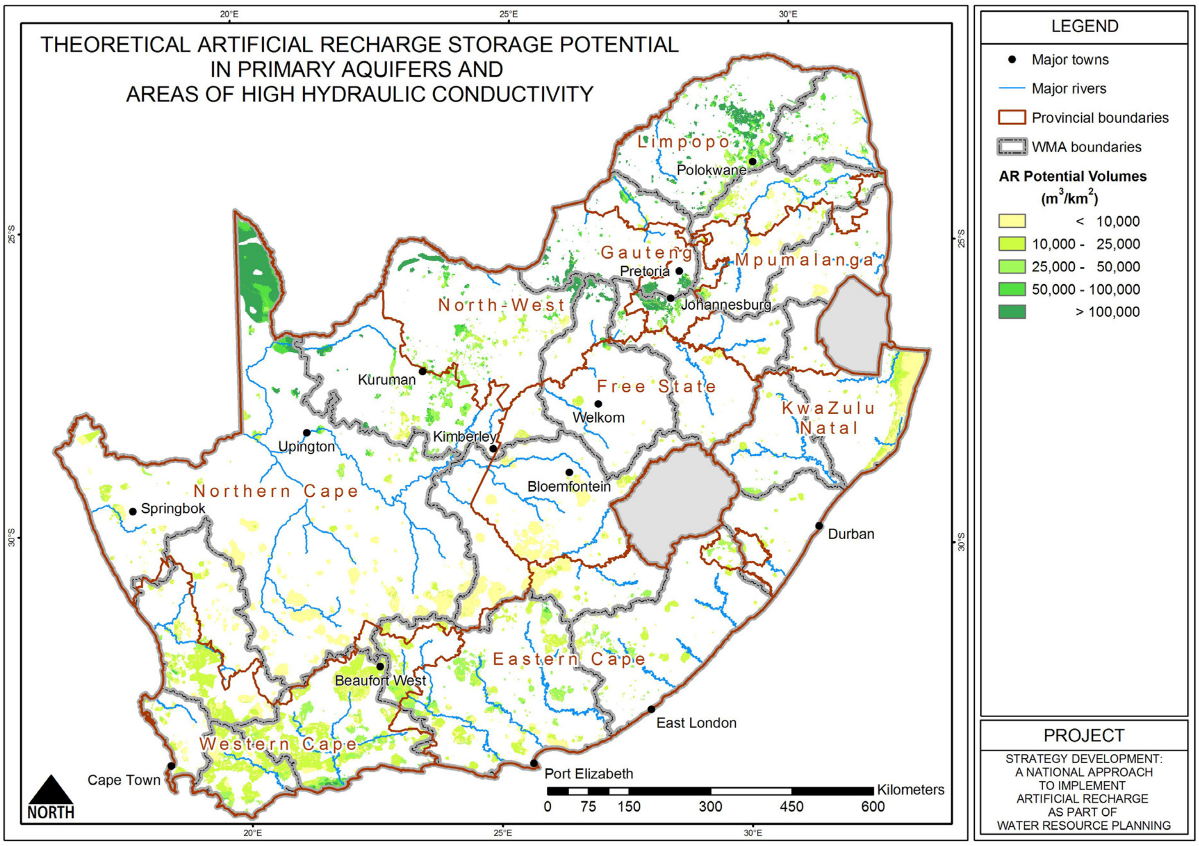


Figure B.27: Potentially favourable artificial recharge areas based on aquifer storage and hydraulic conductivity (areas of high borehole yields)

Table B.22/….

Table B.22: Theoretical potential artificial recharge storage

	Theoretical potential AR storage (million m³)			
Water Management Area	**Integranular**	**Fractured and karst areas with boreholes with yields >10l/s**	**Fractured and karst areas with boreholes with yields 5-10l/s**	**Total potential AR storage**
1. Limpopo	54	807	302	1163
2. Luvuvhu	18	98	11	127
3. Crocodile West Marico	16	486	733	1235
4. Olifants	7	114	42	163
5. Inkomati	2	14	2	17
6. Usutu-Mhlatuze	66	6	1	73
7. Thukela	0	12	15	27
8. Upper Vaal	0	259	183	441
9. Middle Vaal	0	282	199	481
10. Lower Vaal	298	566	382	1247
11. Mvoti-Umzimkulu	0	21	5	27
12. Mzimvubu-Keiskamma	0	74	24	98
13. Upper Orange	0	77	22	100
14. Lower Orange	1406	156	58	1620
15. Fish-Tsitsikamma	12	270	55	337
16. Gouritz	100	267	84	451
17. Olifants-Doorn	10	98	47	155
18. Breede	26	97	35	157
19. Berg	12	9	4	25
Total	**2027**	**3713**	**2203**	**7944**

The key factors that would influence the artificial recharge storage volumes listed above are:

- The surface area selected
- The aquifer storage coefficient
- The heterogeneity of the aquifer in terms of hydraulic conductivity and storage
- The available aquifer storage
- The relative timing of aquifer storage availability and recharge source water availability. An aquifer is only useful for artificial recharge if it can accept the water at the same time that the source water is available. The proportion of storage that is practically useable will be dependent on how the artificial recharge scheme is managed.

The theoretical artificial recharge storage potential in the identified prime areas is graphically presented per WMA in Appendix 1. The same method used to identify the prime artificial recharge areas as described in Section B.4.4.2 was used.

The GRA II project provides an estimate of the useable groundwater storage (excluding AR) by taking the volume of water stored between the average water level and the 5m drawdown water level (illustrated in Figure B.25). Five metres was selected to represent a reasonable level to which groundwater levels could be drawn down without causing the dewatering of aquifers or environmental problems. It is an aquifer management level, and for the GRA II project, was generalised over the entire country, to be 5m.

The 5m drawdown storage volume has been selected for the artificial recharge favourable areas (from Figure B.27) and is listed per WMA in Table B.23 together with the potential artificial recharge storage. Adding the 5m drawdown storage to the potential artificial recharge storage provides an estimate of the total potential useable storage in the selected high artificial recharge potential areas.

Table B.23: Natural groundwater storage and theoretical potential artificial recharge storage

Water Management Area	5m drawdown storage in AR favourable areas (million m^3)	Potential AR storage in AR favourable areas (million m^3)	Combined potential groundwater storage: AR + 5m drawdown (million m^3)
1. Limpopo	652	1163	1815
2. Luvuvhu	101	127	228
3. Crocodile West Marico	834	1235	2069
4. Olifants	138	163	301
5. Inkomati	15	17	32
6. Usutu-Mhlatuze	54	73	127
7. Thukela	15	27	42
8. Upper Vaal	323	441	764
9. Middle Vaal	454	481	935
10. Lower Vaal	845	1247	2092
11. Mvoti-Umzimkulu	12	27	39
12. Mzimvubu-Keiskamma	67	98	165
13. Upper Orange	119	100	219
14. Lower Orange	398	1620	2018
15. Fish-Tsitsikamma	249	337	586
16. Gouritz	312	451	763
17. Olifants-Doorn	104	155	259
18. Breede	100	157	257
19. Berg	42	25	67
Total	**4834**	**7944**	**12778**

B.4.4.4 Existing groundwater use

Figure B.28 to Figure B.30 illustrate current groundwater use per quaternary catchment per annum for the high artificial recharge potential areas (identified in paragraph B.4.4.2). High levels of current groundwater use can be associated with existing infrastructure for abstracting (and in future, possibly recharging) groundwater. In areas of greater groundwater use, the groundwater is more likely to be stressed and the aquifer is more likely to have available storage space, thereby increasing the possibility of implementing artificial recharge to restore groundwater levels. The GRA II data of groundwater use per quaternary catchment was used.

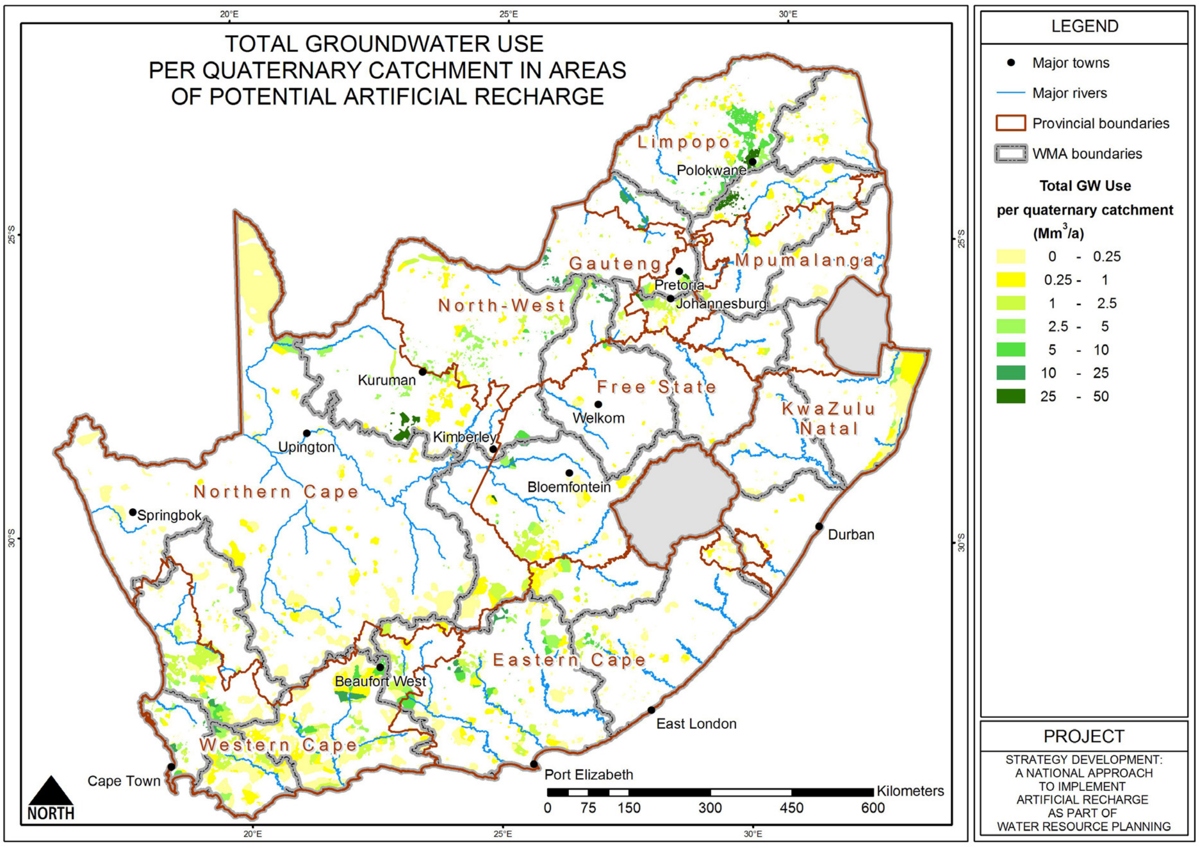


Figure B.28: Total groundwater use per quaternary catchment in areas of potential artificial recharge

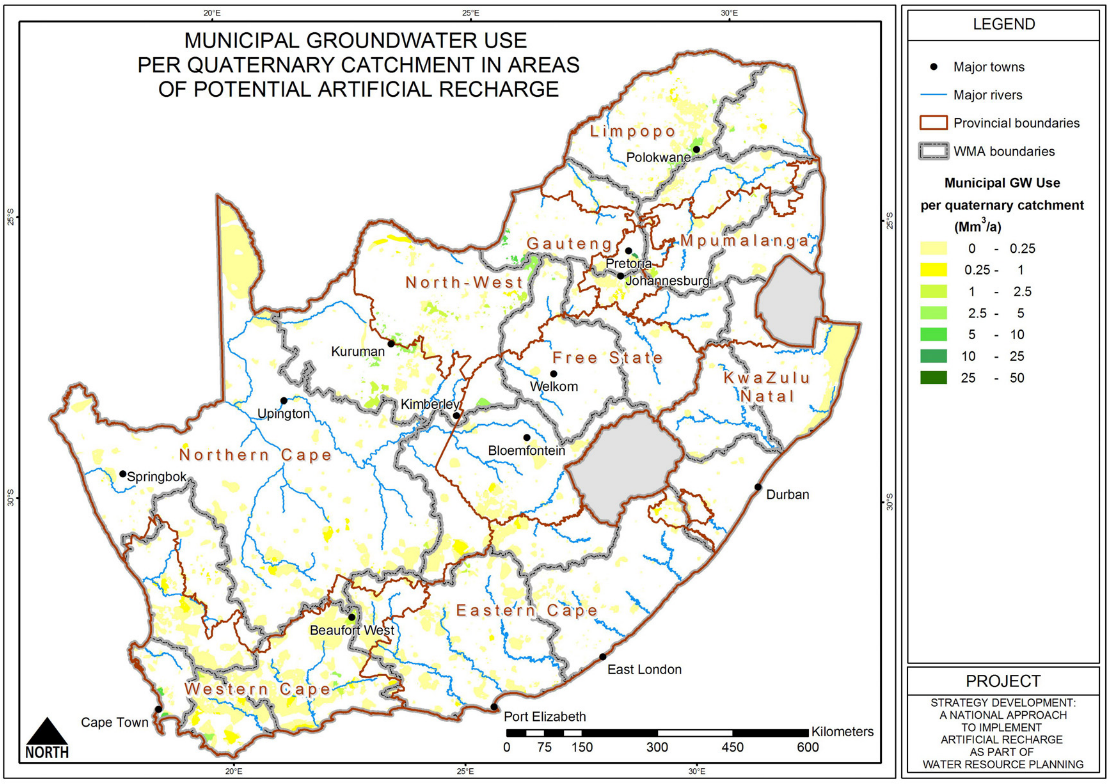


Figure B.29: Municipal groundwater use per quaternary catchment in areas of potential artificial recharge

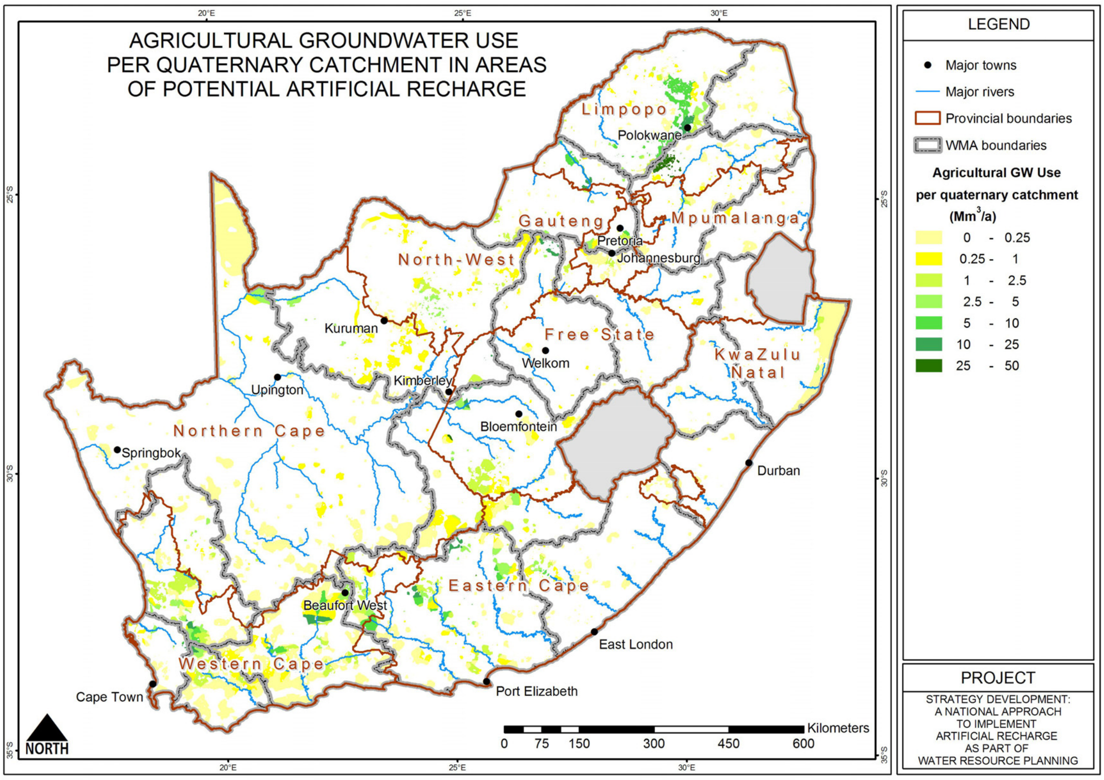


Figure B.30: Agricultural groundwater use per quaternary catchment in areas of potential artificial recharge

SECTION C:
IMPLEMENTATION AND AUTHORISATION

C.1 CRITERIA FOR SUCCESSFUL IMPLEMENTATION

This section summarises the key factors that the potential for implementing a successful artificial recharge project. It draws on a number of documents and reports, including the Water Research Commission Report entitled, *"Artificial Recharge: A Technology for Sustainable Water Resource Development"* (Murray and Tredoux, 1998).

Since most artificial recharge concerns, and therefore research, revolve around water quality and clogging issues, they are discussed in far greater detail than other issues. Although there are numerous factors that affect the viability of artificial recharge schemes, it appears that, in most international cases, an understanding and an ability to deal with water quality and clogging issues are essential for the successful operation of a scheme.

In South Africa, this is likely to be the same for unconsolidated, sandy aquifers. While both water quality and clogging issues will also be a concern in hard-rock aquifers, the nature of the sub-surface flow will likely be of equal or greater concern. This is because the heterogeneity of fractured aquifers offers the additional complication of "where is the water going to?" and "where will it be best to re-capture it?" Fortunately, a large component of groundwater research in South Africa has been conducted on flow in fractured aquifers, and thus our scientists are well equipped to deal with such issues.

The key issues have been divided into:

1. The need for an artificial recharge scheme
2. The source water
3. Aquifer hydraulics
4. Water quality (including clogging)
5. The artificial recharge method and engineering issues
6. Environmental issues
7. Legal and regulatory issues
8. Economics
9. Management and technical capacity
10. Institutional arrangements

All artificial recharge Pre-feasibility and Feasibility Studies should include information on the above ten "success criteria".

C.1.1 A clearly defined need

Artificial recharge schemes generally serve a primary need and one or more secondary needs. The objectives of an artificial recharge scheme must be clearly articulated and an approach to assess its success defined, such as defining key performance indicators.

Most schemes throughout the world have been implemented to address a localised water-related problem, for example, water supply for a town or a farming area. This will probably continue to be the case in South Africa; where a localised problem exists, and where both the water source and the aquifer are suitable for artificial recharge. On a regional scale, however, there are areas where both the surface and groundwater resources are nearly fully developed and utilised (e.g. in a number of WMAs in the northern part of the country), and over-exploitation occurs in some localised areas (NWRS, 2004). There is a need to maximise water conservation measures in these areas, and artificial recharge could play an important role where the conditions are favourable for its implementation.

Water supply authorities often think that artificial recharge will solve their problems whereas there may be other measures that could be implemented prior to considering artificial recharge, such as water demand management (WDM), extending existing wellfields or developing new wellfields. Most municipalities in South Africa do not adequately monitor groundwater levels and abstraction, and therefore have little, if any knowledge on how their aquifers are performing. The common statement that “our boreholes run dry” is frequently a statement of mismanagement and an indication that the boreholes are pumped at too high a rates – and not necessarily that the aquifers have been dewatered. That is, the rate at which water can enter boreholes from the aquifer is less than the rate at which they are pumped. By monitoring water levels in both production boreholes and non-production boreholes located away from the pumped boreholes, it would be possible to establish whether aquifers’ are indeed stressed, and/or whether borehole pumping rates are too high. Artificial recharge is only required for water supply purposes if aquifers are stressed or have potential to be stressed.

During the artificial recharge pre-feasibility study (described in Section C.2), all existing groundwater level and abstraction data must be assessed, and if there is a lack of such data, then a monitoring programme has to be implemented immediately. At the very least, a full year of groundwater level data is required to establish whether artificial recharge is necessary or not.

Groundwater level data is critical to assess whether artificial recharge is necessary.

As soon as an artificial recharge project is conceived, start monitoring groundwater levels and abstraction; and establish seasonal groundwater and artificial recharge source water quality.

C.1.2 The quantity and reliability of the source water

The quantity, reliability and quality of a water source determine whether or not it is suitable for artificial recharge. This section discusses quantity and reliability, and the following section address water quality. Recharge water can be obtained from a variety of sources, but mostly from surplus surface water, which cannot be used or reused directly for a variety of reasons, and is lost as outflow to the sea, or through evaporation.

The total available surface water yield (at a 98 percent assurance of supply) for the country is estimated to be 10 240 Mm^3/a derived from a natural mean annual runoff (natural river flow) of 49 040 Mm^3/a (NWRS, 2004). There is therefore plenty of water available on a national scale for sub-surface storage. Even in areas such as the northern parts of the country, where the water resources are nearly fully utilised, surplus river water is available (the natural river flow far exceeds the reliable local yield). The suitability for AR will likely relate to the timing of the available water (seasonality) together with other factors such as water quality, ability of the local aquifer to receive the water, etc.

It is important that the water for aquifer recharge purposes is of consistently high quality and has fairly predictable quantity over time. Water quality is covered in the following section. In most artificial recharge schemes, there is a reasonable consistency in supply during the infiltration/injection stage, but in schemes that rely on surface runoff, particularly those in arid and semi-arid areas, reliability is a problem. However, the value of opportunistic artificial recharge can still significantly increase the security of supply.

Table C.1 provides a comparison of the quantity, reliability and quality of various water sources. In regards to rivers and dams, quantity and reliability are related to size, existing allocations and geographic location (climatic region).

Table C.1: Water sources for AR

Source water	**Quantity**	**Reliability**	**Quality**
Rivers	Variable	Variable	Variable
Dams	Variable	High	Low - High
Treated municipal waste water	Consistent	High	Low - High
Aquifers (i.e. transfers from other sub-surface reservoirs)	Consistent	High	Consistent
Urban runoff	Variable	Moderate - High	Variable
Agricultural return flows	Variable	High	Low
Rainfall harvesting	Variable	Moderate - High	High

C.1.3 Aquifer hydraulics

Two main physical characteristics determine whether or not an aquifer is suitable for accepting, storing and recovering artificially recharged water. These are the aquifer's hydraulic conductivity and its storage capacity. A third important factor is the aquifer's hydraulic gradient and the natural geological barriers to flow. These relate mostly to the recovery of the recharged water. The key questions are:

- Will the recharge water be able to flow into the aquifer (permeability/hydraulic conductivity)?
- Will the aquifer have sufficient space to accept the water (storage)?
- Will the water be recoverable?

Aquifers which have high hydraulic conductivity and which have high storage capacity are more suitable for receiving additional recharge water than those which have low conductivity and capacity (Figure C.1). Highly permeable aquifers, however, are not always ideal for artificial recharge if high quality water is stored in a saline aquifer, as this may result undesirably high blending ratios. Aquifers with high hydraulic conductivity and high hydraulic gradient may also be problematic, as water will flow rapidly away from the point of recharge and may be difficult to recover. This problem is greatest in fractured aquifers and can be averted either by placing recovery boreholes down-gradient of the recharge facility, or by applying ASR principles and reversing the hydraulic gradient during pumping so that water flows back towards the initial point of recharge.

The key issues of storage and hydraulic conductivity are depicted in Figure C.1

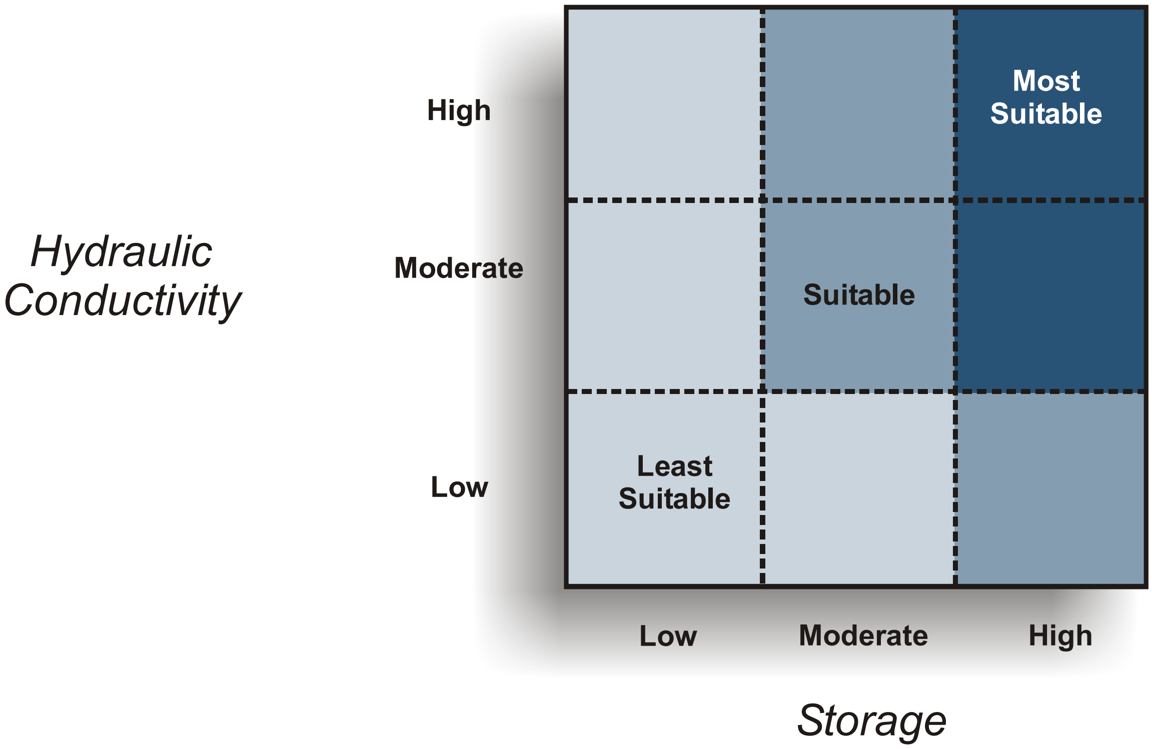


Figure C.1: Suitability of an aquifer to receive artificially recharged water (Murray and Tredoux, 1998)

C.1.3.1 Aquifer geology and geometry

The first step in establishing the hydraulic characteristics of the aquifer is to develop an understanding of its the geological setting. This includes defining which geological formations comprise the aquifer or aquifers targeted for artificial recharge. It requires developing a conceptual flow model for the aquifer based on its geological setting (including its boundaries) and an assessment of the natural recharge and discharge areas.

C.1.3.2 Storage potential

Unconsolidated, inter-granular aquifers have a greater storage capacity than hard-rock aquifers. Their coefficient of storage, which is related to porosity, is generally one to three orders of magnitude greater. For this reason, alluvial aquifers, coastal sands and the infrequent thick inland sandy deposits are prime targets for the storage of considerable volumes of water. These environments also provide good media for basin recharge and water treatment (SAT).

In South Africa, many aquifers are filled up during the rainfall season. Groundwater levels are commonly within 10 – 20 m of the land surface, and groundwater discharges as springs and seeps. In many areas, the elevated wet-season water levels in rivers, dams and wetlands, are due to overflowing groundwater. Under these conditions, it makes no sense to artificially recharge groundwater. However, artificial recharge creates the opportunity to modify groundwater management practices and to abstract groundwater at rates over and above the naturally sustainable rate – provided that this does not have major environmental or social impacts. The most common impact is caused by lowering the water table, and this can reduce groundwater outflow to areas that previously received a perennial supply (from springs and seeps). It can also cause land subsidence in vulnerable geological environments and boreholes to go dry.

Boxes B.1 and C.1, adapted from DWAF's Groundwater Resource Assessment II Project (DWAF, 2005), provide an overview to the issues related to maximising groundwater use. A key message is that, by applying scientific tools, it is possible to obtain reasonable estimates of sub-surface storage However, in many instances, it remains a management decision, based on prevailing policies, that determines the proportion of the storage volume that can be allocated for use.

Based on particular management criteria, the volume of storage available for use in an artificial recharge scheme will need to be determined. In some cases, where the environmental and social costs are high, it may not be possible to utilise static storage. In other areas, where the environmental and localised social costs are small, and where the broader social needs of having access to water, and the economic gains of having a secure supply outweigh the environmental costs, the allocatable storage may also include the static component.

In Section B.4, a regional scale GIS-based approach is used to assess the artificial recharge potential that includes an assessment of available storage.

Box C.1 Groundwater use: An issue of science, policy and terminology

The volume of water held in sub-surface storage is variable depending on how full the aquifer is, which is a function of inflows and outflows. The reason for quantifying groundwater is to know how much water on a time basis can be abstracted from a specific area to meet certain requirements. That is, it is time-based, and it is requirements-based. From this definition, the quantity of groundwater that should be pumped over a given period could range from none (the requirement, for example, may be to strive towards pristine conditions) to as much as possible, where the requirement, for example, may be to mine the water as an emergency need whilst another source is being developed for the long-term supply.

This approach takes into account both the procedures of science and guidance of policy. Put simply, science can provide an estimate of how much water is available for use, and policy dictates how much of that must be “left alone” or “used” to meet specific environmental and social requirements.

It is worth noting that there has been considerable debate ever since the first negative effects of large-scale groundwater abstraction were noticed. In 1920, the concept of safe yield was introduced after large-scale abstraction in the western USA was made possible with deep boreholes and electricity-driven turbine pumps. Since then the safe yield concept has been modified and numerous papers have been written on approaches to quantifying groundwater. Some of the terms and concepts that have been developed since the early 1900s are:

- Safe yield
- Sustainable yield
- Groundwater availability
- Exploitation potential
- Abstraction potential
- Harvest potential
- Optimal yield
- Consensus yield.

Added to these terms are those that are commonly used without precise meaning or definition:

- Groundwater overexploitation, over-use, over-extraction and over-development
- Groundwater mining
- Stressed aquifer
- Unsustainable use.

This latter group of terms is used particularly in areas where groundwater is intensively exploited, but the terms are also being used to refer to problems of simple interference between boreholes or mismanagement.

C.1.3.3 Hydraulic conductivity

Hydraulic conductivity of a soil or rock defines its ability to transmit water. It is dependent on a variety of physical factors, which for sandy aquifers, includes porosity, particle size and distribution, shape of particles, arrangement of particles, etc. In hard rock aquifers, the factors include density, apertures and roughness of the fractures.

For the successful application of infiltration and injection artificial recharge schemes, hydraulic conductivity needs to be sufficient both at the point of recharge and further afield. In hard rock environments, this means that the fractures need to be reasonably extensive and interconnected.

The GIS study in Section B.4 takes hydraulic conductivity indirectly into account by prioritising areas with high yielding boreholes.

C.1.3.4 Hydraulic gradient and flow directions

The hydraulic gradient determines where the water will flow once it has entered the sub-surface. This is important to know for locating the recovery boreholes. In many cases, it may be possible and cost-effective to recover the water at the point of recharge (eg using ASR boreholes). Depending, for example, on the planned storage residents times, or whether in situ treatment (eg SAT) is needed, it may be preferable to abstract the water down-gradient of the recharge point.

C.1.4 Water quality

The introduction of artificial recharge generally addresses problems such as the over-exploitation of water resources, saline water intrusion, and a whole series of other issues threatening the continued use of the resource. However, artificial recharge can only succeed if the longer-term sustainability of the practice can be assured. In this respect, experience gained over many decades has demonstrated that the quality of recharge water is the key issue. As a result, extensive pre-treatment of recharge water has been developed for reducing the dependence on purification and blending in the aquifer for quality improvement.

Ecological sustainability issues currently seem to be the most important concern of artificial recharge applications abroad. Pressures are exerted to restore the hydrological systems to their more natural state and to concentrate artificial recharge activities on more confined areas (Olsthoorn & Mosch, 2002). These perspectives need to be taken into account in the development of local artificial recharge schemes, implying that artificial recharge schemes should not overly rely on subsurface water quality improvement but rather be mainly designed for the storage or banking of water. Subsurface storage of water generally adds a safety/protection "barrier" for drinking water supply systems but, where relevant, any water quality improvement in the subsurface should be considered a bonus.

Dillon (2005) sets out a number of objectives for the ASR Code of Practice being developed in Australia. Six of the aims of the primary objective specifically relate to water quality and state the following:

- Protect or improve groundwater quality wherever ASR and ASTR is practised
- Ensure that the quality of the recovered water is fit for its intended use
- Prevent problems such as clogging and excessive recovery of aquifer material
- Ensure that the impacts on surface waters, downstream of ASR and ASTR operations, are acceptable and are taken into account in catchment water management
- Ensure that an appropriate public and environmental health risk assessment and management strategy is in place to deal with potential variations in water quality of injectant.

These objectives are generally valid for all artificial recharge schemes and these form the basis for the water quality aspects discussed below.

C.1.4.1 Quality of groundwater

One of the objectives of artificial recharge is to protect or improve groundwater quality. In the majority of cases where groundwater is utilised as a potable supply, or for stock-watering, irrigation or other purposes, the objective would be to recharge with good quality water that would maintain the existing use or even elevate it to a higher level. The recharge water quality would then not be worse than that of the natural groundwater in the particular aquifer. This principle should be adopted as a general rule and exceptions should need individual investigation and approval. An example of an exception would be the recharge of wastewater into highly saline aquifers (e.g. for disposal).

The natural quality of groundwater will also determine the extent to which blending with compatible water is possible without affecting the aquifer and the usability of the water.

Converting saline aquifers to useable water resources by means of artificial recharge is becoming increasingly popular. Suitable “brackish” aquifers in South Africa need to be identified where recharge with good quality water would gradually dilute or replace the ambient saline groundwater and make them usable.

C.1.4.2 Blending of source water and natural groundwater

Surface water used for recharge in an artificial recharge scheme is usually saturated with oxygen. Most groundwater, on the other hand, may still contain dissolved oxygen, but in general, deeper layers of the aquifer are more anoxic or even anaerobic. Thus, the relevant hydrochemical species such as iron, manganese and other metallic ions, as well as nitrogen and sulphur compounds, will be in the reduced form. The oxidation-reduction potential (Eh) of the recharge water will therefore differ significantly from that of the groundwater.

The oxygen content and Eh of groundwater vary from humid to arid regions. This is largely due to the presence of organic compounds that are more abundant in humid areas. The oxidation of such compounds consumes oxygen, causing reducing conditions at shallower depths in humid regions. Pyne (1995) describes Eh as one of the most important measurements for in situ groundwater, particularly when the iron and manganese concentrations are more than 0.1 mg/L. Likewise, dissolved oxygen (DO) is an important field measurement for both groundwater and surface water (Pyne, 1995). In the case of chlorinated surface water, the Eh may be elevated and the DO value may be more meaningful.

Groundwater abounds with micro-organisms that mostly originate from the soil horizon. Although chlorination may sterilize the recharge water, the microbiological activity in the aquifer is sufficient to promote bacterially-mediated reactions such as nitrification, denitrification, and reduction of sulphate, iron, and manganese when recharge water blends with groundwater. It may be impossible to modify the oxidation-reduction potential in the subsurface but compounds that will cause changes in the subsurface hydrochemistry can be eliminated. In this way, the recharge water can be made more compatible with the ambient groundwater.

C.1.4.3 Water-rock interactions

As indicated above, high quality surface water is generally well-aerated, that is, saturated with oxygen. Injection of such water into the aquifer introduces oxygen into areas which are less oxidising or even reducing. Similar to the interaction with the ambient groundwater, the significant change in oxidation-reduction potential has to be accepted, the only possibility being to limit the concentration of compounds that are sensitive to changes in Eh.

The geological material of primary aquifers is often deposited from lakes and other water bodies including marshes. This causes the material to be inherently reducing, as it will contain reduced ions and compounds such as ammonium, sulphide, and organic constituents. Oxidation of pyrite occurring in the aquifer matrix (also bacterially mediated) will increase the sulphate concentration of the groundwater and will also bring iron into solution. Should the recharge water also contain nitrate, it may be denitrified, but the reaction will enhance the oxidation of sulphide. These characteristics are also found in fractured aquifers of sedimentary origin (e.g. the quartzite in the Windhoek aquifer). Igneous rocks or intrusions, containing ammonium ions in the rock matrix, may also give rise to aquifers of reducing nature. In addition, unwanted constituents forming part of mineral assemblages in the geological matrix (e.g. arsenic present in pyrites) will also enter into solution. This is the case with the Calvinia breccia pipe which is highly alkaline and has strong reducing properties (Cavé & Tredoux, 2002).

In carbonate aquifers, the removal of calcium carbonate may be substantial. This may compromise the stability of the aquifer in the longer term (example: Vanderzalm *et al*., 2002).

The sustainability of the intended artificial recharge scheme can be tested using the approach by Stuyfzand (2002) to predict and quantify the hydrogeochemical impact and sustainability of artificial recharge schemes.

C.1.4.4 Clogging

Clogging, or “plugging”, (Pyne, 1995) refers to the reduction in permeability of the filtration surface of the recharge facility, or, the reduction in available pore volume and permeability in the aquifer. This phenomenon is complex and is due to a combination of physical, biological and chemical processes (Pérez-Paricio, 1998). The effect of filtration surface clogging can be observed readily in the reduction of the infiltration / injection rate. Aquifer clogging is more difficult to detect as it generally occurs gradually. In the case of injection boreholes, the surface area is relatively small and the phenomenon of clogging can be rapid and irreversible. It is generally more easily managed in basin recharge.

Various forms of clogging, each of which could be a combination of physical, biological and chemical processes, have been listed (Dillon & Pavelic, 1996; Pyne, 1995):

- Filtration of suspended solids
- Microbial growth
- Chemical precipitation
- Clay swelling and dispersion
- Air entrapment (or entrainment)
- Gas binding (release of dissolved or generated gases)
- Mechanical jamming and mobilisation of aquifer sediments.

Clogging is an operational problem largely related to the quality of the recharge water. However, site-specific conditions, such as aquifer and groundwater characteristics, borehole construction and recharge facility design, all influence the clogging process (Pyne, 1995). According to Rinck-Pfeiffer *et al* (2002), clogging remains the main factor affecting the feasibility of new ASR projects using low-quality source water. Biological clogging is considered to be of primary importance when nutrient-rich reclaimed water is injected into boreholes.

According to Dillon & Pavelic (1996), some 80 percent of ASR sites surveyed reported clogging problems. Half the sites reported physical clogging due to filtration of suspended solids. Microbial growth was a problem at 15 percent of sites and chemical precipitation caused clogging at 10 percent of sites. Other causes of clogging included air entrapment (10 percent), clay swelling and dispersion (5 percent) and mechanical jamming and mobilisation of aquifer sediments (5 percent).

Over the longer term, almost all artificial recharge schemes will be affected by clogging, although the rate and intensity of the problem will vary. For this reason, all schemes should make provision for remedial measures. However, Pérez-Paricio (1998) stated that prevention remained the best approach, in spite of the existence of sophisticated redevelopment techniques. Recharge water quality is the key factor and suspended solids are listed as the main criterion for both surface infiltration schemes and borehole injection. Other important parameters include pH, organic carbon concentrations and nutrients. In the case of artificial recharge by injection, air entrapment or gas generation should be avoided.

Adequate and timely identification of clogging generally leads to the opportunity to restore the initial capacity of the scheme by using a suitable redevelopment method (Pérez-Paricio, 1998). However, the prediction of clogging remains uncertain, despite many attempts at using parameters such as total suspended solids and turbidity for physical clogging, and total organic carbon, dissolved organic carbon and assimilable organic carbon for biological clogging.

The practical approach, as advocated by Pyne (1995), (Pérez-Paricio, 1998) and confirmed by Bouwer (2002), calls for site-specific pilot recharge tests for determining clogging potential of a duration of up to two years or more. Buik & Willemsen (2002) meanwhile developed an approach using a Fouling Index (called the MFI) for deriving physical clogging potential and demonstrated that the calculated values closely approximated the actual field data. They are of the opinion that all other forms of clogging (i.e. those caused by gas bubbles, bacteria and chemical reactions) can be prevented, and they state that physical clogging can be predicted and controlled.

In addition to clogging of the filtration surface and the aquifer, clogging of recovery wells may also occur (Moorman *et al*., 2002). In the Amsterdam dune area, treated Rhine water with high oxygen content was injected into a deep aquifer with naturally anoxic water. The native groundwater had a relatively high iron content of 3 mg/L as well as other reduced chemical species. The recovery well clogged suddenly after two years' operation. The clogging material consisted mainly of ferric (hydr)oxides and ferric hydroxyphosphates, with hydroxyapatite as accessory deposit. Incompatibility of injected and aquifer water is discussed in paragraph C.1.4.2 above and water-rock interaction in paragraph C.1.4.3. Such interactions may be partially responsible for the mobilisation of the iron, although the native groundwater in the above example already had a high iron content. Although iron clogging occurred in the recovery borehole, such clogging is not limited to artificial recharge schemes but also occurs in wellfields where natural groundwater is abstracted.

C.1.4.5 Pre-treatment prior to artificial recharge

The extent of pre-treatment required will depend on:

- The type and quality of the source water
- The type of artificial recharge system employed
- The sustainability requirement of aquifer use
- The intended use of the recovered water.

The type of artificial recharge system and the clogging potential of the water will be important criteria in setting the treatment requirements for recharge water. The removal of suspended solids by flocculation and filtration would be widely applicable for reducing clogging potential. Further, water quality guidelines exist for all types of water use and these will determine the extent of required treatment. However, the interaction between the recharged water, the aquifer material and the ambient groundwater will determine the longer-term sustainability of using an aquifer for AR.

Following the above discussion on blending reactions and the hydrochemical water-rock interaction, pre-treatment principles need to be defined. The principles should include protection of the aquifer, taking potential interactions between the different components into account, and setting limits to any possible degeneration.

C.1.4.6 In situ treatment (including soil aquifer treatment)

The early artificial recharge schemes relied to a considerable extent on the soil/unsaturated zone and hydrochemical reactions in the saturated zone for in situ improvement of recharge water quality. Soil aquifer treatment (SAT) schemes generally rely on the ability of the soil to transform or remove from the recharge water contaminants that may affect groundwater quality (ASCE, 2001).

The Dan Region Project in the coastal region of Israel is the largest water reclamation scheme in the country and relies on SAT as an integral part of the wastewater treatment process (Idelovitch & Michail, 1984). However, the abstracted water from the Project was not intended for indirect recycling of treated wastewater, and the use of abstracted water for potable purposes was discontinued once the recycled water constituted more than 5 percent of abstracted groundwater.

As a result of the limited pre-treatment with high lime dosage in the early stages of the project, breakthrough of contaminants occurred relatively soon. Subsequently, the reclaimed water was used for non-potable purposes, particularly unrestricted irrigation in the south of the country (Kanarek & Michail, 1996). In contrast, where potable recycling is intended, the natural processes during SAT are only relied on to "polish" treated wastewater (Fox, 2002).

Kopchynski *et al*. (1996) studied the effects of soil type and effluent pre-treatment on SAT, using different soils and effluents in soil column studies. The authors confirmed the need for wetting and drying cycles for optimum purification but found that low concentrations of residual organic carbon remained in the water despite variations in conventional pre-treatment. This leads to the conclusion that pre- or post-treatment may need to involve activated carbon adsorption or membrane filtration for removing organic compounds.

The extent to which an aquifer can serve to remove other constituents, such as heavy metals, will depend on policy decisions regarding the acceptable use of the soil-aquifer system and whether any degeneration should be allowed. Re-mobilisation of the pollutants is possible once the oxidation-reduction conditions in an aquifer change. Approaches by different countries are divergent but, in the Netherlands, pressures exist to reduce the "footprint" of artificial recharge activities, and even to restore hydrological systems to their more natural state (Olsthoorn & Mosch, 2002).

The application and effectiveness of in situ treatment relies largely on:

- The type of source water (and potential contaminants)
- The type of aquifer
- The final use of water
- The long term sustainability of the in situ treatment process
- The need for aquifer protection.

C.1.4.7 Post-treatment

The quality of the recovered water, and hence the need for post-treatment will depend largely on:

- The quality of the recharge water
- Interaction of the recharge water with the natural groundwater
- Rock-water interaction in the aquifer with the potential introduction of unwanted species into solution
- The subsurface retention period
- The intended use of the recovered water.

C.1.4.8 Water quality monitoring strategy

Water quality monitoring will need to fulfil a number of objectives:

- Provide detailed information on recharge water quality
- Demonstrate the efficiency of pre-treatment processes
- Provide details of background water quality in the aquifer
- Demonstrate that groundwater quality in the aquifer is maintained or improved
- Monitor the recovered water quality according to criteria for the intended use.

C.1.4.9 Public and environmental health risk

ASCE (2001) warns that failure to research the legal factors early in the process can lead to unnecessary delays and possible failure of the project. Careful attention to the identification of environmental impacts, as well as open communication with environmental groups, is necessary during the entire process. Two of the legal issues to be addressed are (ASCE, 2001):

- Controls on the use of reclaimed wastewater
- Liabilities associated with water quality issues.

Associated risks include, as an example, the use of reclaimed wastewater for any purposes that were not intended. Controls are necessary to prevent such an eventuality. Other risks may involve discharge into the environment of water unsuitable for recharge due to poor quality. Unforeseen discharges into the environment may also occur due to high water levels in the receiving aquifer. Other examples may include unforeseen quality variations of recovered water.

The risk assessment should cover the entire life cycle of the project, including decommissioning.

C.1.5 Artificial recharge method and engineering issues

The types of artificial recharge are described in Section B.1. This section describes the components of artificial recharge schemes and identifies some of the key issues relating to the recharge method and technical design. Successful schemes are well designed – both in terms of the effectiveness and efficiency of the infrastructure and the ease of operation and maintenance.

The key infrastructure components that form part of artificial recharge projects are shown in Figure C.2.

The primary engineering function in artificial recharge scheme design is the sizing and matching of the various components:

- Source abstraction works
- Pump stations and pipelines
- Pre-injection treatment works
- Injection supply pumps and pipelines
- Injection boreholes and well head works
- Infiltration basins/trenches
- Abstraction boreholes, pumps and pipelines
- Post-injection treatment works
- Storage and distribution

The **source water** to supply the scheme is usually surface water, but can be groundwater (groundwater transfer scheme) or treated wastewater. Usually there is a seasonal fluctuation in the water availability and artificial recharge schemes are designed to store the excess water from the high flow periods. With this scenario, no new abstraction works are needed and the artificial recharge scheme can help to increase the use of the existing abstraction works, pump stations and pipelines.

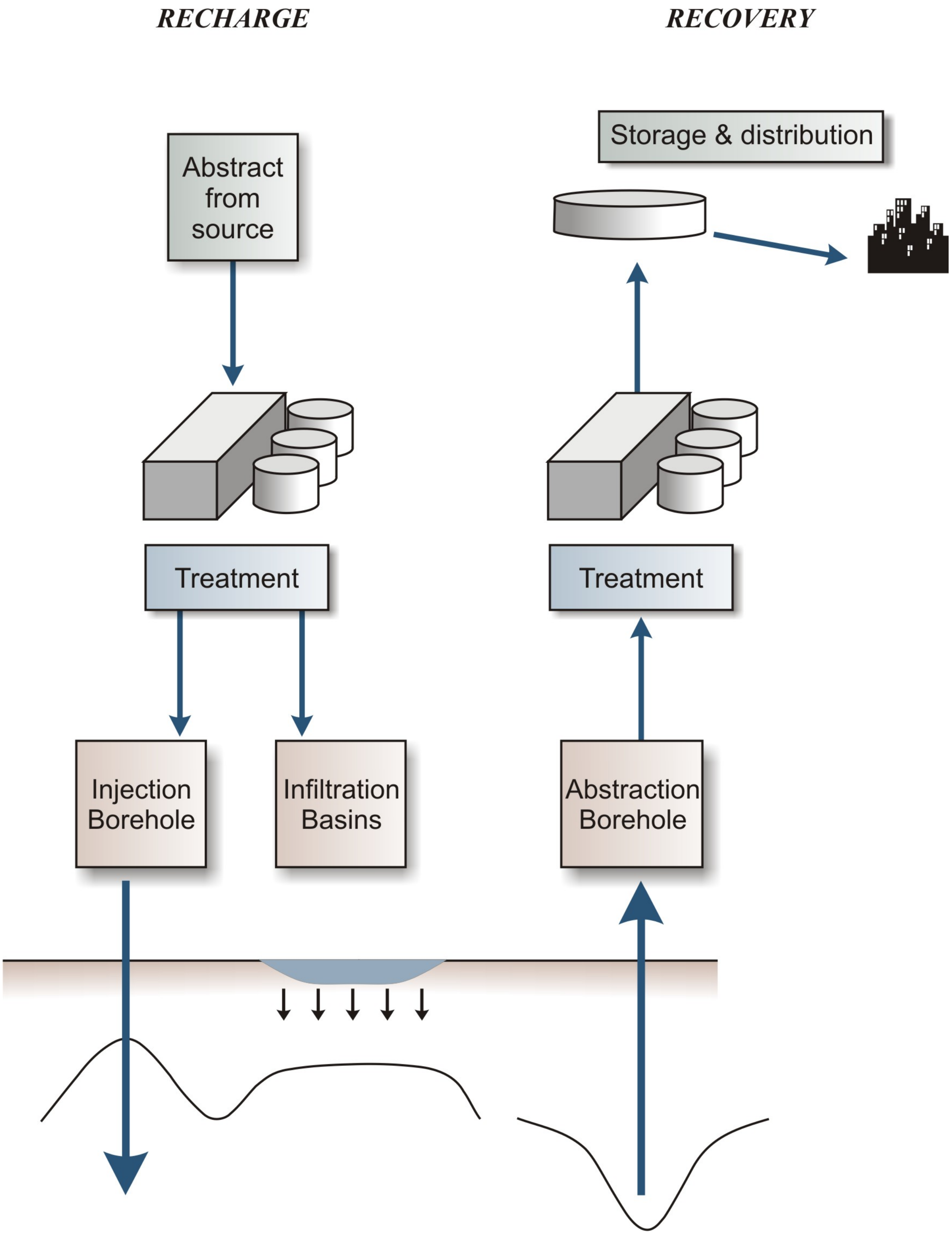


Figure C.2: Infrastructure components of artificial recharge schemes

The extent of **water treatment** required prior to recharge relates to the quality of the source water, the type of artificial recharge system employed and the intended use of the recovered water. Minimising clogging is a key design factor, and this relates directly to the quality of the recharge water and the type of artificial recharge scheme (see Section C.1.4). Post-recharge treatment requirements depend on the intended use of the recovered water.

Key engineering issues are:

- Which artificial recharge method is most efficient and cost-effective?
- Are the engineering logistics practical and cost-effective regarding the transfer of source water to the point of recharge; and from the point of abstraction to the point of consumption?
- How can the scheme be designed to minimise clogging?
- The design must be appropriate for the operation and maintenance skills levels.

Artificial recharge method. The most efficient artificial recharge method to be used must be assessed based upon the site-specific conditions that include:

- The quality of the water used for recharge.
- The hydrogeological environment.
- Existing infrastructure and the costs of additional infrastructure required.
- The management and technical capacity needed to operate the scheme.

Cooperative planning between the engineering, hydrogeological and geochemical disciplines during the conceptual design stage is the best approach to ensure that the artificial recharge scheme is well planned and makes maximum use of available resources.

In order to design a cost effective scheme that makes best use of existing infrastructure, it is necessary to establish the capacity and operating procedures of existing water supply infrastructure. Understanding the capacity and level of use of the different components of the supply system will assist in designing an artificial recharge scheme that optimally uses existing infrastructure and minimises new infrastructural required. This is particularly true of pipelines, above ground storage and treatment facilities.

In Plettenberg Bay, where the feasibility of artificial recharge is being assessed, an additional benefit to water supply during their high summer peak demand period, is that with artificial recharge, they would use their existing water treatment plant to capacity during the low-demand period, and thereby extend its design life. Treated water would be stored in the off-peak winter months, to be used in the summer months without having to pass through the treatment plant again. The treatment plant can operate at higher capacity during low-demand times, and not be stretched to capacity throughout the high-demand times.

Incremental development. Artificial recharge schemes are usually developed incrementally, where increases in capacity are based on the performance of the system during initial operation. Thus infrastructure planning needs to accommodate the initial artificial recharge development, but must identify the requirements for future increases in scheme capacity. Where new infrastructure such as pipelines and treatment facilities are required, it is usually cost effective to design these for the full capacity of the scheme.

Borehole and wellhead design. Existing boreholes are often suitable for injection, however, if new boreholes are planned, the following requirements must be taken into account:

- Material for piping both above and below ground should be non ferrous to minimise the potential of to minimise the potential of corrosion and rusting.
- Provide facilities for pipeline flushing and waste flow discharge.
- Provide sampling taps for water quality sampling of both recharge and recovered water.
- Design down-hole flow control (either fixed or variable) to ensure that cascading does not occur.
- Remove or minimise air from the recharge water prior to injection.
- Ensure that the pipelines remain under a positive pressure or design for negative pressure pipelines to avoid pipeline collapse.

C.1.6 Environmental issues

Artificially recharging groundwater can have both detrimental and positive impact on the environment. These are listed and briefly described in Section B.1. A common motivation for artificial recharge schemes is the rehabilitation of impacted environments. In South Africa this would typically be recharging of aquifers that were previously overexploited or mined. In other parts of the world artificial recharge schemes have been used to rehabilitate groundwater dependent ecosystems like in the case of the Florida everglades (Pyne, 2005).

The main environmental concerns associated with artificial recharge schemes relate to the lowering and raising of water tables (or piezometric levels) over and above those of existing use, and issues associated with water quality changes within the aquifers. Table C.2 lists key potential negative impacts.

Table C.2: Potential negative environmental impacts of artificial recharge schemes

Effects	Consequence
Raised groundwater levels	**Vegetation dieback** Raising the water table close to the soil surface may cause vegetation dieback as a result of soil saturation or the establishment of invasive alien plants. **Damage to structures** Destabilize or damage structures such as roads or buildings. **Pollution** A raised water table is more vulnerable to contamination by industry, wastewater disposal facilities, cemeteries etc. **Flooding** Raising the water table may exacerbate flooding during wet periods due to surface saturation and reduction in the ability of water to infiltrate. **Discharge of foreign water into wetlands and rivers** Changes in the wetland environment such as water temperature, oxygen levels, pH, turbidity, salinity, maximum and minimum water depths, could have an effect on groundwater-dependant species (fish, invertebrates, amphibians) and ecosystems (Brownlie, 2005). The pH, turbidity and salinity of the groundwater is often fairly constant due to long retention times and the organisms that depend on this water can be sensitive to fluctuations in water quality. **Salinisation by increased evaporation** The salinity of water in near-surface water tables can increase due to evaporation.
Lowered groundwater levels	**Wetlands and rivers** Depending on the relationship between surface and groundwater, the lowering of groundwater levels could affect river flow regimes (including baseflow), and wetland and riverine ecosystems. Seeps may be important breeding or feeding areas for birds and other wildlife. Changes in water level or water quality may affect habitat quality and wetland function (e.g. flood control). **Trees** Roots of some large trees reach aquifers. Rooting depths of tropical savanna trees averages 15 m, for desert trees 10 m, and riparian trees such as Acacia karroo have roots at 10-25 m below ground level (Canadell *et al*. 1996). Dewatering, or large fluctuations in the water table may change vegetation structure and composition by causing dieback of riparian trees (Le Maitre *et al* 1999). This in turn will change habitats for birds and other animals that depend on woodland patches, particularly in arid environments. Drainage line woodlands are movement corridors for many animal species. Woodland dieback may reduce the stability of alluvium during floods. Woodland dieback has aesthetic as well as biodiversity consequences. **Land subsidence** Land subsidence can occur in particular environments (especially in unconsolidated sediments) if groundwater levels are significantly lowered. Dolomitic aquifers are vulnerable to sinkhole formation. **Drying up of boreholes** Other groundwater users could be affected.

Effects	Consequence
Water quality issues	**Clogging** This refers to the clogging in and around recharge boreholes due to chemical precipitation or microbiological growth. This has consequences for recharge capacity and borehole rehabilitation or replacement costs. **Mobilising undesirable chemical constituents** Determinands such as existing arsenic in an aquifer can be mobilized by lowering the water table and creating an oxidising environment. The health of groundwater users (domestic, industry, livestock and irrigation) could be affected by the release of such constituents. **Aquifer organisms** The transfer of foreign water into an aquifer with different characteristics and quality could be problematic for the aquifer organisms. This applies particularly to water of impaired quality and treated waste water. There may be residual concentrations of chemicals such as chlorine in the water, which could have a detrimental impact on organisms in the aquifer.

The extent and significance of the abovementioned impacts would depend on numerous site-specific factors. In environmentally-sensitive areas it may be necessary to place operational restrictions on schemes, like only allowing water level fluctuations between a few metres below the top of the aquifer and the lowest natural water levels.

In the environmental study that forms part of an artificial recharge feasibility assessment, potential environmental issues need to be identified and where appropriate, baseline ecosystem data collected and ecological monitoring requirements identified. The risk and reversibility of environmental impacts should be discussed. Risks relates to the significance of the potential impacts, and the likelihood of those impacts occurring. Depending on the extent of available data, it may not be possible to adequately define risks, and a comprehensive monitoring plan may be needed.

Aquifers which are well monitored and well understood carry less risk, and it is easier to predict the consequences of artificial recharge and make informed management decisions. Environmental risks depend on a number of factors inter alia the nature of the source of the water, the volume of recharged water, aquifer parameters, the sensitivity of groundwater-driven ecosystems and the extent and nature of existing aquifer use.

The concept of reversibility is critical when considering the significance of an impact. Determining how quickly a component of the environment could recover from a particular stress due to groundwater recharge is challenging. If impacts are irreversible or only reversible over long periods of time, the significance of the impacts are that much greater, and may be considered to be unacceptable. Impacts on the built environment are more easily and quickly reversible through engineering solutions than impacts on the biophysical environment. However, impacts on the biophysical environment can be more challenging to reverse, and commonly happen over a longer period of time.

A risk management approach to implementing artificial recharge schemes based on the informed precautionary principle should be adopted after identifying all potential problems (Dillon, 2005).

The extent, magnitude and significance of environmental risks associated with artificial recharge schemes need to be discussed (in the feasibility study) in relation to the benefits of the scheme (both water supply and environmental), and compared with alternative water supply options.

C.1.7 Legal and regulatory issues

All artificial recharge schemes need to need licensed. Obtaining the necessary permits is thus crucial to the success of new projects. Section A.2 provides the legislative framework, and Section C.2 describes, in detail, the artificial recharge authorisation process and associated legal matters. This section identifies the key legal issues (which are dealt with in depth in Section C.2).

The key legal issues regarding the assessment and operation of artificial recharge schemes include:

- Water use licensing for artificial recharge schemes
- Environmental authorisation requirements for both testing and implementing the scheme (i.e. Basic Assessment or Environmental Impact Assessment)
- Environmental Management Plans (EMPs)
- Compliance with regulations (e.g. relating to water reuse)
- Rights associated with the use of artificially recharged water.
- Compliance with the conditions and reporting requirements of the water use licence and environmental authorisation.

South Africa's water use and environmental legislation have not yet been tested with the processing of applications for artificial recharge schemes. However, both the National Water Act and the NEMA provide the framework for processing artificial recharge applications (see Section C.2).

C.1.8 Economics

Unused aquifer storage capacity can often be developed at a significantly lower cost than surface storage facilities, and without the adverse environmental consequences frequently associated with surface storage (Pyne, 1995). In relation to water treatment, natural attenuation of waste water using aquifer media is a cost-effective means of improving water quality.

When undertaking economic option analyses, it is important to evaluate all options on the same basis, and to include all capital and operational costs. The Windhoek case study in Section B.3 provides a good example of a comparative cost assessment.

In the Windhoek economic assessment, the proposed artificial recharge scheme was compared to alternative water supply options for Windhoek and other recent or planned projects in the central region of Namibia (SWECO, 2002). Windhoek's priority was to increase the security of supply and on that basis the following four factors were evaluated:

1. Present worth cost including the following costs and revenues:

   - Initial capital investment cost
   - Annual depreciation and residual value (discounted to present value)
   - Average incremental annual pumping cost
   - Average incremental annual operation and maintenance cost

2. The incremental security of supply (ISS). The study modelled the supply for each scenario as well as a baseline "do nothing" scenario. The ISS is the difference between the expected annual shortfall of the particular scheme scenario and the "do nothing" scenario during a 10 year planning period. The ISS is measured as a volume per year.

3. Water Saving (or scheme efficiency) based on evaporation losses for each alternative scheme

4. Ratio of cost to ISS (in R/annual volume).

Other factors that could be assigned an economic value include:

- The strategic value of drought mitigation measures
- The efficient use of local resources compared with developing sources in other distant areas

An economic study should compare the cost per cubic meter of water supplied for each alternative supply option. It is important that the same method be used to price water. This is particularly important when water is purchased from a bulk water provider such as a water board or when compared with existing schemes, as the price of water may be subsidised.

Figure C.3 describes the different levels of water pricing adopted in the Windhoek economic assessment (SWECO, 2002). In many cases water is priced only on the financial cost, but ideally, an accurate comparison should be based on the total water supply cost.

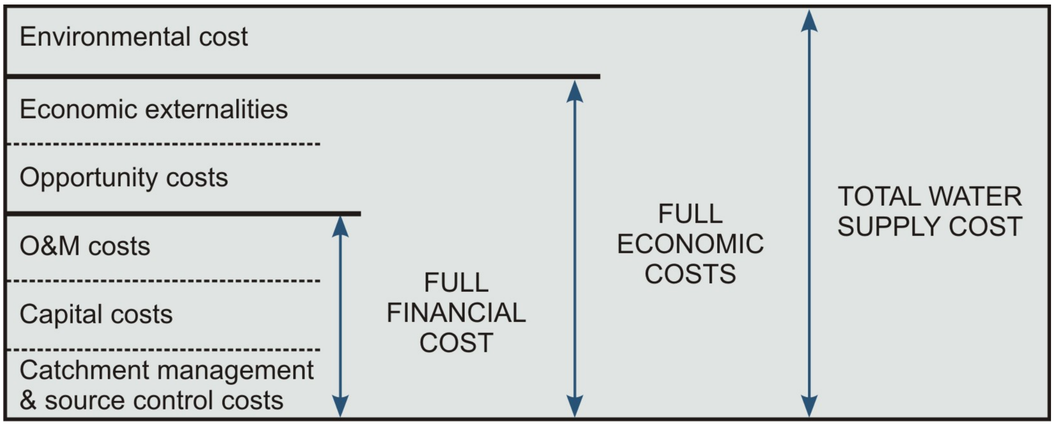


Figure C.3: Levels of water pricing (after Heyns, 1998)

For small to medium municipal scale projects, DWAF's Typical Unit Cost for Water Services Development Projects: A Guide for Local Authorities (DWAF, 2003) provides a uniform tool for estimating the cost of water supply options.

C.1.9 Management and technical capacity

The successful operation of an artificial recharge facility depends largely on an effective management strategy and on the availability of sufficiently skilled or competent staff to carry out the necessary tasks. Maximum benefit from an artificial recharge scheme involves integrating the scheme into the planning and management of the overall water supply system. Depending on the scale of the artificial recharge scheme, this can include management of the entire catchment. The overall aim is to optimise both surface and groundwater resources and their storage capacities.

Artificial recharge schemes commonly involve surface or waste water capture, treatment, pumping, water quality monitoring and clogging control. Careful planning and management is required to ensure that these processes are efficient. This assumes the availability of competent personnel who, in the case of large facilities, need to be dedicated solely to the task of managing the scheme. In such cases, the responsibility of operating the scheme should not be viewed as just another task of the water supply engineer, but rather as another water resource that requires a manager.

In some cases, management requirements are minor, such as the Kharkams scheme in Namaqualand where weekly inspections during operations are sufficient. In other cases, and in particular where water quality management is critical for clogging or health reasons, relatively high-level technical management is required. In both cases, however, artificial recharge management is critical for the successful operation of the scheme.

Knowledge of the following subjects may be needed to operate an artificial recharge scheme successfully:

- Hydrogeology of the basin
- Integrated water cycle of the catchment and source water supply
- Recharge and recovery technology
- Groundwater level monitoring
- Water treatment and water quality management
- Water supply engineering.

There is currently a shortage of technical skills in South Africa, especially at the municipal sphere of government. Artificial recharge project feasibility studies must identify the technical and management skills required to operate the scheme and from where the skills will be sourced and funded.

The technical skills required to assess the feasibility and to design an artificial recharge scheme vary with the type and size of the scheme and may include:

- Geology
- Hydrogeology

- Aquifer simulation modeling
- Hydrology
- Geochemistry
- Environmental impact assessment
- Pipeline hydraulics
- Borehole and pump station design
- Water treatment

Other skills may be required to address legal and regulatory issues. Failure to accommodate all of these disciplines at the planning and conceptual design stages can lead to costly mid-course corrections, or even scheme failure.

C.1.10 Institutional arrangements

Associated with artificial recharge scheme licences are monitoring and reporting requirements. The institutional capacities of both the scheme operator and the regulatory authority need to be sufficient to ensure that the scheme is operated according to design standards. This applies particularly when water of marginal quality is used for recharge. If the scheme operators or regulatory authorities lack the capacity to manage and "oversee" schemes, the schemes will lose efficiency through clogging, poor maintenance, etc, and perform well below design capacities. Reporting and performance monitoring systems need to be in place to maintain optimal scheme operation.

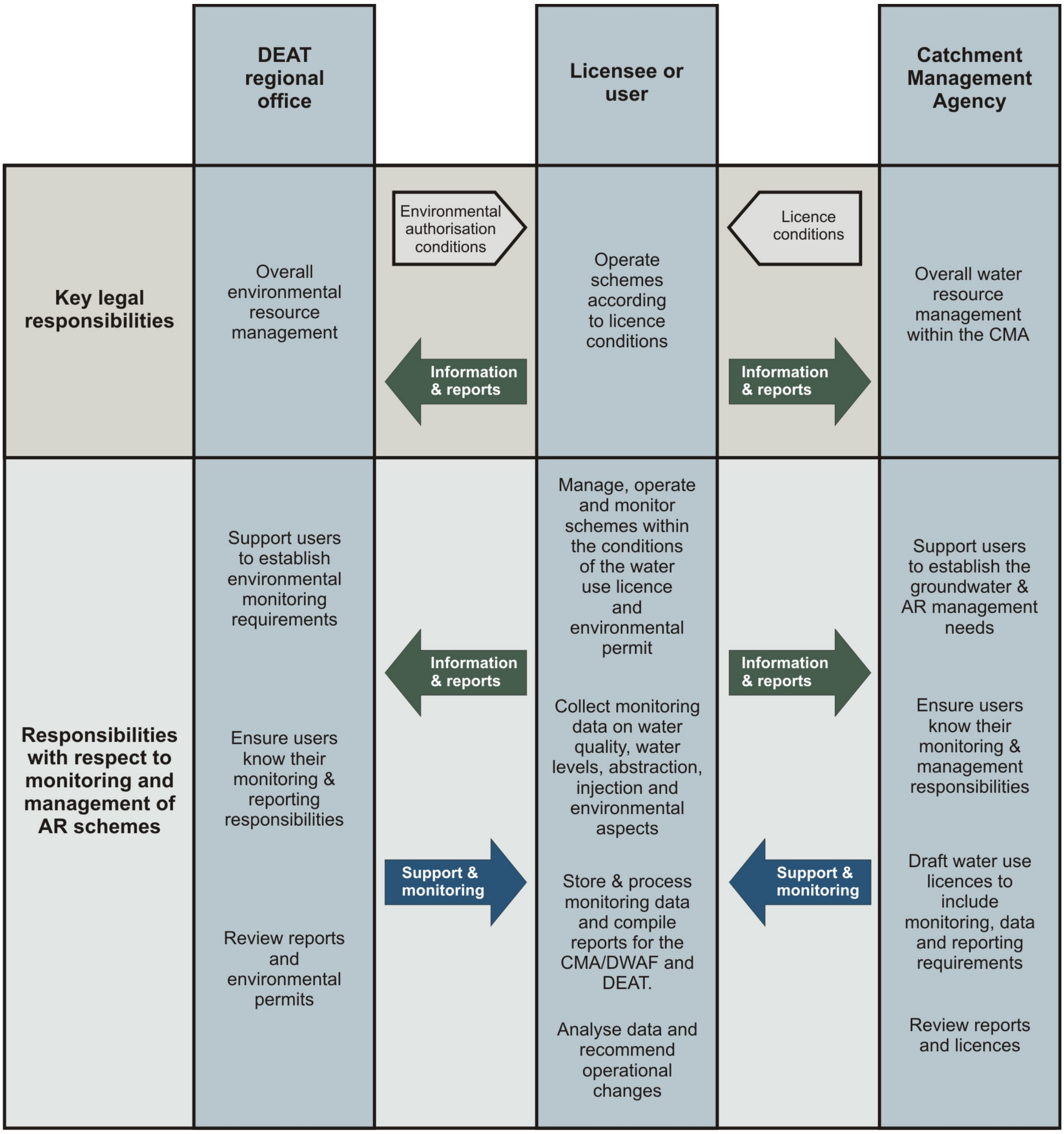
Besides small-scale individual (typically farmer) artificial recharge operations, the responsible authorities for authorising, licensing and operating artificial recharge schemes could include:

- DWAF/CMA
- Water Services Authority (WSA)
- Water Services Provider (WSP), including Water Boards (WB)
- Water User Association (WUA)
- DEAT

While the institutional arrangements are clear with respect to water services provision (DWAF, 2004e), such arrangements have as yet, not been considered for artificial recharge applications. The key issues relate to:

- Licensing
- Monitoring
- Water quality control
- Reporting
- Support.

The institutional framework for artificial recharge management is presented in Table C.3.



	DEAT regional office		Licensee or user		Catchment Management Agency
Key legal responsibilities	Overall environmental resource management	Environmental authorisation conditions → ← Information & reports	Operate schemes according to licence conditions	← Licence conditions Information & reports →	Overall water resource management within the CMA
Responsibilities with respect to monitoring and management of AR schemes	Support users to establish environmental monitoring requirements Ensure users know their monitoring & reporting responsibilities Review reports and environmental permits	← Information & reports Support & monitoring →	Manage, operate and monitor schemes within the conditions of the water use licence and environmental permit Collect monitoring data on water quality, water levels, abstraction, injection and environmental aspects Store & process monitoring data and compile reports for the CMA/DWAF and DEAT. Analyse data and recommend operational changes	Information & reports → ← Support & monitoring	Support users to establish the groundwater & AR management needs Ensure users know their monitoring & management responsibilities Draft water use licences to include monitoring, data and reporting requirements Review reports and licences

Table C.3: Institutional framework for artificial recharge management

Many artificial recharge schemes rely on cooperation between water services authorities, bulk suppliers and water resource management institutions. In Windhoek, for example, large-scale borehole injection has been put on hold until agreements between the source water supplier (NamWater) and the manager/user of the scheme (the City of Windhoek) have been finalised.

The seriousness of “getting the institutional arrangements sorted out” cannot be overemphasised. Eight out of ten of the most significant impediments to implementing a cost-effective conjunctive management program in California related to institutional issues (Utah, 2002). The identified impediments are listed below, and should be anticipated in project planning:

- Inability of local and regional water management governance entities to build trust, resolve difference (internally and externally), and share control.
- Inability to match benefits and funding burdens in ways that are acceptable to all parties, including third parties.
- Lack of sufficient federal, state and regional financial incentives to encourage groundwater conjunctive use to meet state-wide water needs.
- Legal constraints that impede conjunctive use, regarding storage rights, basin judgments, area of origin, water rights, and indemnification.
- Lack of state-wide leadership in the planning and development of conjunctive use programs as part of comprehensive water resources plans, which recognize local, regional, and other stakeholders’ interests.
- Inability to address quality differences in “put” versus “take”; standards for injection, export, and reclaimed water; and unforeseeable future ground water degradation.
- Risk that water stored cannot be extracted when needed because of infrastructure, water quality or water level, politics, and institutional or contractual provisions.
- Lack of assurances to prevent third-party impacts.
- Lack of creativity in developing lasting “win-win” conjunctive use projects, agreements, and programs.
- Supplemental suppliers and basin managers have different roles and expectations in relation to conjunctive use.

C.2 PROJECT STAGES, LEGISLATION AND AUTHORISATION

C.2.1 Project stages

It is important that artificial recharge projects follow the normal water supply project development stages of planning, design, authorisation and implementation. Artificial recharge schemes cannot be considered simple interventions whereby excess surface water is transferred underground on an ad hoc basis in the hope that this will solve water shortage problems. If the project is not properly planned, it is unlikely that it will have the expected benefits and it could have negative repercussions. For example, the scheme could become inefficient due to clogging, or there may be legal or environmental issues that could lead to scheme failure.

Artificial recharge projects differ from conventional water supply infrastructure development projects in two significant ways:

- A significant period of testing is almost always required prior to developing the design and implementation plan.
- Artificial recharge projects are site specific and each project will have its own particular objectives.

While testing helps to understand the project specific conditions, it is also important to start relatively small and have incremental increases in capacity as the variables of the particular situation are monitored and better understood.

Artificial recharge projects cannot be considered as mere management interventions, as there is always some level of infrastructure development associated with them.

Table C.4 summarises the recommended artificial recharge project stages, key activities and authorisation requirements. The recommended authorisation process is described in detail in Section C.2.3. The project stages have been developed and informed by lessons learnt while assessing the feasibility of the Plettenberg Bay and Prince Albert artificial recharge schemes.

C.2.1.1 Pre-feasibility Stage

The pre-feasibility study for all planned artificial recharge schemes serves three main purposes:

1. It requires the applicant to formulate the proposal.
2. It provides an initial assessment of the scheme's viability.
3. It identifies the authorisation requirements. Applicants must make the initial contact with DWAF and DEAT regional offices to establish which "water uses" will be applicable, the licensing requirements, and the environmental authorisation requirements. This relates to both the proposed scheme and artificial recharge tests (which usually from part of the feasibility stage).

During the Pre-feasibility Stage, the need for the proposed artificial recharge scheme must be justified; the volumes of water to be recharged must be quantified; and the proposed method of recharge described. Based on existing information, the ability of the aquifer to accept and store the water, and the ability to recover the water, must be evaluated. Possible environmental impacts must also be identified.

The pre-feasibility report should include the following:

- The conceptual design of the project
- Existing permits and licences
- Existing data on water availability, borehole water levels and water quality; and existing and planned data monitoring systems
- A report on the viability of the project, taking into account the ten criteria for successful implementation (see Section C.1). The report should identify information gaps and how these will be addressed in the feasibility study
- A report on the listed activities in the testing phase that require environmental authorisation and water use licensing
- The proposed tests to assess the feasibility of the scheme
- The feasibility study plan and cost estimate.

Table C.4: Recommended artificial recharge project stages, key activities and authorisation requirements

Project Stage	Key Activities	Authorisation requirements
Pre-feasibility Stage	Identify the potential AR project and describe the information currently available. Based on existing information, comment on the feasibility of the project. Describe the work required for the Feasibility Stage and estimate the cost of undertaking the feasibility study.	None
	Establish existing water use licence conditions and authorisation requirements from DWAF and DEAT.	
Feasibility Stage	If needed, obtain a water use licence and environmental authorisation for the recharge tests. Conduct the feasibility study. This should include AR testing (eg injection tests, infiltration tests, pumping tests, water quality assessments, etc) Develop a preliminary infrastructure design. Identify the project implementation phases if a phased approach is necessary (eg starting small and expanding after successive recharge cycles). Estimate the costs of the project. Identify funding sources Compile a detailed project implementation plan.	None, or a short-term water use licence for AR testing and possibly environmental authorisation for AR testing
Implementation Stage	Obtain the necessary water use licence and environmental authorisation for the AR scheme. Drilling and testing new injection and abstraction boreholes or infiltration basins Set up the groundwater and recharge water monitoring system Develop the detailed infrastructure design, carry out the tendering processes, and construct the project. Compile monitoring, operation & maintenance procedures.	Water use licence and possibly environmental authorisation
Operation and Maintenance Stage	Carry out performance monitoring during production. Modify operation & maintenance procedures based on scheme performance. Develop final monitoring and reporting system.	Compliance monitoring and reporting.

The pre-feasibility report must be submitted to DWAF. DWAF may need to convene an “Artificial Recharge Authorities Committee Meeting” where the report is discussed amongst the relevant departments (DWAF, DEAT, etc), and the applicant.

If a water use licence is required for the testing stage, the pre-feasibility report should accompany the licence application. If no licence is required, the applicant can continue with the tests, subject to the conditions set by the Artificial Recharge Authorities Committee Meeting.

In order to assess whether environmental authorisation is required for the planned tests, the applicant will need to identify listed activities that trigger an environmental study and establish which activities exceed the trigger limits. The listed activities and their limits are contained in Tables C.6 and C.7. The applicant may need to consult an Environmental Assessment

Professional (EAP). If environmental authorisation is triggered by the planned artificial recharge tests, the applicant should submit the required documentation (Basic Assessment Report or Scoping Report) together with the pre-feasibility report. This is important to ensure that the authorisation process is processed in the shortest possible time.

C.2.1.2 Feasibility Stage

The purpose of the feasibility study is to determine whether the artificial recharge scheme is feasible, affordable and sustainable prior to implementing the scheme. This stage of the study usually involves the testing of the artificial recharge scheme – either at a pilot scale or at full scale.

Once authorisation has been received, testing can commence taking cognisance of the conditions set out by DWAF and DEAT. Besides water quality, water level, injection/infiltration rate and environmental monitoring, the authorities may require a public participation process prior to testing.

Site-specific information needs to be gathered during this stage to assess the ability of the aquifer to receive water, the efficiency of the artificial recharge process, and the hydraulic and environmental effects of recharging the aquifer. Data collected during the feasibility study will provide a baseline against which monitoring data can be compared in future.

Testing usually lasts between two and six months, but may be longer, depending on the duration of the planned production/recharge cycles and the level of confidence required prior implementing the full-scale scheme. Typically, this will involve a period of infiltration/injecting followed by a period of monitoring the aquifer’s response after the recharge tests, and then an abstraction period.

The feasibility study should report on the all the items listed in the criteria for successful implementation (Section C.1):

1. A clearly defined need
2. The quantity and reliability of the source water
3. Aquifer hydraulics
4. Water quality
5. Artificial recharge method and engineering issues
6. Environmental issues
7. Legal and regulatory issues
8. Economics
9. Management and technical capacity
10. Institutional arrangements

The report should also include:

- Preliminary infrastructure design
- A detailed project implementation plan
- A funding plan identifying funding sources and requirements
- A comparison with other water supply alternatives.

The applicant should establish the environmental authorisation and water use licensing requirements and submit the appropriate applications together with the feasibility study to DWAF. DWAF may need to convene an Artificial Recharge Authorities Committee Meeting to decide whether the project can proceed to implementation and to set the conditions for implementation.

C.2.1.3 Implementation Stage

Once authorisation to proceed is received by the applicant, the Implementation Stage of the project can commence. This would typically consist of:

- Further groundwater infrastructure development (drilling & testing)
- Setting up the groundwater monitoring system (artificial recharge volumes, groundwater levels and water quality)
- Ensuring that the required water use licence and environmental authorisation is obtained
- Developing detailed infrastructure design, carrying out the tendering process and constructing the scheme
- Compiling the monitoring, operation & maintenance procedures.

C.2.1.4 Operation and Maintenance Stage

During the Operation and Maintenance, or Production Stage, monitoring of the artificial recharge scheme is geared towards optimising the scheme performance and expanding its capacity where feasible. Activities include:

- Monitoring scheme performance and the aquifer response during recharge and abstraction
- Modifying operation and maintenance procedures
- Implementing incremental increases in the scheme’s capacity (up to the authorised limits)
- Reporting on information required in terms of the water use licence and environmental authorisation.

C.2.2 Legislation

The legislative framework governing artificial recharge projects is described in Section A.2. This section describes relevant aspects of the key legislation documents.

C.2.2.1 National Water Act (NWA)

The two key points relevant to artificial recharge are:

1. How artificial recharge is defined in the National Water Act
2. Whether artificial recharge needs to be licensed.

Chapter 4 of the NWA refers to the use of water and eleven uses are described in Section 21 of the Act (Table C.5). Two of these "uses" clearly fall within the realm of artificial recharge, namely "storing water", and "the intentional recharging of an aquifer with any waste or water containing waste". Other uses such as "altering the bed, banks, course or characteristics of a watercourse", could be applicable in the case of a bank filtration artificial recharge scheme. Based on the definitions as contained in the NWA, artificial recharge can therefore be considered a water use.

In considering an application for a licence to store water the applicant would have to show that the aquifer ("storage unit") is able to contain the water and that it would not flow away from the capture zone before it is abstracted. Alternatively, licence conditions may require the water to be abstracted within a certain time period after recharge (i.e. prior to leakage out the aquifer or away from the capture zone).

In general a water use needs to be licensed unless it is (NWA, 1998):

- Listed in Schedule 1
- Is an existing lawful use
- Is permissible under a general authorisation, or
- If a responsible authority waives the need for a licence.

Schedule 1 use includes, amongst others, small-scale domestic use, gardening and watering of animals. Most artificial recharge schemes will be geared to municipal or other large scale users and will therefore fall outside of Schedule 1 use. Examples of Schedule 1 use artificial recharge schemes include earth dams that farmers build to enhance groundwater recharge, and rainwater harvesting that involves sub-surface storage.

Existing lawful use refers to a legal water use prior to the commencement of the NWA in 1998. An example of this that relates to artificial recharge is Polokwane, which has historically discharged treated waste water into a river bed which, in turn, enhances recharge (described in Section B3).

Permissible use under a general authorisation is described in Part 6 of the NWA (Section 39). The storage of water underground is specifically excluded from general authorisation in Government Notice No 26187 of 26 March 2004. As a result, all artificial recharge is subject to being issued a water use licence by DWAF.

Artificial recharge schemes need to be licensed because storing water underground is defined as a "water use" in the National Water Act.

Artificial recharge cannot be excluded from licensing under pretext of a general authorisation, as the storage of water underground is specifically excluded from general authorisation.
(Government Notice No 26187 of 26 March 2004)

A responsible authority could only waive the need for a licence if other legal requirements are met, such as those that may be required to meet environmental requirements. A responsible authority may only dispense with the requirement for a water use licence if it is satisfied the objectives of the NWA will be met by the granting of a licence, permit or other authorisation under any other law.

Table C.5: Water uses recognized in Section 21 of the NWA that may be applicable to artificial recharge projects

Section	Water uses
s21(a)	Taking water from a water resource;
s21(b)	**Storing water**;
s21(c)	Impeding or diverting the flow of water in a watercourse
s21(d)	Engaging in a stream flow reduction activity (currently only commercial afforestation)
s21(e)	Engaging in a controlled activity – activities which impact detrimentally on a water resource (activities identified in s37(1) or declared as such under s38(1)) namely: - Irrigation of any land with waste or water containing waste which is generated through an industrial activity or a waterwork; - An activity aimed at the modification of atmospheric precipitation; - A power generation activity which alters the flow regime of a water resource; or - **Intentional recharge of an aquifer with any waste or water containing waste**
s21(f)	Discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit
s21(g)	Disposing of waste or water containing waste in a manner which may detrimentally impact on a water resource
s21(h)	Disposing in any manner of water which contains waste from, or has been heated in any industrial or power generation process
s21(i)	Altering the bed, banks, course or characteristics of a watercourse
s21(j)	Removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people
S21(k)	Using water for recreational purposes

There are sections in South African water law where artificial recharge is either mentioned or implied:

- In Section 37 of the NWA, intentional recharging of an aquifer with any waste or water containing waste is declared a controlled activity; and thus subject to authorisation. This would include recharging with wastewater or wastewater effluent, storm water and water containing any other substance considered waste.
- The storage of water underground is specifically excluded from general authorisation in Government Notice No 26187 of 26 March 2004. While this may refer to the storage of water in disused mine shafts and caves, etc, it nevertheless implies that all artificial recharge is subject to being issued a water use licence by DWAF.

While an artificial recharge scheme may include a number of water uses that require a licence, the physical process of artificially recharging groundwater is not defined as a use in terms of the NWA. However, because in most instances the primary purpose of artificial recharge would be to store water in an aquifer, the “use” associated with artificial recharge projects will be s21(b), “the storing of water”.

It is evident that subsurface storage was not considered at the time of drafting the legislation. Government notice No 26187 defines storage as follows: "storage" means storing water not containing waste, in a watercourse or off-channel storage. Further, the licence application form pertaining to storage (DW774 L2b) describes the storage of water in dams and is inadequate to describe the storage of water in an aquifer.

The dam safety regulation will be applicable in recharge basins where the "dam" can contain more than 50 000 m^3 of water, and which has a wall of a vertical height of more than 5 metres, or which has been declared as a dam with a safety risk.

C.2.2.2 National Environmental Management Act (NEMA)

Regulations published under the National Environmental Management Act (Act 107 of 1998) (NEMA) do not specifically address artificial recharge as an activity, but some of the listed activities could be part of implementing an artificial recharge scheme. For example, authorisation is required for the construction of facilities or infrastructure for the bulk transportation of water in pipelines with an internal diameter of 0.36 m or more, or with a peak throughput of 120 L/s or more. Limits that trigger the need for environmental authorisation that could be applicable to artificial recharge schemes are listed in Table C.6 and C.7.

Activity 13 of NEMA Regulation 386 stipulates environmental authorisation is required when the abstraction of groundwater exceeds the general authorisation volume issued in terms of the NWA. The regulations require a Basic Assessment be undertaken.

Environmental authorisation is required in instances where a listed activity associated with a planned artificial recharge scheme exceeds the limits set out in Tables C.6 and C.7.

Table C.6 Activities that require Basic Assessment, as stipulated in NEMA Regulation 386

Section	Activities
1	The construction of facilities or infrastructure for:
1(k)	the bulk transportation of sewage and water, including stormwater, in pipelines with (i) an internal diameter of 0.36 m or more, or (ii) a peak throughput of 120 L/s or more
1(m)	any purpose in the 1 : 10 yr flood line of a river or stream (or within 32 m from the bank of a river or stream where the floodline is unknown) excluding purposes associated with existing residential use, but including canals, channels, bridges, dams and weirs
1(n)	the off-stream storage of water, including dams and reservoirs, with a capacity of 50 000 m^3 or more, unless such storage falls within the ambit of the activity listed in item 6 of Government Notice 387 of 2006
1(s)	the treatment of effluent, wastewater or sewage with an annual throughput capacity of more than 2 000 m^3 but less than 15 000 m^3
4	The dredging, excavation, infilling, removal or moving of soil, sand or rock exceeding 5 m^3 from a river, tidal lagoon, tidal river, lake, in-stream dam, floodplain or wetland

5	The removal or damaging of indigenous vegetation of more than 10 m^2 within a distance of 100 metres inland of the high-water mark of the sea
6	The excavation, moving, removal, depositing or compacting of soil, sand, rock or rubble covering an area exceeding 10 m^2 in the sea or within a distance of 100 metres inland of the high-water mark of the sea
12	The transformation or removal of indigenous vegetation of 3 ha or more; or of any size where the transformation or removal would occur within a critically endangered or an endangered ecosystem listed in terms of section 52 of the National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004)
13	The abstraction of groundwater at a volume where any general authorisation issued in terms of the National Water Act, 1998 (Act No. 36 of 1998) will be exceeded
15	The construction of a road that is wider than 4 m or that has a reserve wider than 6 m, excluding roads that fall within the ambit of another listed activity or which are access roads of less than 30 m long
20	The transformation of an area zoned for use as public open space or for a conservation purpose to another use.

Table C.7: Activities that require a Scoping Study and an EIA, as stipulated in NEMA Regulation 387

Section	Activities
1	The construction of facilities or infrastructure for:
1(e)	any process or activity which requires a permit or licence in terms of legislation governing the generation or release of emissions, pollution, effluent or waste and which is not identified in Government Notice No. R. 386 of 2006
1(n)	the transfer of 20 000 m^3 or more water between water catchments or impoundments per day
1(p)	the treatment of effluent, wastewater or sewage with an annual throughput capacity of 15 000 m^3 or more
2	Any development activity, including associated structures and infrastructure, where the total area of the developed area is, or is intended to be, 20 ha or more
6	The construction of a dam where the highest part of the dam wall, as measured from the outside toe of the wall to the highest part of the wall, is 5 m or higher or where the high-water mark of the dam covers an area of 10 hectares or more

While some of these activities may be triggered by an artificial recharge scheme, the act of artificially recharging groundwater would not trigger a Basic Assessment or a Scoping Study and EIA. However, under section 28 of NEMA, DEAT needs to comment on (and can set conditions for) any activity that may have a potential environmental impact, even if that activity does not trigger a Basic Assessment or a Scoping Study and EIA.

In some provinces, DWAF and the delegated DEAT authority are developing Memoranda of Understanding regarding their co-operative relationship. These could cater for having a combined process for obtaining both a licence and environmental authorisation.

As is the case with the NWA, under Chapter 5 of NEMA Regulation 385, an applicant may apply for an exemption from any provision described in the NEMA Regulations. The NEMA Regulations stipulate the procedure to be followed when applying for exemption and factors that need to be taken into account when considering an application for exemption.

The NEMA regulation 385 provides timeframes of 14 days for administrative actions, 45 days for the review and decision-making on minor reports and between 60 and 105 days for the review and decision-making on complex reports.

In terms of section 32 of regulation 385 an EIA has to contain a draft Environmental Management Plan (EMP). Section 36 describes what needs to be covered in the EMP.

C.2.3 Authorisation Process

So far, no artificial recharge project has been authorised in South Africa and thus there is no authorisation precedent. Existing schemes were implemented prior to the new water laws and fall within the realm of “existing lawful use”.

What follows is a recommended process that is based on current legislation. The only new development that is envisaged is the formation of an “Artificial Recharge Authorities Committee Meeting” (Authorities Meeting) that is held whenever an artificial recharge application is made. The Authorities Meeting would be convened by DWAF, and include regional DWAF and DEAT officials and any other affected Department.

Artificial recharge projects can be authorised within the existing structures and systems of DWAF and DEAT. Technical support on artificial recharge issues would be required in the regions and it is proposed that DWAF head office ensure that an artificial recharge “expert” is available to attend Authorities Meetings with the regional DWAF and DEAT case officers. Both the NWA and NEMA require that authorisation processes are harmonised across departments and thus a single process for both authorisations (DWAF and DEAT) is proposed.

The Authorities Meeting is required at least twice during the process of artificial recharge scheme development:

1. The first is prior to the testing phase, at the end of the Pre-feasibility Stage. The Authorities Meeting must decide whether the testing requires water use licensing (DWAF) and environmental authorisation (DEAT). Conditions for testing would need to be prescribed.

2. The second is after the testing period, on completion of the Feasibility Stage. The Authorities Meeting needs to consider the feasibility study report and decide on the legal, monitoring and reporting requirements for project implementation.

In addition to the above, the Authorities Meeting would need to convene after a period of operation to review the monitoring data and to consider licence renewal. This may also be required from time to time during the Operation and Maintenance Stage of the project.

Figure C.4 and Table C.8 describe the proposed process for artificial recharge water use licensing and environmental authorisation.

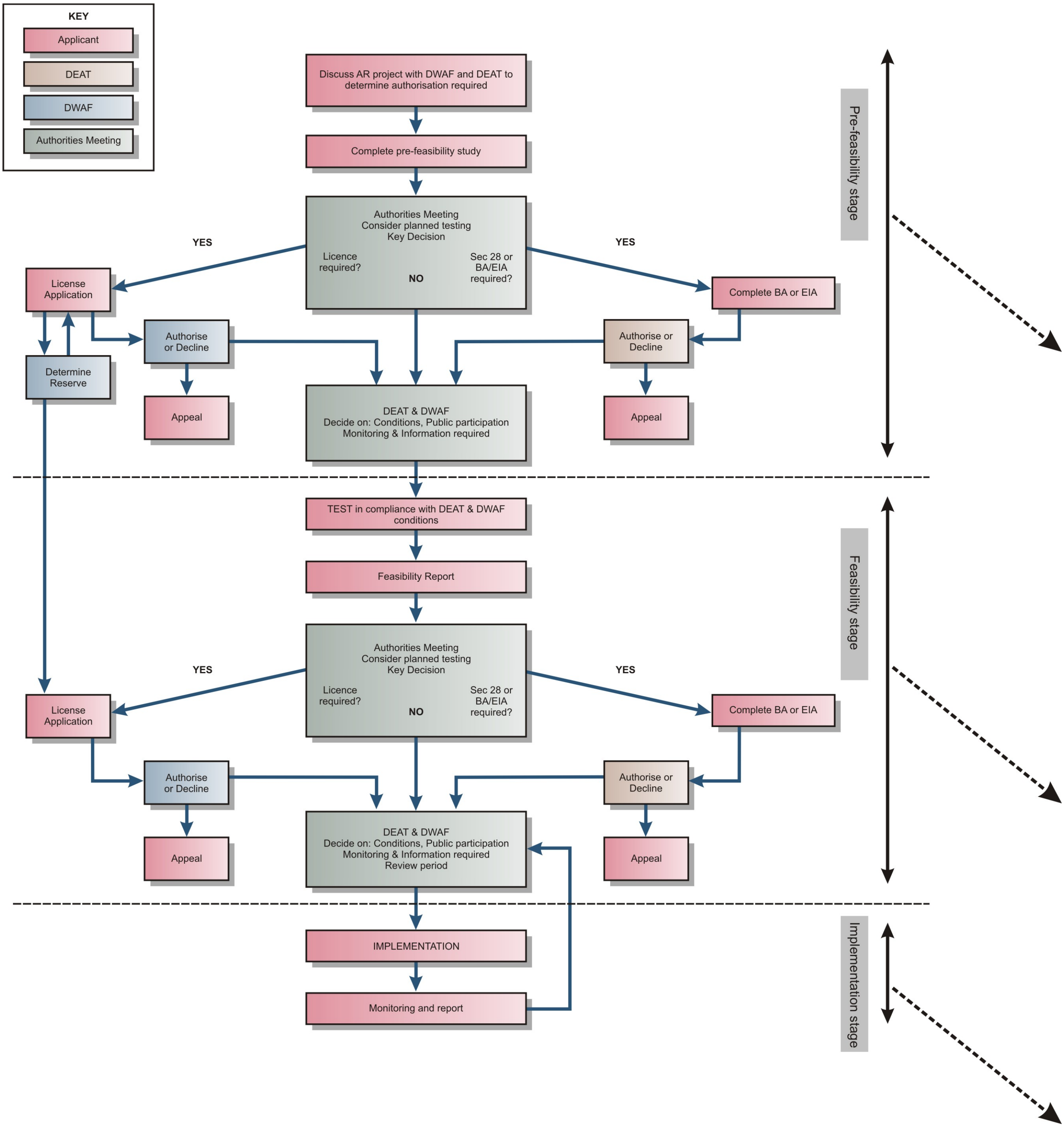
Below are a list of related references and guideline documents, some of which are described in Section C.3:

- Procedure for Approving and Licensing Groundwater Development and Use (Parsons, *et al*, 2006).
- Department of Water Affairs and Forestry, 2000. Water Use Authorisation Process for Individual Applications. Revision 3, Chief Directorate: Water Conservation.
- NEMA EIA Regulations Guideline & Information Document Series (DEA&DP, July, 2006 & November, 2006)
- Guidelines for Involving Hydrogeologists in EIA Processes (Saayman, 2005).

In addition to local guideline documents, recent documents pertaining to ASR that include authorisation issues are:

- Aquifer Storage Recovery: A Guide to Groundwater Recharge Through Wells. (Pyne, 2005).
- Draft Code of Practice for Aquifer Storage and Recovery. (Dillon, 2005).

Figure C.4/……..



Note: If a licence or Sec 28 or BA/EIA is not required prior to the Feasibility or Implementation Stages, conditions for testing/implementation should be set immediately at the "Authorities Meeting"

Figure C.4: Proposed artificial recharge project authorisation process

Table C.8: Summary of tasks for proposed artificial recharge authorisation

	TASKS FOR APPLICANT	TASKS FOR DWAF	TASKS FOR DEAT
Pre-feasibility Stage	Meet with DWAF and DEAT to discuss the project and authorisation requirements. Compile a Pre-feasibility report including the items listed below: • A conceptual design of the project, information currently available and existing permits and licences. • A description of existing data and the current systems in place for data collection. • An assessment of the AR potential based on existing information and the 10 criteria for successful implementation. Identify the information gaps and how these will be addressed in the Feasibility Stage. • A proposed sequence of tests for establishing the AR potential and a description of the activities requiring environmental and water use authorisation. • A description of the work required and costs to undertake the feasibility study. Establish whether a water use licence and an environmental permit is required for **conducting AR tests** (to be carried out in the Feasibility Stage), and if so, apply to DWAF and DEAT for the necessary permission.	Meet with the applicant to discuss the project and authorisation requirements. Provide the applicant with guidance on the compilation of a Pre-feasibility report. On receipt of the application and/or Pre-feasibility report, undertake the following activities: • Acknowledge receipt of the application and/or Pre-feasibility report within 14 days. • Send DEAT regional authority a copy of the application. • Review the application and/or Pre-feasibility report and request further details or clarification from the applicant if needed. Consult with AR specialists as required. • Formulate DWAF requirements and conditions for proceeding with AR testing. • Convene an Authorities Meeting with DEAT and other affected Departments within 30 days of acknowledging receipt of the application. • Set conditions for AR testing during the Feasibility Stage and describe the public participation processes requirements. • Specify monitoring and reporting requirements (including pre-testing/baseline monitoring; monitoring requirements during testing; and post-testing monitoring). • Inform the applicant of DWAF/DEAT requirements within 10 days. • Process the licence application and initiate a reserve calculation if required. • Set a time period for the validity of the AR testing.	On receipt of the application and/or Pre-feasibility report from DWAF, undertake the following activities: • Review the Pre-feasibility report and request further information or clarification from the applicant if needed. • Formulate DEAT requirements for the testing activities proposed. Establish whether a Basic Assessment or an EIA is required. • Participate in the Authorities Meeting. • Set conditions for AR testing during the Feasibility Stage and describe the public participation processes requirements. • Specify monitoring and reporting requirements (including pre-testing/baseline monitoring; monitoring requirements during testing; and post-testing monitoring). • Process the required environmental permits.
Feasibility Stage	If necessary, obtain a water use licence and an environmental permit from DWAF and DEAT **for AR testing**. Initiate a public participation process as and if required. Undertake monitoring and AR testing based upon the plans in the pre-feasibility study and the conditions set by DWAF and DEAT. Produce a Feasibility report including the following: • An assessment of the AR potential based on the results of the AR tests, all available information and the 10 criteria for successful implementation. • A preliminary infrastructure design. • A description of project implementation phases and time frames, and clarify which phase the authorisation application covers. • An economic assessment including estimates of the project implementation costs using lifecycle costing and comparing with alternative water supply options. • A list of funding sources (ensure the feasibility study complies with all requirements of the proposed funder). • A project implementation plan. Apply to DWAF for a water use licence **for implementing and operating** the AR scheme, and to DEAT for environmental authorisation.	Be available to clarify and discuss issues with the applicant. On receipt of the feasibility report: • Schedule and convene an Authorities Meeting with DEAT and other affected Departments within 30 days of receipt of the Feasibility report. • Review the Feasibility report. • Establish whether the conditions for carrying out AR testing were met. • Formulate DWAF's licence requirements for project implementation and production. • Describe the public participation processes requirements. • Stipulate monitoring and information reporting requirements. • Inform the applicant within 10 days of the decisions taken at the Authorities Meeting.	Be available to clarify and discuss issues with the applicant. On receipt of the feasibility report: • Review the Feasibility report. • Establish whether the conditions for carrying out AR testing were met. • Participate in the Authorities Meeting. • Formulate DEAT's requirements for project implementation and production. • Describe the public participation processes requirements. • Stipulate monitoring and information reporting requirements.
Implementa-tion Stage	Implement the project. Report to DWAF and DEAT as per the authorisation agreements.	Review the compliance monitoring reports. Review the licence conditions at the interval stipulated in the licence agreement.	Review the compliance monitoring reports. Review the authorisation conditions.

C.3 GUIDELINE DOCUMENTS

Most artificial recharge schemes have been implemented in unconsolidated, primary aquifers and porous hard-rock aquifers. Very few schemes exist in fractured, hard-rock aquifers. The research and documentation regarding artificial recharge schemes, including guideline documents, reflect this, and thus what is presented here is based primarily on studies in primary aquifers. The exceptions are carbonate aquifers, in which large-scale schemes exist and information derived from studies on these schemes have been incorporated into guideline documents.

Guideline documents, however, need to be used with caution, as there are usually more differences between schemes than aspects in common. This observation has led to statements such as: "…artificial recharge should be tuned to each individual setting. Guidelines have a narrow significance and cannot be applied in general" (Peters, 1996); and "…it was concluded that due to lack of knowledge …..it was not possible to set quality criteria for surface water" (Dahlstrom and Pedersen, 1996). Such comments should not down-play the significance of guideline documents, since the international knowledge pool will develop as the lessons for successful implementation are documented and common "success factors" understood. However, it must be noted that each scheme has site-specific factors that need to be understood and the complexities of natural processes cannot be simplified into generic guidelines.

Sections C.3.1 and C.3.2 provide a summary of general and issue-based artificial recharge guideline documents. The key issues raised in these guideline documents are discussed in Section C.1.

C.3.1 General artificial recharge guideline documents

C.3.1.1 Draft Code of Practice for Aquifer Storage and Recovery

Reference:	Dillon (2005). Draft Code of Practice for Aquifer Storage and Recovery. CSIRO Land and Water, Australia.
Availability:	This is an updated version of the document of the same title by the South Australia Environmental Protection Agency (2002).
Number of pages:	24 (paper size: A4).

Major issues:
The following issues are listed as "Guiding Principles for Best Practice":

1) *Risk management.* This should account for uncertainty in aquifer characteristics, variations in water source quality and quantity, and changes in land uses and management that may take place over the operating life of the ASR scheme.
2) *Prevention of irreparable damage.* Although it is recognised that all the information required to predict the performance of an ASR/ASTR site will not be available until the site is operational, it is nevertheless necessary to identify all foreseeable modes of failure, take preventative action to ensure that these do not occur, and identify contingency plans to prevent irreparable damage.
3) *Demonstrations and continuous learning.* Emphasis is placed on monitoring in order to understand the systems better.

4) *Informed precautionary principle.* A risk management approach should be adopted after identifying all potential problems.
5) *Water quality requirements.* The quality of the water injected should be determined by the designated environmental values (beneficial uses) of native groundwater in the aquifer.
6) *Attenuation zone.* Cognisance of attenuating properties of aquifer media (to reduce contaminant properties) should be taken into account.
7) *Rights of water bankers and recoverable volumes.* The guiding principle should be that water stored in the aquifer is available to the operator of the ASR scheme.
8) *Finite storage capacity of aquifers and interference effects between sites.* In licensing ASR schemes, the aquifer's storage capacity and the spacing of adjacent ASR schemes must be taken into account.

Comment on the document:
This Code of Practice outlines the requirements of the Environmental Protection Agency and the Department for Sustainable Development within the State of Victoria, Australia. It provides guidance for projects intended to store water for drinking, irrigation, industrial and ecosystem support purposes, but not for waste water disposal purposes. Source waters include drinking water, stormwater, reclaimed water and groundwater.

Much of the focus on ASR in Australia has been on water quality issues, and hence the Code of Practice covers these issues in greater detail than other issues such as the ability of aquifers to receive injected water (hydraulic issues).

The document refers to the challenge of coordinating environmental regulation and water resource management roles in the approval of new projects.

The Code of Practice includes, amongst other topics:

- Groundwater protection policies in relation to ASR (including injectant water quality criteria)
- Procedure for licence application
- The components of ASR systems
- A generic plan to assess and manage the risk of polluting groundwater and failure to meet required water quality criteria for the recovered water (the Hazard Analysis and Critical Control Point Plan – HACCP) .

C.3.1.2 Standard Guidelines for artificial recharge of Groundwater

Reference:	American Society of Civil Engineers. 2001. Standard Guidelines for artificial recharge of Ground Water, EWRI/ASCE 34-01. ISBN: 0784405484.
Availability:	ASCE website: www.asce.org (bookstore: www.pubs.asce.org).
Number of pages:	106 (paper size: A4).

Major issues:
This document provides a comprehensive overview of the issues that affect the planning, design, construction, operation and closure of various types of artificial recharge scheme. In so doing, it identifies many issues that have to be dealt with for the successful implementation of an artificial recharge scheme. These include technical, environmental, legal, economic and social issues.

Comment on the document:
This document summarises the issues that need to be considered when taking an artificial recharge project from its conception stage, through construction and operation, to closure. The chapter headings are:

1) General (including purpose and types of schemes)
2) Planning
3) Field investigations and field testing
4) Design
5) Regulatory and water rights issues
6) Environmental issues
7) Economics
8) Construction
9) Start-up, operation and shutdown procedures
10) Operation, maintenance and closure

The document does not claim to provide a comprehensive "how to" guideline on each topic, but rather aims to describe the many steps required to develop, operate and maintain an artificial recharge project. In this regard, it is comprehensive, and although it generally offers little information on how to address the issues, it goes into greater depth on certain topics, such as those regarding the use of treated waste water.

This document can be used as a good checklist of issues that need to be taken into account when planning an artificial recharge scheme.

C.3.1.3 Groundwater Recharge and Wells: A Guide to Aquifer Storage and Recovery

Reference:	Pyne, R.D.G. 2005. Aquifer Storage Recovery: A Guide to Groundwater Recharge through Wells. Second Edition. ASR Press, Florida, USA.
Availability:	ASR Systems, PO Box 969, Gainsville, Florida, 32602, USA.
Number of pages:	608 (paper size: between A4 and A5).

Major issues:
The book raises and addresses most of the issues pertaining to ASR schemes. A major focus is on implementation stages, scheme design, water quality and geochemistry (and associated issues such as clogging), and the book includes information on a number on other technical and non-technical issues.

The book is divided into the following chapters:
Introduction

1) ASR Programme development
2) Design of ASR systems
3) Selected ASR technical issues
4) Geochemistry
5) Selected ASR non-technical issues
6) Alternative ASR applications
7) Selected case studies
8) Future directions

Comment on the document:
The book provides a comprehensive description of all the key issues affecting ASR schemes. It has been updated to include, amongst other topics, the considerable research that has gone into assessing the fate of pathogens during subsurface storage.

The book describes how to undertake feasibility studies and has an in-depth section on design issues. It includes an in-depth section of water quality issues, including pre- and post-treatment, geochemical issues and clogging.

This is the definitive guide to ASR, accompanied by numerous case studies.

C.3.1.4 Artificial Recharge of Groundwater: Hydrogeology and Engineering

Reference:	Bouwer, H. 2002. Artificial recharge of groundwater: hydrogeology and engineering. Hydrogeology Journal (2002) 10:121-142. Springer, Heidelberg, Germany.
Availability:	Hydrogeology Journal.
Number of pages:	21 (paper size: A4).

Major issues:
In this paper, Herman Bouwer summarises the key issues that affect the design and operation of artificial recharge schemes. Emphasis is placed on infiltration basins, on which subject Prof Bouwer has vast experience.

The key topics covered include:

- The mathematics of, and the factors that affect, infiltration from surface recharge schemes (including soil clogging)
- The role of recharge in water reuse.

The governing equations of infiltrating water are summarised in this paper, but are dealt with in greater detail in numerous other groundwater and engineering text books. These include those written, or contributed towards, by Prof. Bouwer in Huisman and Olsthoorn (1983) and in other journal papers.

Planned water reuse is expected to become increasingly important in future, and artificial recharge is identified as a cost-effective means to utilise surplus waste water. This option is “often cheaper than the treatment for discharge into surface water that is necessary to protect in-stream and downstream users of that water against unacceptable pollution”.

The paper presents a practical approach to implementing artificial recharge schemes: “Design and management of artificial recharge systems involves geological, geochemical, hydrological, biological and engineering aspects.”

> *"Because soils and underground formations are inherently heterogeneous, planning, design and construction of groundwater recharge schemes must be piecemeal, first testing for fatal flaws and general feasibility and then proceeding with pilot and small-scale systems until the complete system can be designed and constructed." Bouwer, 2002.*

Comment on the document:
Prof. Bouwer is one of the world's leading experts on surface recharge schemes. This paper consists of a summary of the key issues affecting flow from surface recharge facilities. For an aquifer to receive recharged water, it needs to be sufficiently transmissive, and this must be established by field investigations.

This document provides a succinct summary of concerns regarding the use of waste water in artificial recharge facilities, and summarises the advantages (water quality improvements) associated with soil aquifer treatment.

C.3.1.5 Artificial Recharge: A Technology for Sustainable Water Resource Development

Reference:	Murray, E.C. and Tredoux, G. 1998. Artificial recharge: A technology for sustainable water resource development. Water Research Commission, Report No 842/1/98. Pretoria, South Africa.
Availability:	Water Research Commission.
Number of pages:	152 (paper size: A4).

Major issues:
The key issues identified and discussed are:

1) Hydrological factors:
    - Recharge water sources: quantity, quality and reliability
    - Soil matrix chemistry and water quality issues
    - Hydraulic factors
    - Clogging potential
    - Numerical modelling
    - Recovery efficiency
2) Socio-Economic issues:
    - Economic
    - Management
    - Legal
    - Social

Comment on the document:
The document includes a section on "Guidelines for establishing artificial recharge schemes". The document is divided into the processes that are required for planning recharge basins and ASR schemes.

C.3.1.6 Artificial Groundwater Recharge

Reference:	Huisman, L. and Olsthoorn, T.N. 1983. Artificial Groundwater Recharge. Pitman Advanced Publishing Programme, Boston, London, Melbourne.
Availability:	Pitman Advanced Publishing Programme, Boston, London, Melbourne.
Number of pages:	310.

Major issues:
This text book covers the key technical issues relating to artificial recharge.

C.3.1.7 Guide on Artificial Recharge to Ground Water

Reference:	Central Groundwater Board. 2000. Guide on Artificial Recharge to Ground. Ministry of Water Resources, New Delhi, India.
Availability:	Central Groundwater Board, Ministry of Water Resources, New Delhi, India.
Number of pages:	93.

This document covers the planning of artificial recharge projects; artificial recharge techniques and design; project monitoring; and case studies. The appendices include a format for preparation of artificial recharge projects; a checklist for planning artificial recharge projects; and guidelines for evaluating artificial recharge projects.

C.3.2 Issue-based artificial recharge guideline documents

C.3.2.1 Clogging and artificial recharge of groundwater

Reference:	Pérez-Paricio, A. and Carrera, J. 1999. Clogging Handbook. EU Project on artificial recharge of groundwater. Contract ENV4-CT95-0071. Technical University of Catalonia (UPC), Barcelona, Spain.
Availability:	Uncertain.
Number of pages:	184 (paper size: A4).

Major issues:
All forms of clogging.

Comment on the document:
This is the most comprehensive document on all aspects of clogging in both surface and borehole recharge schemes. It includes clogging processes, prevention, redevelopment practices, how to detect and measure clogging, and empirical and numerical models for predicting clogging.

C.3.2.2 Guidelines on the Quality of Stormwater for Injection into Aquifers for Storage and Re-use

Reference:	Dillon, P.J. and Pavelic, P. 1996. Guidelines on the quality of stormwater and treated wastewater for injection into aquifers for storage and reuse. Urban Water Research Association of Australia. Research Report No. 109. ISBN 1 876088 13 3.
Availability:	Centre for Groundwater Studies, Flinders University, GPO Box 2100, SA 5001, Australia.
Number of pages:	48 (paper size: A4)

Major issues

The guidelines cover:

- Licensing
- Pre-treatment
- Monitoring
- Guidance for maximum contaminant concentrations in injectant
- Residence time prior to recovery
- Management of ASR operations.

Comment on the document:

The document reviews international practice and guidelines for artificial recharge of reclaimed waters by injection. It differs from other guidelines in that it does not assume potability as an essential objective, and it caters for treatment of the water by natural processes in the aquifer.

C.3.2.3 Guidelines for the Use of Reclaimed Water for Aquifer Recharge

Reference:	DNDE 1982. Guidelines for the use of reclaimed water for aquifer recharge. Department of National Development and Energy. Australian Water Resources Council: Water Management Series No. 2, Australian Government Publishing Service, Canberra. ISBN 0 644 01892 5.
Availability:	Uncertain.
Number of pages:	103 (paper size: A4).

Major issues:

1. Reclaimed water characteristics:
    - Degree of treatment
    - Toxic contaminants
    - Salinity
    - Biochemical oxygen demand
    - Suspended solids
    - Temperature.
2. Aquifer characteristics:
    - Aquifer types – confined/unconfined
    - Aquifer zones – saturated/unsaturated zones.

3. Infiltration effects:
    - Chemical effects of infiltration through the unsaturated zone
    - Effects of infiltration on biological characteristics
    - Product water quality
    - Disinfection
    - Long-term effects on recharge.

Comment on the document:
Rather than providing clear guidelines, the document describes the issues that affect artificial recharge using reclaimed water. It provides information on operation and management, including:

- Hydraulic loading and treatment
- Nitrogen removal
- Phosphorus removal
- Pathogen removal
- Sampling and examination of water
- Monitoring the water table.

C.3.2.4 Artificial Groundwater Recharge – State of the Art

Reference:	Frycklund, C. 1992. Artificial Groundwater Recharge – state of the art. VA-FORSKs Raport Series, Sweden. ISBN No. 91-88392-08-2.
Availability:	Uncertain.
Number of pages:	55 (Paper size: A4)

Major issues:
This document focuses on the precipitation of iron and manganese, including bacterial activity that promotes iron and manganese oxidation and precipitation.

Comment on the document:
The document provides a thorough description of the chemical evolution of iron and manganese during recharge processes.

C.3.2.5 The Potential for Aquifer Storage and Recovery in England and Wales

Reference:	Jones, H. K. Macdonald, D. M. J. and Gale, I. N. 1998. The potential for aquifer storage and recovery in England and Wales. British Geological Survey. Technical report No. WD/98/26.
Availability:	British Geological Survey.
Number of pages:	36, excluding appendices (paper size: A4).

Major issues:

1) The development of an approach to establish an aquifer's ASR potential
2) Guidance on dealing with authorisations for artificial recharge and recovery schemes (Appendix J).

Comment on the document:
This report identifies and describes briefly the main factors that affect ASR schemes. It draws heavily from Pyne (1995).

The issues covered are:

- Recovery efficiency
- Clogging
- Aquifer properties
- Operational issues
- Regulatory issues
- Hydrogeological factors (aquifer properties; depth to formation; aquifer confinement; aquifer water quality).

The value of this document, outside of the United Kingdom, is twofold: Firstly, it attempts to develop an approach to assess ASR sites on a regional scale. Although the first approach is abandoned, it nevertheless describes the proposed criteria and weighting system, and this can be used as a starting point to further develop a regional approach to assessing ASR potential. The factors that were considered were aquifer properties, aquifer confinement, depth to the aquifer and aquifer water quality. The finally adopted approach was largely based on geology and transmissivity.

The second major value of this document is that it provides guidance on dealing with authorisations for artificial recharge and recovery schemes (Appendix J). The guide is "reasonably" generic, although it refers, in places, to UK-specific criteria or regulations. Supporting material includes:

- Issues that would need to be covered in an environmental impact appraisal (Appendix J1)
- A summary of (UK) authorisations required for developing artificial recharge schemes (Appendix J2)
- A decision matrix for abstraction consenting and licensing (Appendix J3).

This document provides a sound basis from which to develop a generic authorisation guide.

C.3.2.6 Groundwater Licensing Guide – application procedure for the development and use of groundwater

Reference:	Parsons R, Eichstadt L, Crowther J and Blood J, 2006. Groundwater Licensing Guide – application procedure for the development and use of groundwater. WRC Project K5/1510. Water Research Commission. Pretoria, South Africa.
Availability:	Water Research Commission (In press).
Number of pages:	28 (paper size: A4).

Major issues:
The groundwater licensing guide considers legislation applicable to groundwater use in South Africa, and identifies when a licence and environmental authorisation is required.

Comment on the document:
As updated environmental regulations have only recently been promulgated, definitions, procedures and processes have not been tested, and thus the recommended groundwater licensing guide itself still needs to be tested. The guide provides some useful tools and documentation related to licence applications.

C.3.3 Environmental guideline documents relevant to artificial recharge

C.3.3.1 Guidelines for involving hydrogeologists in EIA processes

Reference:	Saayman, I (2005) Guidelines for involving hydrogeologists in EIA processes - Edition 1; CSIR Report No ENV-S-C 2005 053 D. Republic of South Africa, Provincial Government of the Western Cape, Department of Environmental Affairs & Development Planning, Cape Town.
Availability:	This document can be downloaded from the DEADP website: http://www.capegateway.gov.za/eng/yourgovernment/gsc/406/publications
Number of pages:	54 (paper size: A4).

Major issues:
This document is one of a series of guideline documents pertaining to the EIA process in South Africa. It aims to give guidance as to when a qualified geohydrologists should be involved. It identifies three triggers that require the EIA practitioner consult a hydrogeologists:

- Where influent or chemicals with the potential to change groundwater quality is handled as part of the project or discharged into the environment due to the project.
- The volume of groundwater in storage or entering groundwater storage is changed beyond what is allowed by the DWAF general authorisations.
- The groundwater flow regime is changed.

Once the need for a hydrogeologists to be involved in the project is assessed, the document provide some guidance for drawing up terms of reference, specific tasks that the hydrogeologists may be involved in and specialised input and management actions.

Comment on the document:
The guideline document is unlikely to be particularly useful in any projects involving artificial recharge as a hydrogeologist would always be involved. However, the document provides useful guidance on how to review specialist report, how to address issues such as cumulative impacts and communicating the findings of specialist inputs.

C.3.3.2 Guideline on the interpretation of the listed activities requiring environmental authorisation

Reference:	DEADP (2006) Guideline on the interpretation of the list of activities; NEMA environmental impact assessment regulations guideline and information document series, Department of Environmental Affairs and Development Planning, Cape Town.
Availability:	This document can be downloaded from the DEADP website: http://www.capegateway.gov.za/eng/yourgovernment/gsc/406/publications
Number of pages:	70 (paper size: A4).

Major issues:
In response to promulgation of new regulations pertaining to environmental impact assessment, DEADP produced a guide document on the interpretation of listed activities. Artificial recharge is not addressed directly in the guide, but associated listed activities that may be applicable to artificial recharge projects are.

Comment on the document:
The guide is useful in that it provides an interpretation of listed activities that may be relevant to artificial recharge. It also lists activities that may be pertinent to groundwater abstraction, such as the construction of pipelines, the transformation or removal of indigenous vegetation of 3 ha or more, and the off-stream storage of water of 50 000 m^3, or more.

In addition to these documents, the recently completed Water Research Commission project by Parsons *et al* (2007) describes procedures applicable to groundwater. The report has not yet been published.

SECTION D:
THE ARTIFICIAL RECHARGE STRATEGY

D.1 THE ARTIFICIAL RECHARGE STRATEGY

The document up to this point is intended to provide a basis for the artificial recharge strategy. It has provided an overview of artificial recharge, looked at key issues affecting its application and it has recommended a process for implementing and authorising schemes. This section presents the artificial recharge strategy – the recommended approach for creating an enabling environment for artificial recharge to become an integral part of the country's water resource management philosophy.

The strategy is presented in the following manner:

The Vision:	The long-term goal
The Themes:	Areas that need to be addressed in order to realise the Vision
The Management Objectives:	The objective of each Theme
The Situation Assessments:	The current status ("where we are now") in relation to the Management Objectives
The Strategic Approach:	Key focus areas that need to be addressed in order to reach the Management Objectives
Actions:	The tasks required to fulfil the Strategic Approach
Responsibility:	The organisation responsible for implementing the Actions
Priority:	The order of implementing the Actions

Table D.1 presents the Vision, Themes and Management Objectives, and the following pages provide a full description of each Theme.

Table D.1 Artificial recharge Vision, Themes and Management Objectives

VISION	
To use natural sub-surface storage as part of Integrated Water Resource Management wherever technologically, economically, environmentally and socially feasible.	
Artificial recharge themes	**Management objectives**
1. Knowledge Theme	To create awareness and provide education on artificial recharge.
2. Legislation and Regulation Theme	To enable water management and water services institutions to adopt and regulate artificial recharge as part of IWRM.
3. Planning Theme	To facilitate the use of artificial recharge in achieving sustainable, efficient and cost effective water resource use and management.
4. Implementation Theme	To support water management and water services institutions in implementing artificial recharge.
5. Management Theme	To optimise the management of artificial recharge schemes.
6. Research Theme	To develop a body of knowledge that supports efficient and effective implementation and operation of artificial recharge schemes.
7. Strategy Implementation Theme	To implement and update the artificial recharge strategy.

Theme 1 Knowledge	
Management Objective	Create awareness and provide education on artificial recharge.
Situation Assessment	The concept of transferring surface water to be held in underground storage is usually more efficient than above-ground storage. Evaporation losses are negligible and the risk of contamination is a less than in surface reservoirs. However, artificial recharge is not well known and so far, has not been adopted on a wide scale. Since 1998 two Water Research Commission reports and one booklet have been published on case studies and the factors that affect the viability of artificial recharge schemes. This information has been presented at national water conferences, lectures in major urban centres, and it has had limited coverage in magazines, newspapers and radio. The hydrogeological sector, and to a lesser extent, the broad water sector, have been given access to the artificial recharge concept and its applicability. Once-off lectures on artificial recharge have been given at universities, but it has not been incorporated their curricula.
Strategic Approach	The strategic approach should aim to: 1. Make the artificial recharge strategy accessible; 2. Spread the awareness of artificial recharge to a diverse audience; and 3. Educate people on artificial recharge. A flagship project for awareness and educational purposes should be developed to assist in achieving these aims. More specifically: 1. **Accessible:** Make the artificial recharge strategy broadly accessible by advertising it and presenting it throughout the country. 2. **Awareness:** Broaden awareness on artificial recharge amongst the water and planning sectors and amongst governmental departments other than DWAF. 3. **Educate:** Educate students, government officials and practising professionals on the value, applicability, feasibility, implementation and operation of artificial recharge schemes. 4. Develop a **flagship project** to demonstrate the value and operation of an artificial recharge scheme and serve as an educational centre.

Management Actions, Responsibility & Priority		
Actions	**Responsibility**	**Priority**
1. Make the artificial recharge **Strategy** accessible.		
1.1 Place it on DWAF's website and print hard-copies. Release it to the media: 1. Professional media, including newsletters, magazines and journals from municipal, water, engineering, planning, environmental, agricultural, mining and industrial sectors. 2. Popular media, including newspapers, television and radio.	DWAF HO	1
1.2 Present the strategy in 10 centres around the country: Pretoria, Cape Town, Durban, Port Elizabeth, East London, Kimberly, Bloemfontein, Upington, Polokwane and Nelspruit. The target audience should include: Municipalities, DWAF Regional Offices, CMAs, DEAT Regional Offices, academic/training institutions and engineering, planning, hydrogeological and hydrological consultants.	DWAF HO	2
1.3 Present the strategy at national water, municipal and development planning conferences (eg WISA and IMIESA); and at an international artificial recharge conference(ISMAR).	DWAF HO	2
2. Broaden **awareness** on artificial recharge.		
2.1 Produce posters for DWAF, DEAT and Municipalities. These should include the types of artificial recharge, their benefits and the criteria for successful implementation.	DWAF HO	2
2.2 Produce billboards at existing artificial recharge sites. These should inform people that artificial recharge is practiced in the area and of its main purposes.	DWAF RO	2
2.3 Produce information on artificial recharge. This should include booklets, journal articles and magazine articles. The subject matter should include the types of artificial recharge, their benefits and the criteria for successful implementation. The target audiences should include Government Departments (eg DWAF, DEAT), Local Government, Mines and Energy and Agriculture, Catchment Management Agencies, Water User Associations, Municipal Associations (eg Water Services Authorities and Water Services Providers), Farming Associations, Water Boards and engineering/water science professionals.	DWAF HO & WRC	2

3. Promote artificial recharge **education**.		
3.1 Develop a training course on implementing and operating artificial recharge schemes. Include all the issues that need to be assessed in feasibility studies and the implementation stages, as well as general operation and maintenance procedures. The course should be housed at the information centre of the flagship project.	DWAF HO	3
3.2 Artificial recharge should be incorporated into university curricula. The target disciplines should include development planning, engineering, hydrology and hydrogeology. Presentations and notes need to be developed and made accessible to teaching staff.	WRC	3
4. Promote a **flagship project**.		
4.1 Identify and assist a municipality in developing an artificial recharge scheme that can be used as a demonstration site.	DWAF HO	3
4.2 Develop an information centre at the municipality and train staff as guides for the information centre and field visits. Aim to demonstrate the value of artificial recharge in one or more of the following: Capturing and storing surplus runoff, bridging the peak summer water demand period, providing security against droughts, minimising evaporation losses, improving water quality, enhancing the catchment's water Reserve, improving the ecological status of the area.	DWAF HO	3

Priority 1	Immediate
Priority 2	Within 2 years
Priority 3	Within 5 years

Theme 2 Legislation and Regulation	
Management Objective	Enable water management and water services institutions to adopt and regulate artificial recharge as part of IWRM
Situation Assessment	Artificial recharge with fresh water is not mentioned specifically in the National Water Act but is referred to indirectly in the regulations promulgated in terms of the Act. The regulations effectively state that the storage of any volume of water underground requires licensing. However current application forms are not suited to artificial recharge, as they are geared towards storage in dams. Artificial recharge with waste water is mentioned in the NWA. The discharge of wastewater into an aquifer is regulated and requires registration and licensing in all cases. The only other reference to artificial recharge is in a Government Gazette (No 26187a), in the context of stream flow reduction activities and altering a watercourse. It lists artificial recharge structures as one of the types of infrastructure that is covered by those regulations. The National Environmental Management Act (NEMA) and associated regulations describe a number of activities that would "trigger" the need for either a basic assessment or a full environmental study, comprising a scoping study and an environmental impact assessment. Many of these trigger activities may be part of an artificial recharge scheme, like building roads, a dam etc., but only listed activity 13 is groundwater specific. This stipulates that a basic assessment is required if the volume of groundwater abstracted is greater than the amount authorised under a general authorisation. In summary, artificial recharge is not listed but groundwater abstraction above the general authorisation is a listed activity for a basic assessment and most artificial recharge schemes will trigger a basic assessment on that basis. Once triggered, the environmental study would typically include the assessment of the impact of the project on natural, cultural and socio-economic environments.
Strategic Approach	Under the current legislation artificial recharge projects can be implemented and authorised. However, authorisation will be problematic because the terms and definitions used in current legislation are open to various interpretations when applied to artificial recharge projects. This should be addressed by undertaking the following actions: 1. Clarify the current legal requirements for authorising artificial recharge projects. 2. Clarify the authorisation process and provide guidance and training on this. 3. Review the current legislation and establish whether amendments or new regulations are needed.

Management Actions, Responsibility & Priority		
Actions	**Responsibility**	**Priority**
1. Clarify the current **legal requirements** for authorising artificial recharge projects.		
1.1 Based on the requirements of the National Water Act and the National Environmental Management Act identify the legal requirements for authorising artificial recharge schemes.	DWAF HO	✓ Section C.2
1.2 Update Item 1.1 above after experience has been gained in authorising artificial recharge schemes.	DWAF, Legal Services	3
1.3 Draft a booklet for planners, engineers, environmentalists and hydrogeologists on how to interpret the legal requirements for implementing artificial recharge.	DWAF HO / WRC	3
2. Clarify the **authorisation process** and provide guidance and training on this.		
2.1 Provide guidance on the artificial recharge authorisation process.	DWAF HO	✓ Section C.2
2.2 Produce an artificial recharge authorisation guideline.	DWAF HO	3
2.3 Produce a document to assist regulators in approving / rejecting / improving artificial recharge applications. The document should include the types of conditions that should accompany artificial recharge authorisation. Required supportive documents are listed below and in Objectives 4 and 5.	DWAF HO / WRC	3
2.3.1 Develop principles regarding the modification of natural groundwater taking into account the Resource Quality Objectives as specified by DWAF.	DWAF HO	3
2.3.2 Produce artificial recharge monitoring guideline documents. The documents needed are: 1. Guidelines on water level monitoring; 2. Guidelines on water quality monitoring (including recharge water quality objectives and recovered water minimum quality requirements); 3. Environmental monitoring requirements (including ecological baseline data requirements). The guidelines must relate to the artificial recharge implementation stages and to the scale of artificial recharge schemes.	DWAF HO	3
2.3.3 Define public and environmental health risk assessment needs and management requirements. This relates strongly to the use of reclaimed wastewater and liabilities associated with water quality issues.	DWAF HO	3

2.3.4 Develop principles regarding the right to use artificially recharged water, and how to incorporate this right in the licence agreement.	DWAF HO	3
2.4 Train regulatory authorities in assessing and processing artificial recharge scheme applications and in reviewing the effectiveness of artificial recharge schemes. The main target audience should be DWAF and CMAs.	DWAF HO	3
2.5 Provide a preliminary framework for the institutional arrangements and reporting requirements.	DWAF HO	✓ Section C.1.10
2.6 Update the framework on institutional arrangements to include complex scenarios such as multiple user schemes (eg competing agricultural and domestic users)	DWAF HO	3
3. Review the current **legislation** and establish whether amendments or new regulations are needed.	DWAF, Legal Services	3

Priority 1	Immediate
Priority 2	Within 2 years
Priority 3	Within 5 years

Theme 3 Planning	
Management Objective	Facilitate the use of artificial recharge in achieving sustainable, efficient and cost effective water resource use and management
Situation Assessment	Artificial recharge has many uses. The two prime uses in South Africa are water storage and water conservation. Aquifers, like dams, can be used to store water, and in doing so, water that would otherwise be lost to evaporation or outflow to the oceans, can be conserved for later use. To date, maximising sub-surface storage through artificial recharge has not been considered by water sector planners. This Strategy document provides the first attempt to address this. During the course of developing this Strategy document, the artificial recharge potential at the Water Management Area (WMA) scale was estimated. Only areas with known high permeability were used, as these areas are favourable for rapidly recharging and abstracting groundwater. The total water volume that could be stored over and above existing natural groundwater storage is estimated to be 8 000 Mm^3 (see Chapter B.4). The water conservation concept is prevalent amongst water resource planners and is reflected in most planning documents. Artificial recharge, however, is rarely mentioned, although it is recommended in some Internal Strategic Perspective documents (ISPs). Listed below are a number of strategic documents where water conservation and the wise use of existing water resources are encouraged. • National Water Resource Strategy (NWRS) (DWAF, 2004). The NWRS encourages all forms of water conservation. Artificial recharge, although not mentioned in the NWRS, is one way of achieving conjunctive water use and water conservation. • National Water Conservation and Water Demand Management Strategy (DWAF, 2004a). A National Water Conservation and Water Demand Management Strategy (WC/WDM) was developed by DWAF's Directorate: Water Use and Efficiency, and incorporated into the National Water Resource Strategy (NWRS). One of the roles of the WC/WDM Strategy is to: "promote the use of new technologies which will raise the level of water use efficiency in all sectors". Artificial recharge, although not a "new technology", is an under-utilised, innovative approach to water use efficiency. • Catchment Management Strategies (CMS), once completed, will form the next (lower) level of water resource planning. WC/WDM and groundwater use and management need to be incorporated into the CMSs, and artificial recharge should be mentioned as one form of integrating and maximising available water resources. • Internal Strategic Perspectives (ISPs) were developed as an interim measure for each Water Management Area (WMA) or sub-WMA. Recommendations pertaining to artificial recharge are given in some of the ISPs, for example "Aquifer Storage and Recovery could be used to boost recharge during infrequent periods of surplus flow, taking advantage of aquifer storage". Aquifer Storage and Recovery is an artificial recharge term used specifically for borehole injection. • At the Water Services Level, the documents that include the principles of artificial recharge are: - Integrated Development Plans (IDPs). These are the strategic plan for the development of municipalities.

	- Water Services Development Plans (WSDPs). WSDPs form part of the IDPs, and describe current and planned water resource use and management. South Africa's oldest and largest artificial recharge scheme, Atlantis, is not mentioned in Cape Town's WSDP even though it provides about a third of the water requirements for Atlantis town. Likewise, artificial recharge has not been considered as a potential alternative technology in Cape Town's WSDP or mentioned in its section on Integrated Water Resource Management (IWRM). This reflects the current reality in South Africa, where artificial recharge is not recognised as an effective or potentially effective from of water resource management. DWAF has developed a guide for developing WSDPs, and the latest version includes artificial recharge (DWAF's Guide, Framework and Checklist for the Development of WSDPs, Version 10). - Three separate documents: Water Conservation and Water Demand Management Strategy for the Water Services Sector; the Agricultural Sector; and the Industry, Mining and Power Generation Sector. Artificial recharge, while not mentioned in these documents, is a recognised water conservation measure in the water services sectors.
Strategic Approach	Planning for artificial recharge needs to be accommodated at national, regional and local levels. The following areas should be targeted: 1. Artificial recharge needs to be adequately addressed in strategy and planning documents. Planning tools that include artificial recharge also need to be developed for water resource management institutions and water services institutions. Artificial recharge needs to target two spheres within the water sector: • The Water Resource Management Sphere, and • The Water Services Sphere. 2. The artificial recharge potential per WMA and sub-areas needs to be quantified. Existing figures presented in this document need to be updated using localised data sets and the methodology needs to be verified with case studies. 3. Localised areas where artificial recharge is needed should be identified. This should include areas where water tables have dropped due to high groundwater abstraction, where a suitable source water is available, and where aquifer hydraulics and water quality characteristics are favourable for artificial recharge. 4. Identify specialised planning areas and purposes where artificial recharge could have significant impact. For example, areas where artificial recharge could assist in mitigating the effects of climate change (such as areas vulnerable to an increasing variability in rainfall); and areas where artificial recharge could augment the Reserve. 5. There is a need to better understand the economics of artificial recharge. Internationally, artificial recharge has been found to be far cheaper and more cost effective than other water resource development options.

Management Actions, Responsibility & Priority		
Actions	**Responsibility**	**Priority**
1. Ensure that artificial recharge is incorporated in relevant IWRM documents.		
1.1 Ensure that artificial recharge is incorporated in relevant **National scale** IWRM documents.		
1.1.1 Incorporate artificial recharge in updated versions of the NWRS.	DWAF HO	3
1.1.2 Incorporate artificial recharge in updated versions of the National WC/WDM Strategy.	DWAF HO	3
1.1.3 Incorporate artificial recharge in updated versions of the WC/WDM Strategies for the Water Services, Agriculture and Industry, Mining and Power Generation Sectors.	DWAF HO	3
1.1.4 Incorporate artificial recharge in DWAF's Guide, Framework and Checklist for the Development of WSDPs.	DWAF HO	✓ Section D.2
1.1.5 Incorporate artificial recharge in updated versions of Water Services Feasibility Studies: Applications Procedures, Checklist and Minimum Standards.	DWAF HO	✓ Section D.2
1.1.6 Incorporate artificial recharge in updated versions of Water Services Planning Framework.	DWAF HO	3
1.1.7 Incorporate artificial recharge in updated versions of Implementation Guidelines for Water Conservation and Demand Management in Agriculture: Development of Water Management Plans.	DWAF HO	3
1.1.8 Incorporate artificial recharge in updated versions of Guidelines for Catchment Management Strategies.	DWAF HO	3
1.1.9 Incorporate artificial recharge in updated versions of strategic documents pertaining to environmental affairs and sustainable development (eg A Strategic Framework for Sustainable Development in South Africa: Draft for Review, 2006)	DEAT	3
1.2 Ensure that artificial recharge is incorporated in relevant **Catchment / Water Management Area scale** IWRM documents.		

1.2.1 Incorporate artificial recharge in Catchment Management Strategies.	DWAF HO / CMAs	2
1.3 Ensure that artificial recharge is incorporated in relevant **Municipal scale** IWRM documents.		
1.3.1 Ensure that artificial recharge is included in WSDPs.	DMs	3
2. Assess the artificial recharge potential at the WMA and Local scale.		
2.1 Undertake a preliminary assessment of artificial recharge storage potential at the WMA scale.	DWAF HO	✓ Section B.4
2.2 Undertake a detailed assessment of artificial recharge storage potential at the WMA scale (update item 2.1).	DWAF ROs / CMAs	2
2.3 Identify aquifers with an artificial recharge storage potential of 250 – 500 Mm^3, 500 – 750 Mm^3 and 750 – 1 000 Mm^3.	WRC / DWAF HO: Options Analysis	2
2.4 Quantify the surplus surface water that could be used for artificial recharge	WRC / DWAF HO: Options Analysis	2
2.5 Develop an updated yield balance per WMA and reconciliation figures that include artificial recharge.	CMAs	3
3. Identify localised areas where artificial recharge is needed.		
3.1 Establish areas where water tables have dropped due to high groundwater abstraction, where suitable source waters are available, and where aquifer hydraulics and water quality characteristics are favourable for artificial recharge. Identify Local Municipalities with artificial recharge potential and initiate a localised groundwater monitoring programmes.	CMA / DWAF	2
4. Identify specialised planning areas and purposes for artificial recharge.		
4.1 Identify areas where artificial recharge could be beneficial for purposes such as climate change mitigation and Reserve augmentation.	DWAF HO	3
5. Undertake an economic assessment of artificial recharge.		
5.1 Establish artificial recharge implementation and operation costs and develop an economic model to compare artificial recharge with other water resource development options.	DWAF HO	3

Priority 1	Immediate
Priority 2	Within 2 years
Priority 3	Within 5 years

Theme 4 Implementation	
Management Objective	Support water management and water services institutions in implementing artificial recharge
Situation Assessment	The current status of artificial recharge projects and schemes in South Africa is listed below. Operational schemes: • Atlantis • Kharkams Unplanned scheme: • Polokwane Emergency water supply scheme: • Calvinia Feasibility studies: • Langebaan • Plettenberg Bay • Prince Albert The biggest implementation problem is not whether the country has the skills and resources to implement artificial recharge schemes, but the lack of borehole water level and abstraction data in areas of high groundwater use. Without these it is not possible to rapidly establish whether artificial recharge is necessary or not. The challenge is to upgrade nation-wide water level monitoring for all groundwater-dependant users. In the cases of Plettenberg Bay and Prince Albert existing data was inadequate to establish how the aquifers have responded to large-scale abstraction. According to the pump operators', certain boreholes had "run dry". While artificial recharge may be the most appropriate solutions for both towns, data is required to know this. Boreholes had to be properly equipped for monitoring, staff needed to be trained and borehole data loggers had to be installed. Artificial recharge schemes have to be well designed and appropriate for the level of management expertise in order for them to be efficient and effective. This relates to infrastructure (water supply, water treatment, and recharge and abstraction infrastructure) as well as operation and management capacity. During the feasibility stage, the appropriate level of technology must be established to match current and future operational and management expertise.

Strategic Approach	The approach to supporting the implementation of artificial recharge schemes should follow five key areas: 1. Support groundwater monitoring. 2. Provide guidance on the technical aspects around assessing the viability of schemes, on implementing schemes and on technical aspects regarding authorising schemes. 3. Create an incentive mechanism for local government authorities to adopt artificial recharge. The aim should be to encourage the wise use of existing water resources and infrastructure before developing more costly new sources. 4. Develop support mechanisms for implementing artificial recharge schemes. 5. Develop a training course on implementing artificial recharge schemes.

Management Actions, Responsibility & Priority

Actions	**Responsibility**	**Priority**
1. Support groundwater monitoring		
1.1 Ensure that groundwater monitoring at the local, groundwater user level is incorporated in the National Groundwater Strategy.	DWAF HO	1
2. Produce guideline documents on assessing the feasibility of artificial recharge schemes and implementing artificial recharge schemes. The documents should cover all the criteria for successful implementation and operation. Some of the key guidelines are listed below.		
2.1 Develop a guideline on water quality requirements for artificial recharge. This should include pre- and post-treatment in relation to both health issues and clogging prevention. The guideline should include water quality standards (with respect to turbidity, microbial quality, chemistry, etc) for the different recharge techniques and water types, to prevent, for example, clogging of the filtration surface and the aquifer.	DWAF HO	3
2.2 Develop a guideline on environmental requirements for authorising and monitoring the impact of artificial recharge schemes.	DWAF HO	3
2.3 Develop a procedure for undertaking artificial recharge feasibility studies.	DWAF HO / DEAT	2
3. Create an incentive mechanism for local government authorities to adopt artificial recharge.		
3.1 Develop an incentive mechanism for water resource management and services institutions to adopt artificial recharge as a form of water conservation. Consider ways to discount water resource management costs (for example, by basing it on the premise that water conserved through artificial recharge creates the potential for additional licences for other users).	DWAF HO	3

4. Develop support mechanisms for implementing artificial recharge schemes.		
4.1 Establish an Advisory Committee to assist artificial recharge applications (consider funding sources like the incentive scheme mentioned in 2.1 above).	DWAF HO	3
4.2. Identify local and international institutions/resources that could be approached to support artificial recharge initiatives.	DWAF HO	3
5. Develop a training course on implementing artificial recharge schemes.		
5.1 Develop a training course on implementing and operating artificial recharge schemes. Include all the issues that need to be assessed in feasibility studies and the implementation stages. The course should be housed at the information centre of the flagship project (See objective 1).	DWAF HO	3

Priority 1	Immediate
Priority 2	Within 2 years
Priority 3	Within 5 years

<table>
<tr><th colspan="2">Theme 5

Management</th></tr>
<tr><td>Management Objective</td><td>Optimise the management of artificial recharge schemes</td></tr>
<tr><td>Situation Assessment</td><td>All artificial recharge schemes require management and an operation and maintenance budget. They require staff that are dedicated to optimising the efficiency and effectiveness of schemes.

The following tasks are common to most artificial recharge schemes: transferring the source water to the artificial recharge facility, treating the source water, operating the artificial recharge infrastructure, preventing and managing clogging, monitoring the aquifer’s response to artificial recharge, optimising abstraction after recharge, and monitoring and managing the recovered water quality. Depending on the size and nature of the scheme, these tasks may be very simple or fairly sophisticated, but either way, they all require management if schemes are to run optimally. In addition to these technical tasks, reporting is required to meet licence agreements.

The Atlantis Water Resource Management Scheme has dedicated staff assigned to operating and managing the artificial recharge facilities, and the City of Windhoek appointed a full-time hydrogeologist to manage the Windhoek aquifer and artificial recharge scheme.

In addition to support in managing artificial recharge schemes, it is evident that they need to be regulated. Associated with this is the need for regular reviewing of the operational procedures and the effects of artificial recharge. This is particularly important when water of marginal quality is used as the source water for recharge. The aim should be to ensure that water of unacceptable quality is not used for recharge. Performance monitoring is also important where the environmental consequences of mismanagement are severe, for example, in dolomitic aquifers where sink holes can form from groundwater over-abstraction.</td></tr>
<tr><td>Strategic Approach</td><td>The approach to enhance capacity to manage artificial recharge schemes needs to focus on three key areas:

1. Provide guidance and support mechanisms for effectively operating artificial recharge schemes. This needs to include identifying the skills required to operate schemes, a mechanism for assessing the performance of schemes, and a system to support data capture and management.
2. Develop a training course on the operation and maintenance of artificial recharge schemes.
3. Develop standards pertaining to the operation and management of artificial recharge schemes.</td></tr>
</table>

Management Actions, Responsibility & Priority		
Actions	**Responsibility**	**Priority**
1. Develop a support mechanism for water supply institutions that operate artificial recharge schemes.		
1.1 Develop a checklist of the skills required to operate and manage the various types of artificial recharge schemes. Identify key performance indicators and develop a mechanism for assessing them.	DWAF HO	1
1.2 Develop a system for supporting institutions and staff involved in operating artificial recharge schemes.	DWAF HO	2
1.3 Develop a system for supporting data management.	DWAF HO	2
2. Develop a training course on the operation and maintenance of artificial recharge schemes.		
2.1 Develop a training course on artificial recharge scheme operation and maintenance. The course should be housed at the information centre of the flagship project (see Objective 1).	DWAF HO	3
3. Develop standards relating to the operation and performance of artificial recharge schemes.		
3.1 Develop standards relating to the operation and performance of artificial recharge schemes, and a reporting system that accommodates an annual review of the scheme performance (including data on source- and groundwater quality, volumes recharged and abstracted, and aquifer water levels). The standards should include source water quality (quality limitations suitable for the various types of recharge and end-user use), source water quality monitoring, groundwater level monitoring and groundwater quality monitoring. The standards should be developed with licensing requirements in mind – so that licence conditions can be linked to the standards.	DWAF HO	2

Priority 1	Immediate
Priority 2	Within 2 years
Priority 3	Within 5 years

Theme 6 Research	
Management Objective	Develop a body of knowledge that supports efficient and effective implementation and operation of artificial recharge schemes
Situation Assessment	Two Water Commission Research (WRC) reports have been published in recent years: *Artificial Recharge: A Technology For Sustainable Water Resource Development* (Murray and Tredoux, 1998) and *Pilot Artificial Recharge Scheme: Testing Sustainable Water Resource Development in Fractured Aquifers* (Murray and Tredoux, 2002). In addition to these reports, the WRC published a booklet for the layperson: *Artificial Groundwater Recharge: Wise Water Management for Towns and Cities* (Murray, 2004). Since 1998, numerous papers on artificial recharge have been presented at local and international conferences, and the WRC supported presentations at many cities and towns throughout South Africa. Southern Africa is leading the world in applying artificial recharge to fractured aquifers. New questions will arise as this technology is increasingly applied to different types of fractured aquifers, and research will need to be geared towards developing efficient scheme designs and operating procedures. International research has largely focussed on water quality issues, and in particular, the use of treated waste water for recharge, the prevention and management of clogging in boreholes and infiltration basins, and the prevention of hydrochemical risks. South Africa needs to remain well connected to international researchers and contribute towards in the international knowledge pool. A key challenge for South Africa at the moment is to provide the means to authorise well designed artificial recharge schemes in a timeous and cost-effective manner. The most pressing research needs relate to authorisation and regulation. Officials need guidance on topics such as: the water quality limits acceptable for recharge; the extent to which natural groundwater can be modified (which relate to DWAF's Resource Quality Objectives); acceptable aquifer water level fluctuations, etc. These topics require research that is grounded in international experience and modified to suit South Africa's particular hydrogeological and management conditions. The key water quality research areas that are of immediate relevance are clogging in iron-rich groundwaters, clogging in fractured aquifers and the use of treated effluent as a source water for artificial recharge.
Strategic Approach	There are three areas where research that is particular to South Africa is required: 1. That which is geared towards developing principles or guidelines to assist officials in authorising schemes and setting licence conditions. This theme should focus largely on water quality issues and environmental impacts. 2. Particular water quality issues such as hydrochemical risks and clogging in iron-rich, and fractured aquifers. 3. Issues pertaining to the use of using treated waste water as a source for artificial recharge.

Management Actions, Responsibility & Priority		
Actions	**Responsibility**	**Priority**
1. Research requirements.		
1.1 Establish and prioritise the key research requirements (some of which are listed below).	WRC	1
2. Artificial recharge authorisation		
2.1 Identify the knowledge constraints that could cause lengthy delays in authorising schemes and in establishing licence conditions (eg environmental monitoring requirements).	WRC	1
3. Water quality issues.		
3.1 Research water quality issues pertaining to clogging in iron-rich groundwaters and clogging in fractured aquifers.	WRC	3
3.2 Identify social and environmental requirements for using treated effluent as source water for artificial recharge.	WRC	3

Priority 1	Immediate
Priority 2	Within 2 years
Priority 3	Within 5 years

Theme 7 Strategy Implementation	
Management Objective	Implement and update the artificial recharge strategy
Situation Assessment	This is South Africa's first national artificial recharge strategy and its development has followed a process of compiling two draft versions for review and comment. During the course of developing the strategy, some of the key actions required to create an enabling environment for implementing artificial recharge schemes have been completed. These have been included in the listed actions in this strategy so that progress on strategy implementation can be assessed. The actions listed below are geared to ensure that the strategy is implemented and periodically updated.
Strategic Approach	The artificial recharge strategy will be successful if people from diverse professional backgrounds consider artificial recharge as an option to address water supply, water quality and environmental issues. That is, awareness regarding the benefits and applications of artificial recharge need to reach a wide audience. The focus of implementing the artificial recharge strategy should be to reach this diverse audience and to ensure that the necessary "tools" (technical, legal, etc) are in place for artificial recharge to be implemented efficiently and timeously. This will require artificial recharge champions from DWAF who drive the implementation of the strategy and who are proactive in incorporating artificial recharge within other strategies and planning documents, such as Catchment Management Strategies, Water Conservation and Demand Management Strategies, Water Services Development Plans, etc.

Management Actions, Responsibility & Priority		
Actions	**Responsibility**	**Priority**
1. Find a driver for the artificial recharge strategy		
1.1 Find a home and a champion for the artificial recharge strategy and a funding source for implementing it.	DWAF: Water Resource Planning Systems	✓
2. Facilitate high-level inter-departmental awareness of the strategy		
2.1 Develop an information sheet on the artificial recharge strategy, and inform the Director Generals of the strategy.	DWAF HO	1
3. Ensure that DWAF staff are aware of the strategy and its purpose.		
3.1 Circulate an information sheet on the strategy to all DWAF staff above Deputy Director level.	DWAF HO	1
4. Implement the strategy		
4.1 Develop an artificial recharge implementation plan	DWAF HO	1
4.2 Implement the strategy starting with the 1st Action in Objective 1.	DWAF HO	1
4.3. Develop a plan to ensure that the strategy is reviewed and updated.	DWAF HO	3

Priority 1	Immediate
Priority 2	Within 2 years
Priority 3	Within 5 years

D.2 APPROACH TO INCORPORATE ARTIFICIAL RECHARGE IN WATER RESOURCE PLANNING

D.2.1 Artificial recharge in the context of Water Conservation and Water Demand Management

DWAF recognises that water demand management, water resource management and water conservation need to play a major role in balancing the availability of our country's water resources and future demand. In year 2000, 10 of the 19 Water Management Areas (WMAs) had negative water balances, and the total surplus for the entire country was 186 Mm^3/a (NWRS, 2004). Predictions for year 2025 also indicate that 10 of the 19 WMAs will have negative water balances, but the total balance for the country is estimated to be -234 Mm^3/a. The potential for development is quantified at 5 410 Mm^3/a (NWRS, 2004).

DWAF relates water conservation and water demand management to the efficient and effective use of water and minimising the loss and wastage of water. The challenge lies in developing realistic plans to incorporate artificial recharge as a viable form of water conservation, wherever possible. Although it is not expected that artificial recharge will provide huge water savings in the national water balance, it is envisaged that the savings in certain stressed areas will be highly beneficial. These savings may be small or large, depending on the area. Artificial recharge should be seen as providing a significant conservation measure in strategic areas and not as a form of regional, large-scale water conservation. Artificial recharge should also be seen as a potential cost-effective and natural form of treatment for "polishing" the water. The main advantage, however, is sub-surface storage.

A National Water Conservation and Water Demand Management Strategy (WC/WDM) was developed by DWAF's Directorate: Water Use and Efficiency (DWAF, 2004a), and incorporated into the National Water Resource Strategy (NWRS). One of the roles of the WC/WDM Strategy is to: *"promote the use of new technologies which will raise the level of water use efficiency in all sectors*" (DWAF, 2004a). At this stage of the WC/WDM strategy development, the key water use sectors have been targeted:

- Water services (DWAF, 2004b)
- Agriculture (DWAF, 2004c)
- Industry, mining and power generation (DWAF, 2004d).

These strategies outline measures and interventions aimed at encouraging and supporting water institutions and water users to increase the efficiency of their water use. The concept of artificial recharge as a water conservation measure will need to be incorporated into these strategy documents. For example, where "Dam storage optimisation" is mentioned as a Typical Water Conservation Activity (DWAF, 2004a), artificial recharge or "Aquifer storage optimisation" should also be included.

DWAF has the responsibility of supporting water institutions and helping them to develop and implement strategies that suit their own circumstances and which are economically coherent and financially sound with regard to the cost and benefit of the proposed measures (NWRS, 2004). In this regard, DWAF will support water institutions that include artificial recharge as a water conservation measure. The water services institutions include (National Water Act, 1998 and Water Services Act, 1997):

- Catchment Management Agencies (CMAs)
- Water User Associations (WUAs)
- Water Services Authorities (WSAs)
- Bulk and Retail Water Services Providers (WSPs), such as Water Boards.

The final artificial recharge strategy will target two levels within the water sector:

- The Water Resource Level, and
- The Water Services Level.

Within each level, existing and planned documents are identified for necessary incorporation of the artificial recharge strategy. These documents are:

- Water Resource Level:
    - NWRS
    - Catchment Management Strategies
    - Internal Strategic Perspectives.

- Water Services Level:
    - Integrated Development Plans
    - Water Services Development Plans (and supporting documents)
    - WC/WDM Strategy for the Water Services Sector
    - WC/WDM Strategy for the Agricultural Sector
    - WC/WDM Strategy for the Industry, Mining and Power Generation Sector.

D.2.2 Artificial recharge strategy at the Water Resource Level

D.2.2.1 National Water Resource Strategy

At this stage of artificial recharge development, artificial recharge needs to be incorporated into one section of the NWRS - Chapter 3, Part 3: Water Conservation and Water Demand Management. It is also worth considering incorporating artificial recharge into Chapter 5: National Planning and Co-ordination, and International Co-operation in Water Management. The mention of artificial recharge in Section 1.4: Integrated Water Resource Management (IWRM), is not necessary, as this section only covers the very broad aspects of IWRM and does not detail methodologies, technologies and approaches that could be adopted.

As part of the artificial recharge strategy, it is recommended that the following inclusions be made within the NWRS:

Section 3.3.3: The Principles of Water Conservation and Water Demand Management

In this section of the NWRS, it states that the National WC/WDM Strategy is based on three fundamental principles:

- Water institutions should strive to supply water efficiently and effectively, minimise water losses and promote WC/WDM among their consumers
- Users should not waste water and should strive to use it efficiently
- WC/WDM should be an integral part of the planning process for water resources management, water supply and the provision of water services.

Within these principles, it is stated that water conservation should be implemented, and the broad concept of wise water use should be practised. Phrases are used such as: "Water institutions …should…*develop and implement measures to promote WC/WDM*"; "…the Department will work closely with water institutions…..to *facilitate better management* and regulation of water use"; and, "The participatory and consultative approaches to implementing WC/WDM will…require water institutions and water users to share responsibility for *ensuring the efficient use of water*". In relation to potential inter-basin transfers, it is a requirement that: "…water currently available be *used optimally*, and reasonable measures be taken to *conserve water* before the transfer is effected".

While these are sound principles, the concept of utilising existing water resources optimally could possibly be encouraged more strongly. In this regard, it is recommended that either a fourth principle be added, or that a further message be included in the third principle. The message needing to be conveyed can be stated as follows:

> *"Water institutions should strive to utilise all available water optimally. This should include, where feasible, integrated water resource management, the re-use of waste water, the storage of surplus water in the subsurface, and the use of sub-surface environments to treat water."*

D.2.2.2 Catchment Management Strategies (CMSs)

The NWA provides for the decentralisation and devolution of the responsibility and authority of water resource management from DWAF to 19 Catchment Management Agencies (CMAs). The core purpose of the CMAs is to manage and ensure the sustainable use of water resources in their areas of operation. Once established, each CMA must develop a Catchment Management Strategy (CMS) that is aligned with the NWRS for the water resources within its Water Management Area (WMA). The CMS will form the most important instrument for the integrated management of water resources in each WMA, and this document should capture the CMA's approach to incorporate artificial recharge as part of its integrated water resource development and conservation strategy.

Until such time that the CMAs are established and their CMSs developed, and in order to provide an interim guide to DWAF Regional Offices in water resource management, DWAF has embarked on an exercise of developing Internal Strategic Perspectives (ISPs) for each WMA or sub-area of an WMA.

D.2.2.3 Internal Strategic Perspective (ISPs)

ISP documents typically contain Situation Assessments that describe the water resources of an area, together with its water requirements. As part of their purpose as interim planning documents, they include recommendations regarding Water Use Management Strategies and Water Demand Management Strategies. Water conservation measures are recommended within these strategies. For example, the ISPs for the Amatole-Kei Area of the Mzimvubu to Keiskamma WMA, 2004, and the Tsitsikamma to Coega Area of the Fish-Tsitsikamma WMA, 2004, recommend the following:

> *"Ensure that the WSDPs of local authorities highlight the need to implement local water conservation and demand management strategies prior to the development of new schemes."*

The ISP for the Gouritz WMA, 2004, specifically mentions the concept of AR:

> *"Aquifer Storage and Recovery could be used to boost recharge during infrequent periods of surplus flow, taking advantage of aquifer storage."*

Recommendations such as these should ultimately be incorporated into the CMSs, and in the interim, be encouraged by DWAF Regional Offices.

D.2.3 Artificial recharge strategy at the Water Services Level

D.2.3.1 Integrated Development Plans (IDPs)

Government has legislated that all Local Authorities undertake an Integrated Development Planning (IDP) process (Municipal Systems Act, No. 32 of 2000), and that Water Services Authorities (WSA) undertake a Water Services Development Planning (WSDP) process (Water Services Act, No. 108 of 1997).

An IDP is a strategic plan for the development of the municipality, and it serves to guide all planning, budgeting, management and decision-making within the municipality. This plan needs to integrate and co-ordinate different sector plans into a single strategic planning tool. The Water Services Act states that the WSDP should be part of the municipality's IDP process and should inform the IDP regarding specific requirements in terms of water and sanitation. In the same way, the IDP must inform the municipality's WSDP of the key issues and objectives derived from the IDP process, as they relate to water- and sanitation-specific issues. Municipal planning is thus an iterative process whereby the multi-sectoral IDPs can both inform and take direction from the WSDPs.

The main components of an IDP are:
- Assessment of current realities
- Vision
- Goals
- Situation analysis
- Integrated framework for development

- Development strategies
- Implementation: institutional plan of action
- Implementation: financial plan of action
- Monitoring, evaluation and revision
- Submission of land-development objectives for provincial approval.

Integrated water resources management, including artificial recharge (where appropriate), should be mentioned in the IDP's Integrated Framework for Development and Development Strategies as one of the means to achieve the municipality's vision. This would be relevant to aspects of the vision pertaining to environmental sustainability and economic development. While it may not be necessary to describe specific artificial recharge projects in the IDPs, they should be identified in the Water Services Development Plans.

D.2.3.2 Water Services Development Plans (WSDPs)

All WSAs must prepare WSDPs (Section 12(1) of the Water Services Act). These plans form part of the IDPs, and they must also be accounted for in the responsible authority's Catchment Management Strategy. The main goals regarding water services are:

- Delivery of sustainable water services (including provision of basic services, free basic water and sanitation and higher levels of services and associated needs)
- Integrated water resource management (protection and management of the water resources)
- Efficient and effective Water Services Authority (institutional arrangements for water services provision).

In line with the delivery of sustainable water resources and integrated water resource management, the WSDPs should contain details of water demand management and water conservation measures. Artificial recharge should be considered as one option to promote these sound environmental and management principles.

DWAF has developed several documents to provide guidance and support for those responsible for developing WSDPs and related documents. These include:

- DWAF's Guide, Framework and Checklist for the Development of WSDPs
- Water Services Feasibility Studies: Applications Procedures, Checklist and Minimum Standards
- Water Services Planning Framework.

D.2.3.2.1 DWAF's Guide, Framework and Checklist for the Development of WSDPs (DWAF, 2004)

This document provides the framework on how a WSDP should "look". It includes guidelines and checklists on information requirements and how this information should be presented. It is planned, laid-out and colour-coded to facilitate a simple and logical approach to compiling WSDPs.

Each section that needs to be covered in the document should be described according to the following four “Key Activities”:

- Situation assessment
- Future trends and goals
- Strategic gap analysis
- Implementation strategies.

The sections that need to be described are:

- Socio-economic profile
- Service level profile: Technical option
- Water resource profile
- Water conservation/demand
- Water services infrastructure profile
- Water balance
- Water services institutional arrangements profile
- Customer services profile
- Financial profile
- List of projects.

Artificial recharge activities should be included in the Water Conservation/Demand section. Within this section, under the heading *Water Resource Management Interventions (Section 4.1),* it has been recommended that an additional sub-section be added that encourages consideration of conjunctive water use. As the document currently stands, this would become Section 4.1.1.9.:

> *“Section 4.1.1.9: Conjunctive use of surface- and groundwater*
>
> *Water can be conserved by integrating the management of surface- and groundwater. This can be obtained, by minimising groundwater abstraction during periods of excess surface water (i.e. resting the aquifers), or by artificially recharging aquifers whenever possible. Storing water in aquifers could, for example, minimise evaporation from dams, or provide a means to re-use treated waste water. Describe means to conserve water by means of conjunctive use.”*

D.2.3.2.2 Water Services Feasibility Studies: Applications Procedures, Checklist and Minimum Standards (DWAF, 2005)

This guideline document aims to assist planners and managers to conduct feasibility studies on water services developments projects. It encourages planners to consider all critical factors affecting water resource use and water services within the broader economic, social and environmental development goals.

The document is organised into six parts, of which artificial recharge could be included in the sixth:

- Project application procedures
- Project handling procedures
- Project flow chart
- Feasibility specifications
- Feasibility flow chart and checklists for feasibility studies

- Minimum standards and guidelines for feasibility studies.

Artificial recharge practices should be included within the section: *"Minimum standards and guidelines for feasibility studies."*

D.2.3.2.3 Water Services Planning Framework

The two documents described above are sufficiently generic to include artificial recharge in their water conservation strategies. The information required in the Water Services Planning Framework (WSPF) is specific to each WSA, and thus, once the potential for artificial recharge has been assessed at this level of detail, such plans should be included within the WSPF.

The WSPF includes the topics listed below and the potential for specific artificial recharge schemes should be incorporated into the sections on Water Resource Development and Water Conservation and Demand Management:

- General
- Physical and Socio-Economic Development
- Service Level Development
- Water Resource Development
- Water Conservation and Demand Management
- Water Services Infrastructure
- Water Services Authority Institutional Arrangement
- Customer Service
- Financial Profile
- Project Development.

D.2.3.3 Water Conservation and Water Demand Management Strategy for the Water Services Sector

The water supply and sanitation services sector accounts for about 15 percent of total national water use, and it is the sector with the highest expected growth in demand (NWRS, 2004). Water services institutions are expected to determine their own targets and benchmarks for efficient water use (NWRS, 2004). These are included in the WSDPs, and will be reviewed by the responsible authority (DWAF or CMA) during the water use and licensing process.

DWAF has developed the following guideline document for the Water Services Sector to facilitate efficient water use: *Water Conservation and Water Demand Management Strategy for the Water Services Sector (DWAF, 2004b)*.

Paragraph B.4.3 covers the key issues pertaining to the potential for artificial recharge as a water conservation measure, and is not discussed further here.

D.2.4 Water Conservation and Water Demand Management Strategy for the Agricultural Sector

Many farmers throughout South Africa have constructed earth dams for the purpose of enhancing groundwater reserves. The benefit of such efforts has not been assessed, and thus it is not known whether they have had the planned effect. It is likely that, in many cases, the rate of infiltration is very low due to the accumulation of clay minerals at the base of the dam. It is even possible that, with high rates of evaporation from some of the dams, salt concentrations have increased significantly, with the negative effect of recharging saline water into the subsurface.

As yet, no formal attempt has been made to introduce artificial recharge into the farming sector. However, with the increasing need for conserving water, this should change, particularly in areas where the benefits of artificial recharge would be high. Such areas include alluvial aquifers, where there are potentially significant benefits relating to security of supply and maintaining the Reserve. Other areas are those where farmers are over-utilising the groundwater resources.

Irrigated agriculture accounts for about 62 percent of water used in South Africa. The potential for large-scale savings is thus greatest within this sector. DWAF has produced both a strategy and guideline documents that outline WC/WDM measures for the Agricultural Sector:

- Water Conservation and Water Demand Management Strategy for the Agriculture Sector (DWAF, 2004c).
- Implementation Guideline for Water Conservation and Demand Management in Agriculture: Development of Water Management Plans (DWAF, 2000a)

Compliance with this guideline document is necessary for the approval of Water Management Plans which is the (additional) document required for water use licence applications.

It is likely that many future large-scale agricultural artificial recharge schemes will fall under the management of Water User Associations (WUAs), which, in turn, require Water Management Plans. The inclusion of artificial recharge into future, updated guideline documents on Water Management Plans will encourage the consideration of this water conservation measure within the agricultural sector. This not only makes sense for the farming community, but is also recognised in the NWRS as an important factor in maintaining the Reserve.

D.2.5 Water Conservation and Water Demand Management Strategy for the Industry, Mining and Power Generation Sector

This sector accounts for about 15 percent of the total water used in South Africa. In order to facilitate efficient water use, DWAF has developed the following guideline: *Water Conservation and Water Demand Management Strategy for the Industry, Mining and Power Generation Sectors* (DWAF, 2004d).

Artificial recharge and subsurface storage has potential in three main areas of application. The first is for preventing contaminated mining and industry groundwater from migrating away from the point of contamination. This can be achieved by creating a hydraulic mound around, or down-gradient of, the contaminant plume using the techniques of infiltration or borehole injection. In this way, the plume can be contained and managed. For a description of the regulations pertaining to the protection of water resources, refer to Government Notice No. 704, Operational Guideline No. M6.1: Guideline Document for the Implementation of Regulations on Use of Water for Mining and Related Activities aimed at the Protection of Water Resources (DWAF 2000b).

The second potential artificial recharge application is for the purpose of waste water treatment and reuse. Water of impaired quality can be recycled through artificial recharge for particular uses within the industry, thereby limiting the need for additional water supply and minimising the negative environmental effects of waste water discharge.

The third potential application is in the storage of water in disused mines. This is not strictly an artificial recharge activity, as mines are not aquifers, but there is potential for sub-surface storage in disused mines. The key concern in mine storage relates to water quality issues, in relation to both water blending and water-rock interactions.

The artificial recharge challenge within this sector lies in creating awareness of the potential benefits of subsurface storage and the water treatment that artificial recharge can offer.

D.2.6 Awareness and education

Artificial recharge's potential value and diverse uses need to reach a wide audience if this water conservation and treatment approach is to gain acceptance amongst water resource planners. Artificial recharge should be promoted as a means of contributing towards integrated, sustainable development. In areas where artificial recharge awareness is high, such as in Adelaide, Australia, urban developments have incorporated recharge facilities into the layout of these developments. The principles of artificial recharge should therefore be incorporated into DWAF's strategy on promoting education and awareness in water conservation.

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Appendix 1:

Theoretical artificial recharge potential per water management area

The method for establishing the artificial recharge areas and potential storage volumes is described in Section B.4.

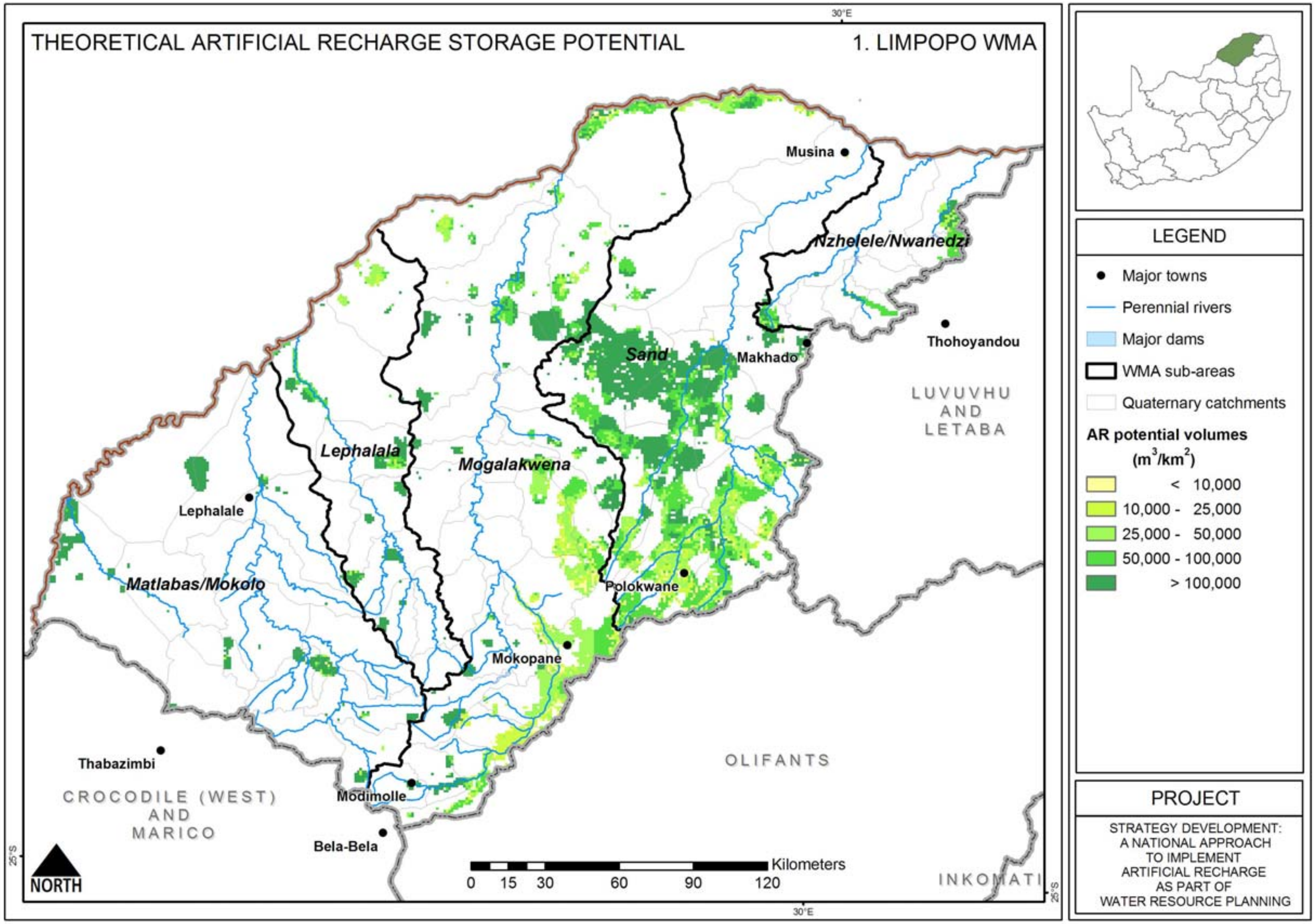
Water Management Area 1: Limpopo

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water requirements for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
1 Limpopo	Matlabas/Mokolo	382	76		46	63	124	232	356
	Lephalala	150	17		42	42	61	91	152
	Mogalakwena	269	41		72	79	172	273	445
	Sand	72	10		91	106	277	540	817
	Nzhelele/Nwanedzi	113	12		30	32	18	28	46
	Total for WMA1	**986**	**156**	**319**	**281**	**322**	**652**	**1163**	**1815**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*


THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL
1. LIMPOPO WMA
30°E
Musina
Nzhelele/Nwanedzi
Thohoyandou
Makhado
Sand
LUVUVHU AND LETABA
Lephalala
Mogalakwena
Lephalale
Matlabas/Mokolo
Polokwane
Mokopane
Thabazimbi
OLIFANTS
CROCODILE (WEST) AND MARICO
Modimolle
Bela-Bela
INKOMATI
25°S
NORTH
Kilometers
0
15
30
60
90
120
LEGEND
Major towns
Perennial rivers
Major dams
WMA sub-areas
Quaternary catchments
AR potential volumes (m³/km²)
< 10,000
10,000 - 25,000
25,000 - 50,000
50,000 - 100,000
> 100,000
PROJECT
STRATEGY DEVELOPMENT: A NATIONAL APPROACH TO IMPLEMENT ARTIFICIAL RECHARGE AS PART OF WATER RESOURCE PLANNING

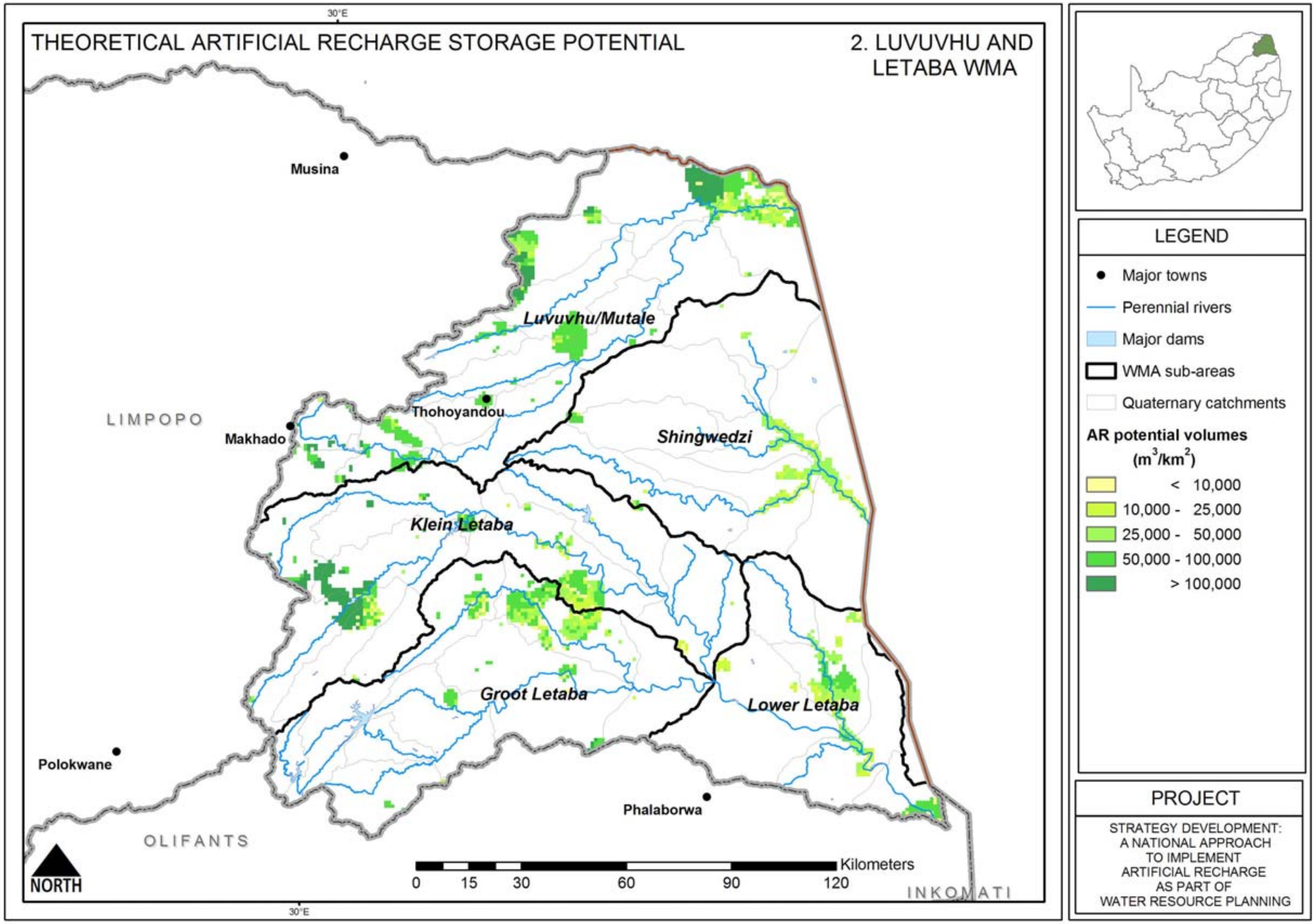
Water Management Area 2: Luvuvhu/Letaba

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water require-ments for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
2 Luvuvhu	Luvuvhu/Mutale	520	105		115	119	43	56	99
	Shingwedzi	90	14		3	3	10	8	18
	Groot Letaba	382	72		159	174	16	19	35
	Klein Letaba	151	20		32	37	21	32	52
	Lower Letaba	42	13		1	0	11	12	24
	Total for WMA2	**1185**	**224**	**531**	**310**	**333**	**102**	**127**	**229**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*


30°E
THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL
2. LUVUVHU AND LETABA WMA
Musina
Luvuvhu/Mutale
Thohoyandou
LIMPOPO
Makhado
Shingwedzi
Klein Letaba
Groot Letaba
Lower Letaba
Polokwane
Phalaborwa
OLIFANTS
INKOMATI
NORTH
0 15 30 60 90 120 Kilometers
LEGEND
Major towns
Perennial rivers
Major dams
WMA sub-areas
Quaternary catchments
AR potential volumes (m³/km²)
< 10,000
10,000 - 25,000
25,000 - 50,000
50,000 - 100,000
> 100,000
PROJECT
STRATEGY DEVELOPMENT: A NATIONAL APPROACH TO IMPLEMENT ARTIFICIAL RECHARGE AS PART OF WATER RESOURCE PLANNING

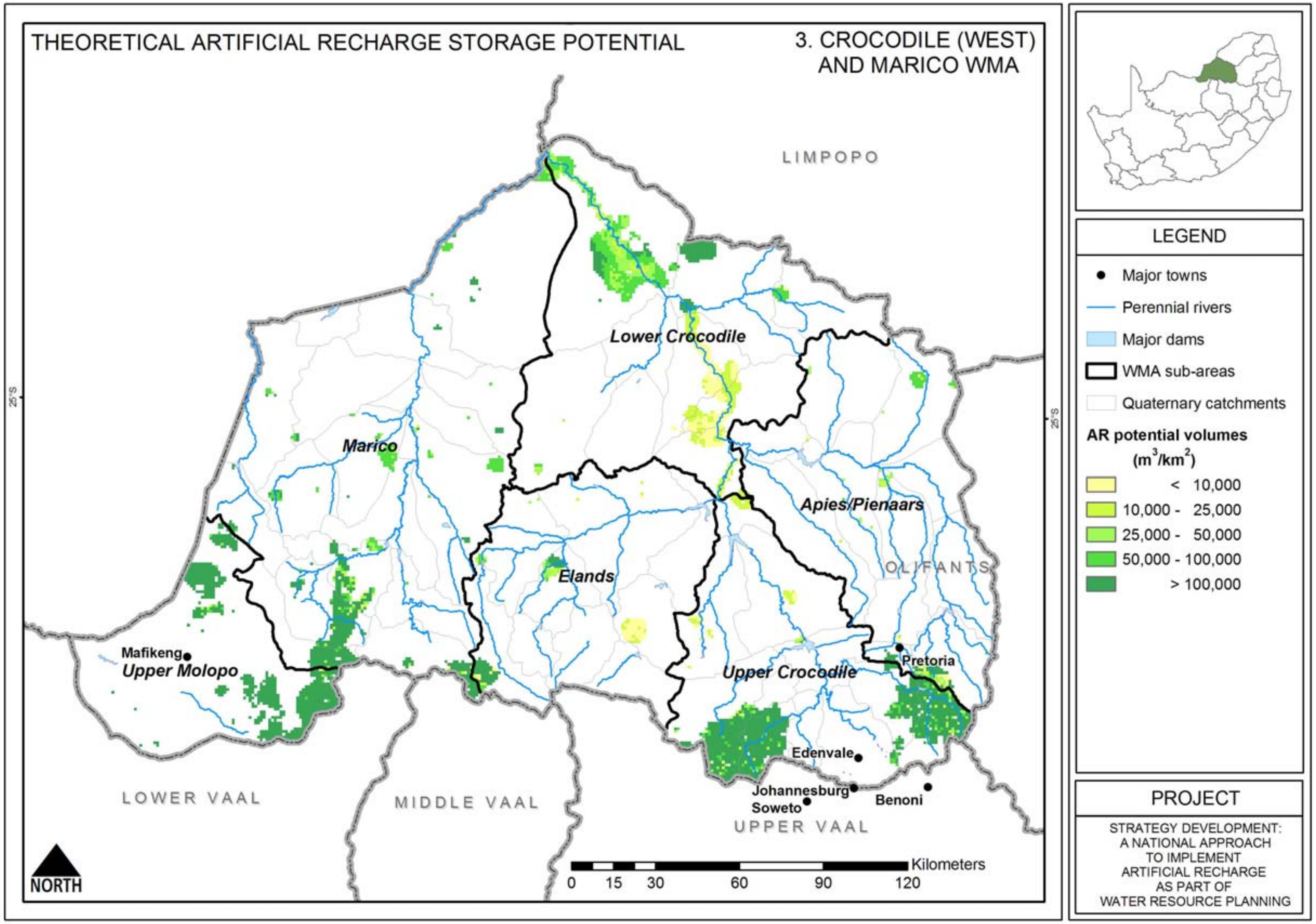
Water Management Area 3: Crocodile West and Marico

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water requirements for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
3 Crocodile West Marico	Apies/Pienaars	142	34		186	280	10	22	32
	Upper Crocodile	253	57		336	556	358	613	971
	Elands	113	15		86	113	8	13	22
	Lower Crocodile	138	25		59	171	25	80	105
	Marico	172	29		32	40	141	284	425
	Upper Molopo	37	4		19	24	293	223	515
	Total for WMA 3	**855**	**164**	**854**	**718**	**1184**	**835**	**1235**	**2070**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*


THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL
3. CROCODILE (WEST) AND MARICO WMA
LIMPOPO
Lower Crocodile
Marico
Elands
Apies/Pienaars
OLIFANTS
Upper Crocodile
Upper Molopo
Mafikeng
Pretoria
Edenvale
Johannesburg
Soweto
Benoni
LOWER VAAL
MIDDLE VAAL
UPPER VAAL
25°S
NORTH
0
15
30
60
90
120
Kilometers
LEGEND
● Major towns
Perennial rivers
Major dams
WMA sub-areas
Quaternary catchments
AR potential volumes (m^3/km^2)
< 10,000
10,000 - 25,000
25,000 - 50,000
50,000 - 100,000
> 100,000
PROJECT
STRATEGY DEVELOPMENT: A NATIONAL APPROACH TO IMPLEMENT ARTIFICIAL RECHARGE AS PART OF WATER RESOURCE PLANNING

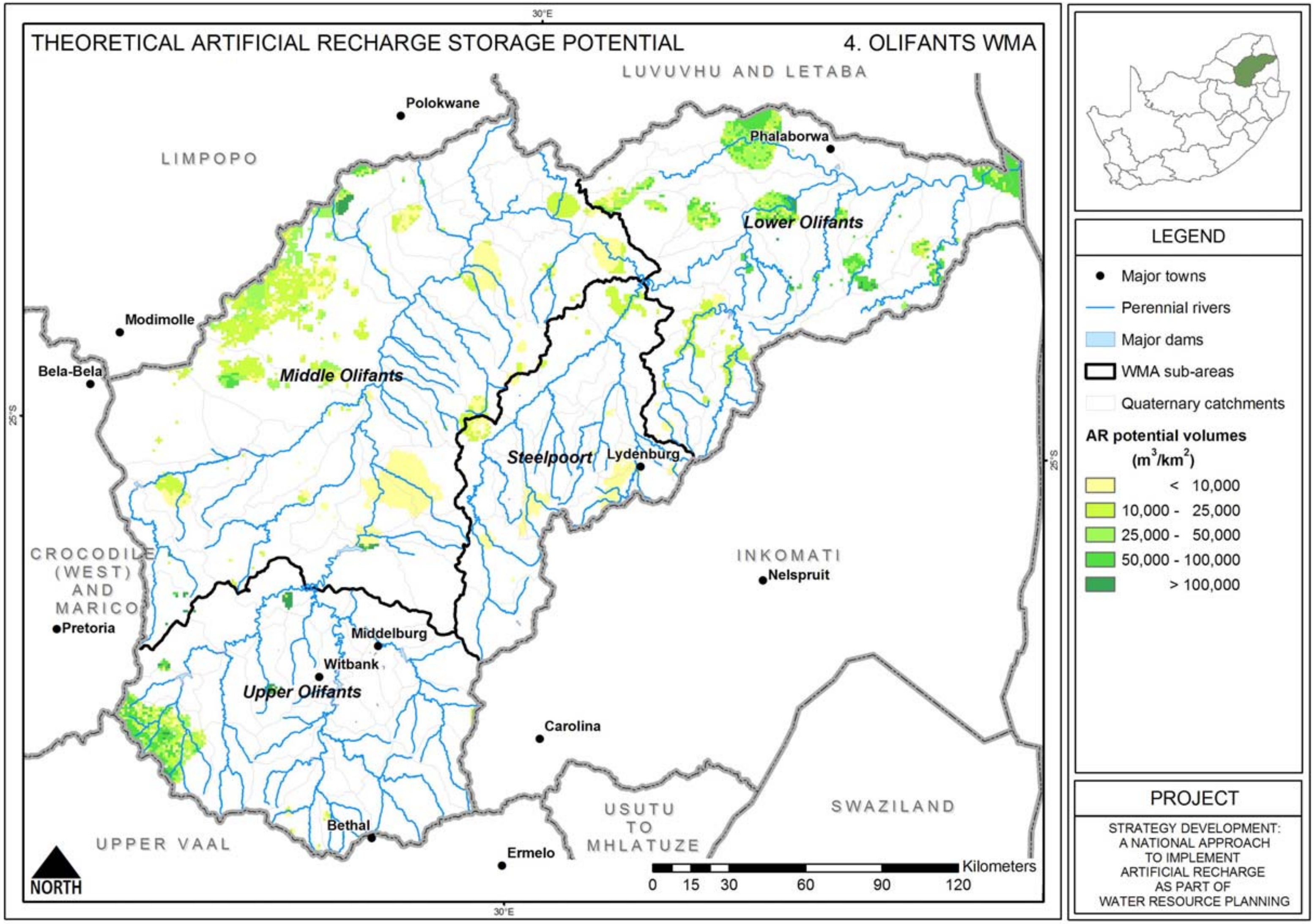
Water Management Area 4: Olifants

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water requirements for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
4 Olifants	Upper Olifants	465	83		238	314	38	35	73
	Middle Olifants	481	69		210	392	38	54	91
	Steelpoort	396	94		61	95	3	5	8
	Lower Olifants	698	214		100	164	59	70	130
	Total for WMA4	**2040**	**460**	**1078**	**609**	**965**	**138**	**163**	**301**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*


THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL
4. OLIFANTS WMA
30°E
25°S
LUVUVHU AND LETABA
LIMPOPO
CROCODILE (WEST) AND MARICO
INKOMATI
USUTU TO MHLATUZE
SWAZILAND
UPPER VAAL
Middle Olifants
Lower Olifants
Steelpoort
Upper Olifants
Polokwane
Phalaborwa
Modimolle
Bela-Bela
Lydenburg
Nelspruit
Pretoria
Middelburg
Witbank
Carolina
Bethal
Ermelo
NORTH
0 15 30 60 90 120
Kilometers
LEGEND
● Major towns
Perennial rivers
Major dams
WMA sub-areas
Quaternary catchments
AR potential volumes (m^3/km^2)
< 10,000
10,000 - 25,000
25,000 - 50,000
50,000 - 100,000
> 100,000
PROJECT
STRATEGY DEVELOPMENT: A NATIONAL APPROACH TO IMPLEMENT ARTIFICIAL RECHARGE AS PART OF WATER RESOURCE PLANNING

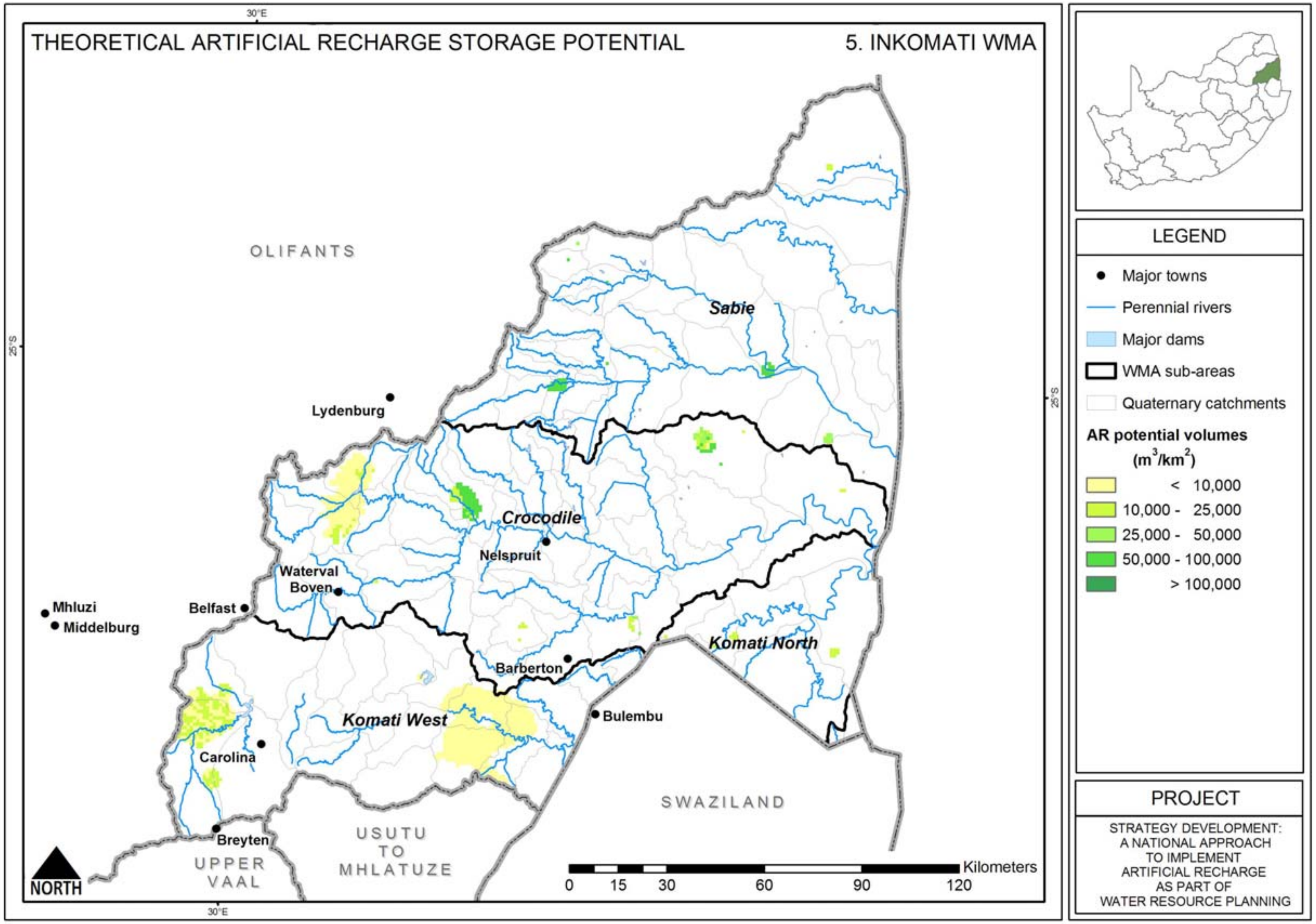
Water Management Area 5: Inkomati

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water require-ments for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
5 Inkomati	Komati (W Swazi)	749	239		118	65	7	7	14
	Swaziland	517	100		185	67	N/A	N/A	N/A
	Komati (N Swazi)	130	25		252	232	0	0	1
	Crocodile	1277	328		246	364	5	7	12
	Sabie	866	316		95	117	2	4	6
	Total for WMA5	**3539**	**1008**	**768**	**896**	**845**	**15**	**17**	**32**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*



THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL 5. INKOMATI WMA

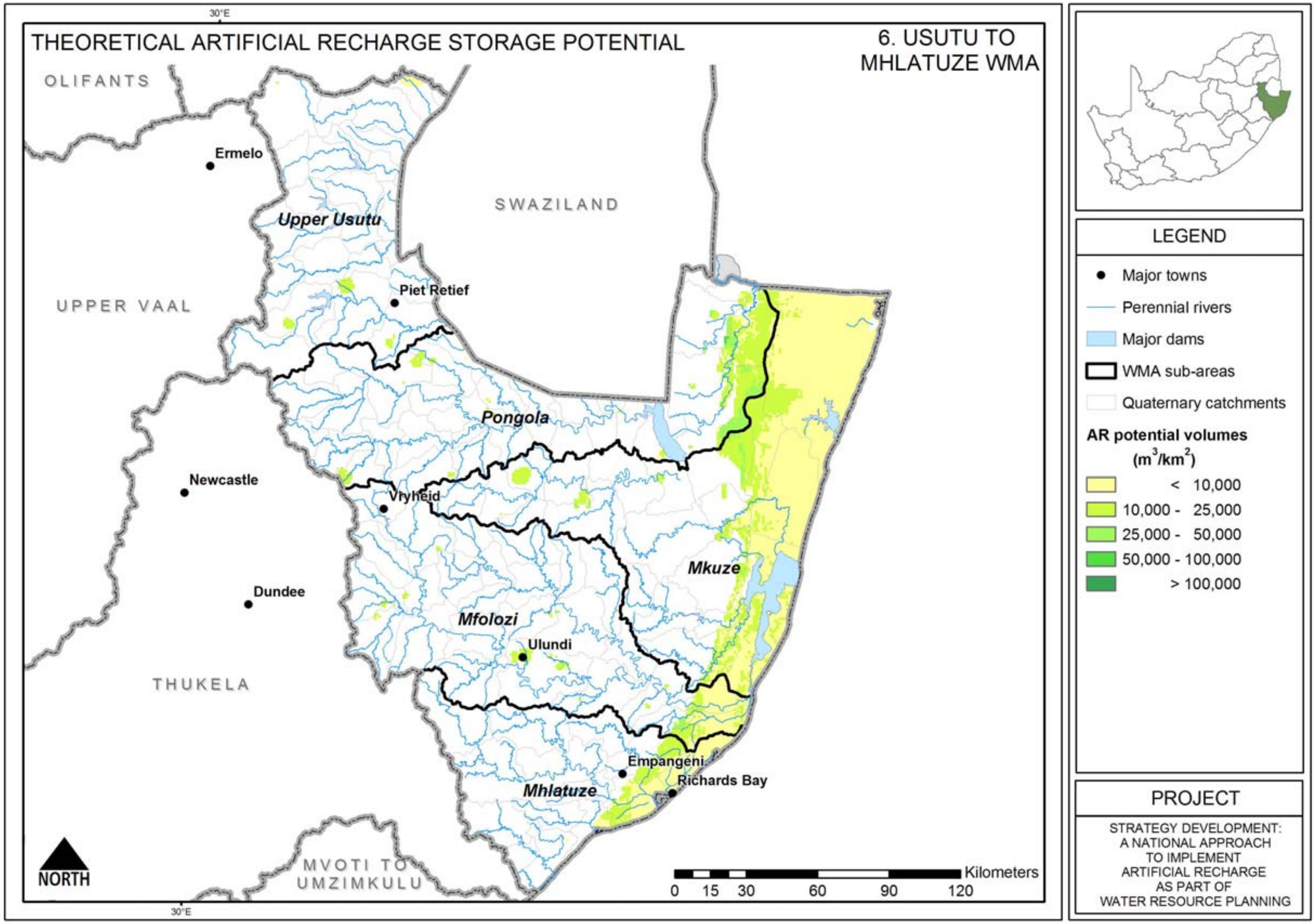
Water Management Area 6: Usutu to Mhlathuze

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water require-ments for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
6 Usutu-Mhlatuze	Upper Usutu	901	328		202	69	1	1	2
	Pongola	1344	200		645	255	7	17	24
	Mkuze	635	218		33	78	36	40	77
	Mfolozi	962	275		51	80	4	6	11
	Mhlatuze	938	171		179	235	6	8	14
	Total for WMA6	**4780**	**1192**	**3692**	**1110**	**717**	**54**	**73**	**127**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*


THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL
6. USUTU TO MHLATUZE WMA
30°E
OLIFANTS
Ermelo
Upper Usutu
SWAZILAND
Piet Retief
UPPER VAAL
Pongola
Newcastle
Vryheid
Mkuze
Dundee
Mfolozi
Ulundi
THUKELA
Empangeni
Richards Bay
Mhlatuze
NORTH
MVOTI TO UMZIMKULU
Kilometers
0 15 30 60 90 120
LEGEND
Major towns
Perennial rivers
Major dams
WMA sub-areas
Quaternary catchments
AR potential volumes (m³/km²)
< 10,000
10,000 - 25,000
25,000 - 50,000
50,000 - 100,000
> 100,000
PROJECT
STRATEGY DEVELOPMENT: A NATIONAL APPROACH TO IMPLEMENT ARTIFICIAL RECHARGE AS PART OF WATER RESOURCE PLANNING

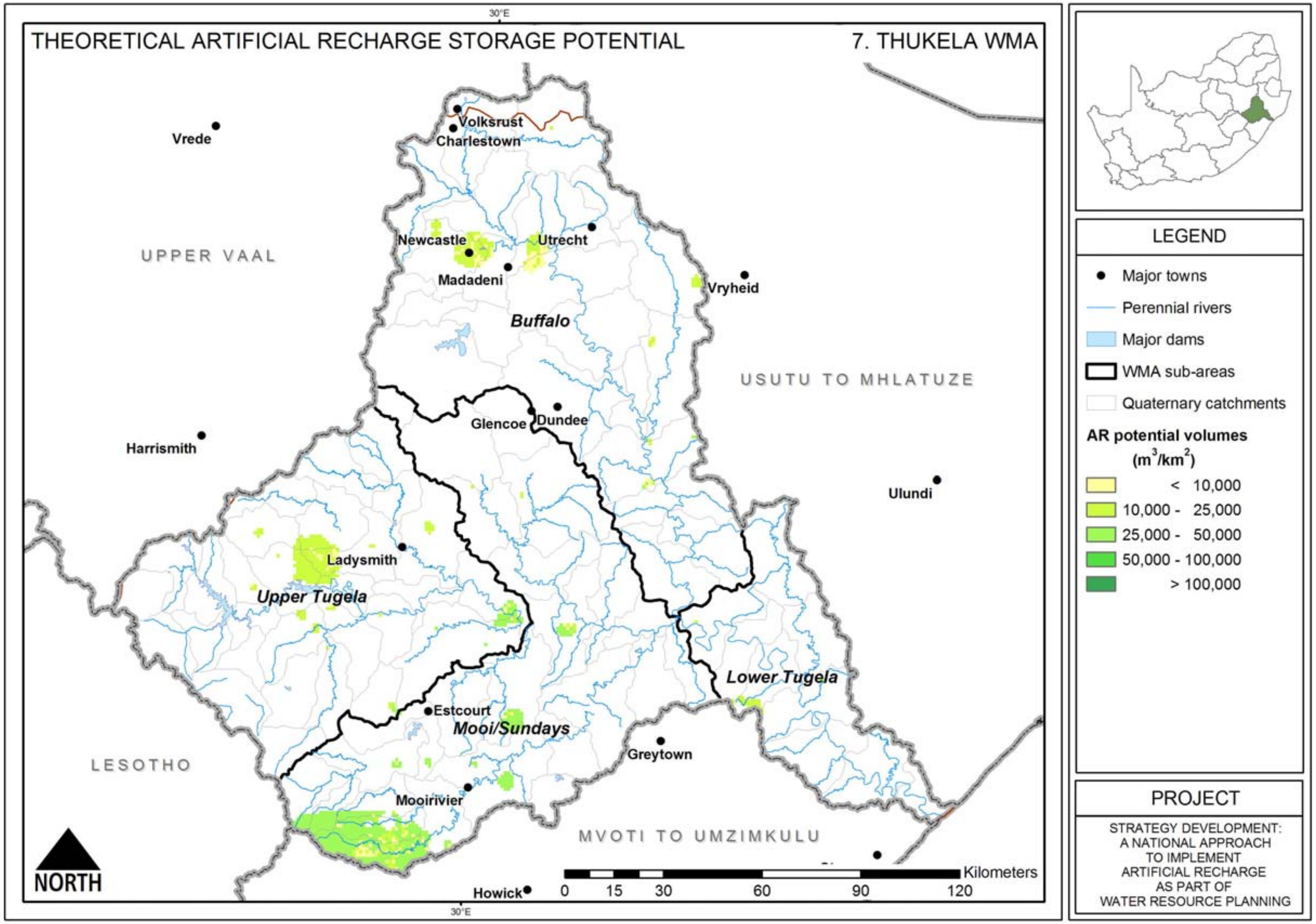
Water Management Area 7: Thukela

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water require-ments for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
7 Thukela	Upper Thukela	1502	392		394	88	4	5	9
	Mooi/Sundays	992	213		128	102	9	18	27
	Buffalo	941	182		136	91	3	3	6
	Lower Thukela	364	72		79	53	0	0	1
	Total for WMA7	**3799**	**859**	**1125**	**737**	**334**	**16**	**27**	**42**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*


THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL
7. THUKELA WMA
30°E
Volksrust
Charlestown
Vrede
Newcastle
Utrecht
Madadeni
Vryheid
Buffalo
UPPER VAAL
USUTU TO MHLATUZE
Glencoe
Dundee
Harrismith
Ulundi
Ladysmith
Upper Tugela
Lower Tugela
Estcourt
Mooi/Sundays
Greytown
LESOTHO
Mooirivier
MVOTI TO UMZIMKULU
Howick
NORTH
0
15
30
60
90
120
Kilometers
30°E
LEGEND
● Major towns
Perennial rivers
Major dams
WMA sub-areas
Quaternary catchments
AR potential volumes
(m³/km²)
< 10,000
10,000 - 25,000
25,000 - 50,000
50,000 - 100,000
> 100,000
PROJECT
STRATEGY DEVELOPMENT:
A NATIONAL APPROACH
TO IMPLEMENT
ARTIFICIAL RECHARGE
AS PART OF
WATER RESOURCE PLANNING

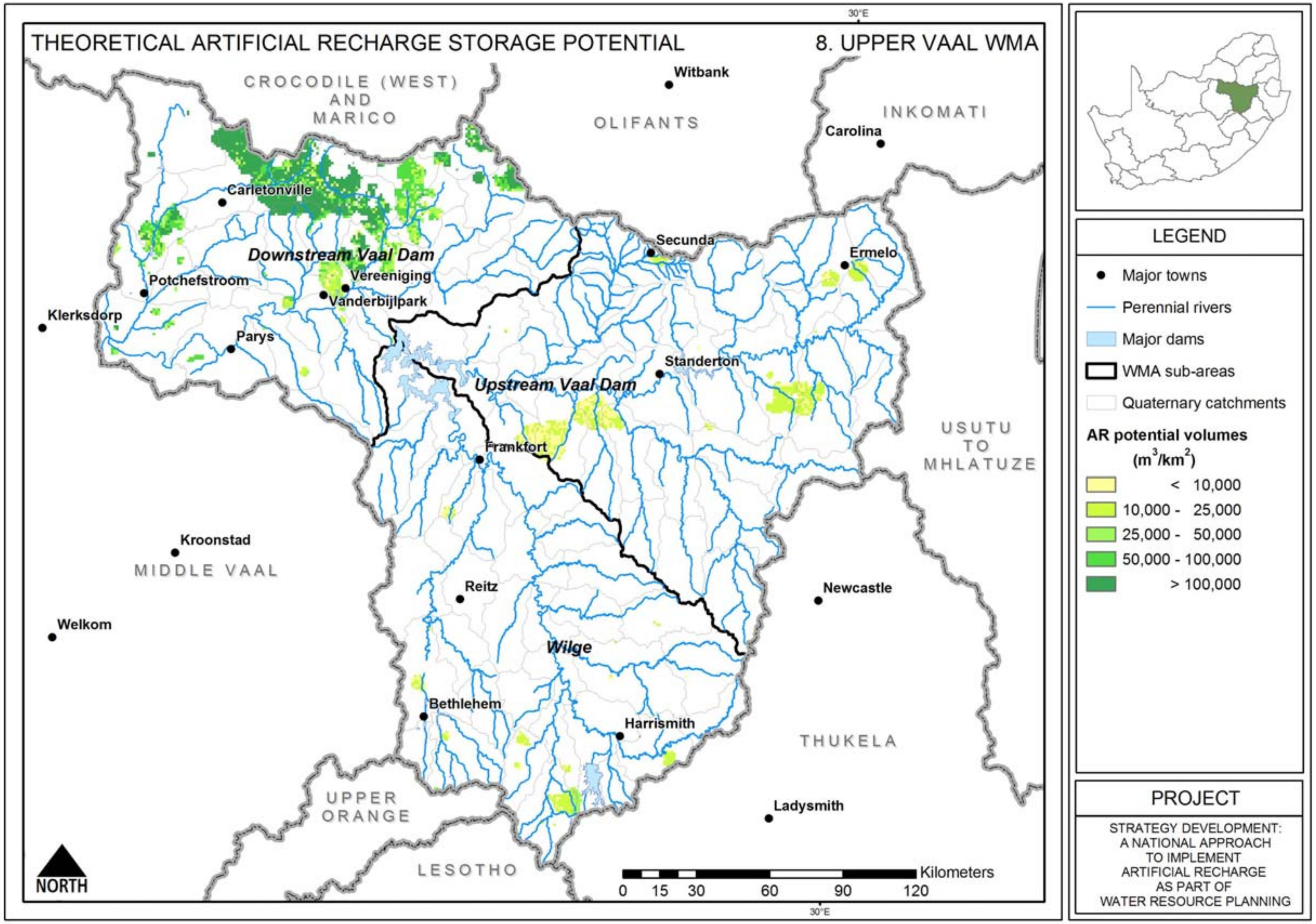
Water Management Area 8: Upper Vaal

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water require-ments for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
8 Upper Vaal	Wilge	868	116		59	60	4	5	9
	Vaal Dam - upstream	1109	126		184	216	14	9	23
	Vaal Dam - downstream	446	57		889	769	304	427	731
	Total for WMA8	**2423**	**299**	**5725**	**1132**	**1045**	**322**	**441**	**763**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*


THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL
8. UPPER VAAL WMA
30°E
CROCODILE (WEST) AND MARICO
OLIFANTS
INKOMATI
USUTU TO MHLATUZE
THUKELA
MIDDLE VAAL
UPPER ORANGE
LESOTHO
Downstream Vaal Dam
Upstream Vaal Dam
Wilge
Witbank
Carolina
Carletonville
Secunda
Ermelo
Potchefstroom
Vereeniging
Vanderbijlpark
Klerksdorp
Parys
Standerton
Frankfort
Kroonstad
Reitz
Newcastle
Welkom
Bethlehem
Harrismith
Ladysmith
NORTH
0 15 30 60 90 120 Kilometers
LEGEND
Major towns
Perennial rivers
Major dams
WMA sub-areas
Quaternary catchments
AR potential volumes
(m³/km²)
< 10,000
10,000 - 25,000
25,000 - 50,000
50,000 - 100,000
> 100,000
PROJECT
STRATEGY DEVELOPMENT:
A NATIONAL APPROACH
TO IMPLEMENT
ARTIFICIAL RECHARGE
AS PART OF
WATER RESOURCE PLANNING

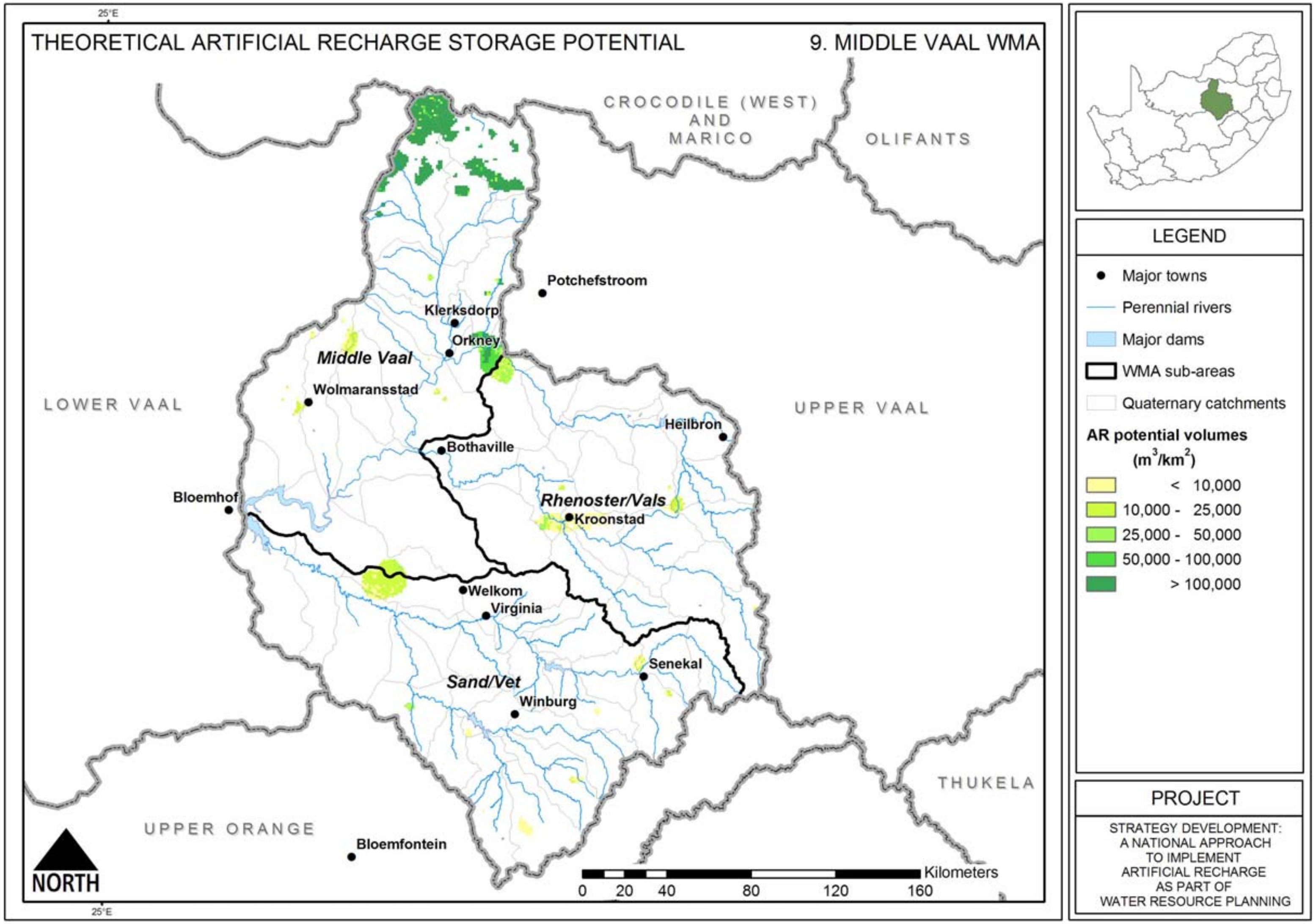
Water Management Area 9: Middle Vaal

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water require-ments for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
9 Middle Vaal	Rhenoster-Vals	295	35		44	54	8	5	13
	Middle Vaal	170	29		-142	129	443	472	915
	Sand-Vet	423	45		147	187	4	4	8
	Total for WMA9	**888**	**109**	**467**	**49**	**370**	**455**	**481**	**935**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*


25°E
THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL
9. MIDDLE VAAL WMA
CROCODILE (WEST) AND MARICO
OLIFANTS
Potchefstroom
Klerksdorp
Orkney
Middle Vaal
Wolmaransstad
LOWER VAAL
UPPER VAAL
Heilbron
Bothaville
Bloemhof
Rhenoster/Vals
Kroonstad
Welkom
Virginia
Senekal
Sand/Vet
Winburg
THUKELA
UPPER ORANGE
Bloemfontein
NORTH
Kilometers
0
20
40
80
120
160
25°E
LEGEND
● Major towns
Perennial rivers
Major dams
WMA sub-areas
Quaternary catchments
AR potential volumes
(m³/km²)
< 10,000
10,000 - 25,000
25,000 - 50,000
50,000 - 100,000
> 100,000
PROJECT
STRATEGY DEVELOPMENT:
A NATIONAL APPROACH
TO IMPLEMENT
ARTIFICIAL RECHARGE
AS PART OF
WATER RESOURCE PLANNING

Water Management Area 10: Lower Vaal

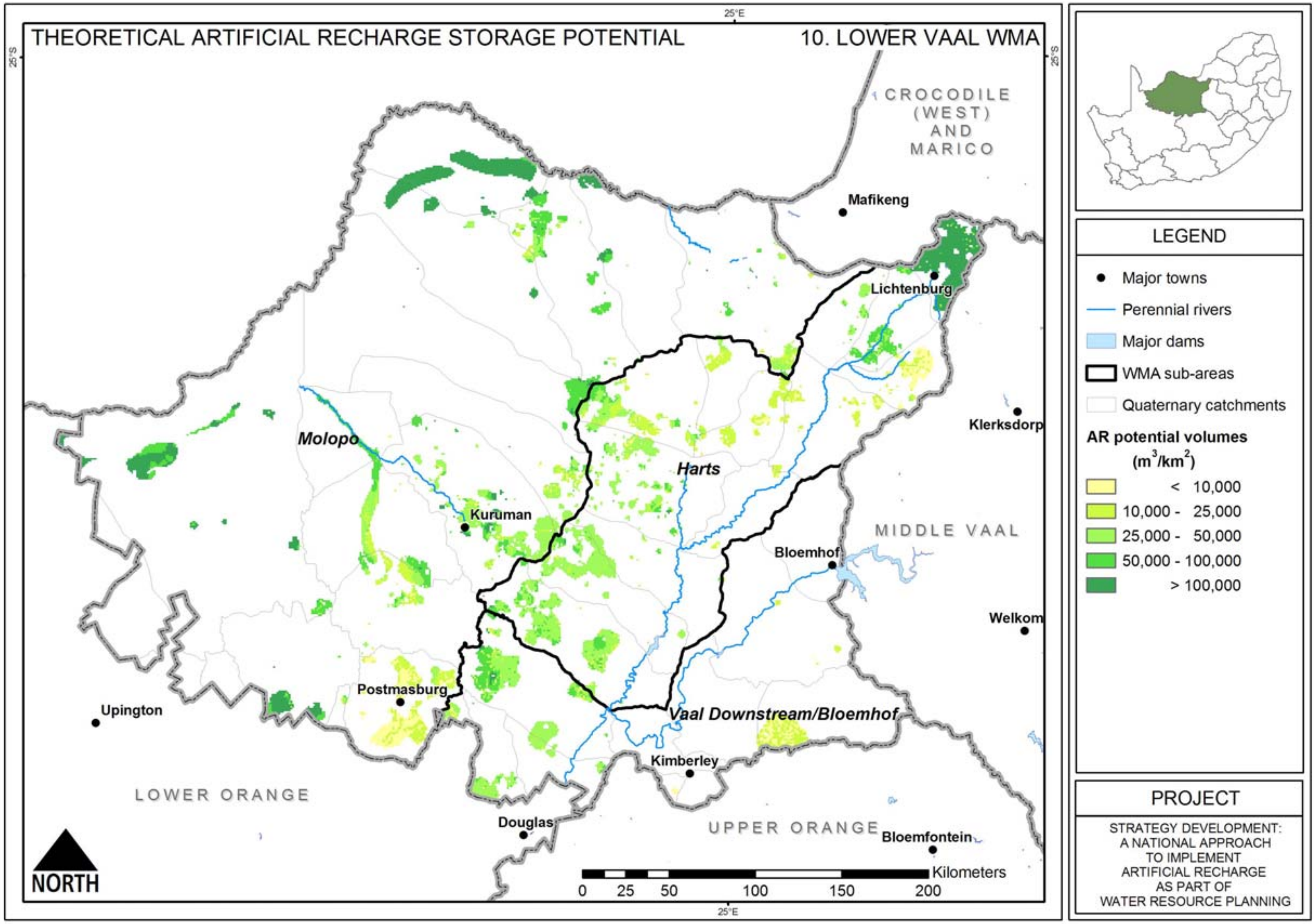
WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water requirements for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
10 Lower Vaal	Harts	138	15		136	494	628	632	1260
	Vaal downstream of Bloemhof Dam	43	5		-46	113	65	63	128
	Molopo	197**	29		35	36	152	552	703
	Total for WMA10	**181**	**49**	**1375**	**125**	**643**	**845**	**1247**	**2092**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*

** *Estimated runoff from catchment, which is lost through evaporation and infiltration before reaching the Orange River. This runoff therefore does not add to the total for the Water Management Area.*


THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL
10. LOWER VAAL WMA
25°E
25°S
CROCODILE (WEST) AND MARICO
Mafikeng
Lichtenburg
Klerksdorp
Molopo
Harts
Kuruman
MIDDLE VAAL
Bloemhof
Welkom
Postmasburg
Upington
Vaal Downstream/Bloemhof
Kimberley
LOWER ORANGE
UPPER ORANGE
Douglas
Bloemfontein
NORTH
0 25 50 100 150 200 Kilometers
LEGEND
● Major towns
Perennial rivers
Major dams
WMA sub-areas
Quaternary catchments
AR potential volumes (m^3/km^2)
< 10,000
10,000 - 25,000
25,000 - 50,000
50,000 - 100,000
> 100,000
PROJECT
STRATEGY DEVELOPMENT: A NATIONAL APPROACH TO IMPLEMENT ARTIFICIAL RECHARGE AS PART OF WATER RESOURCE PLANNING

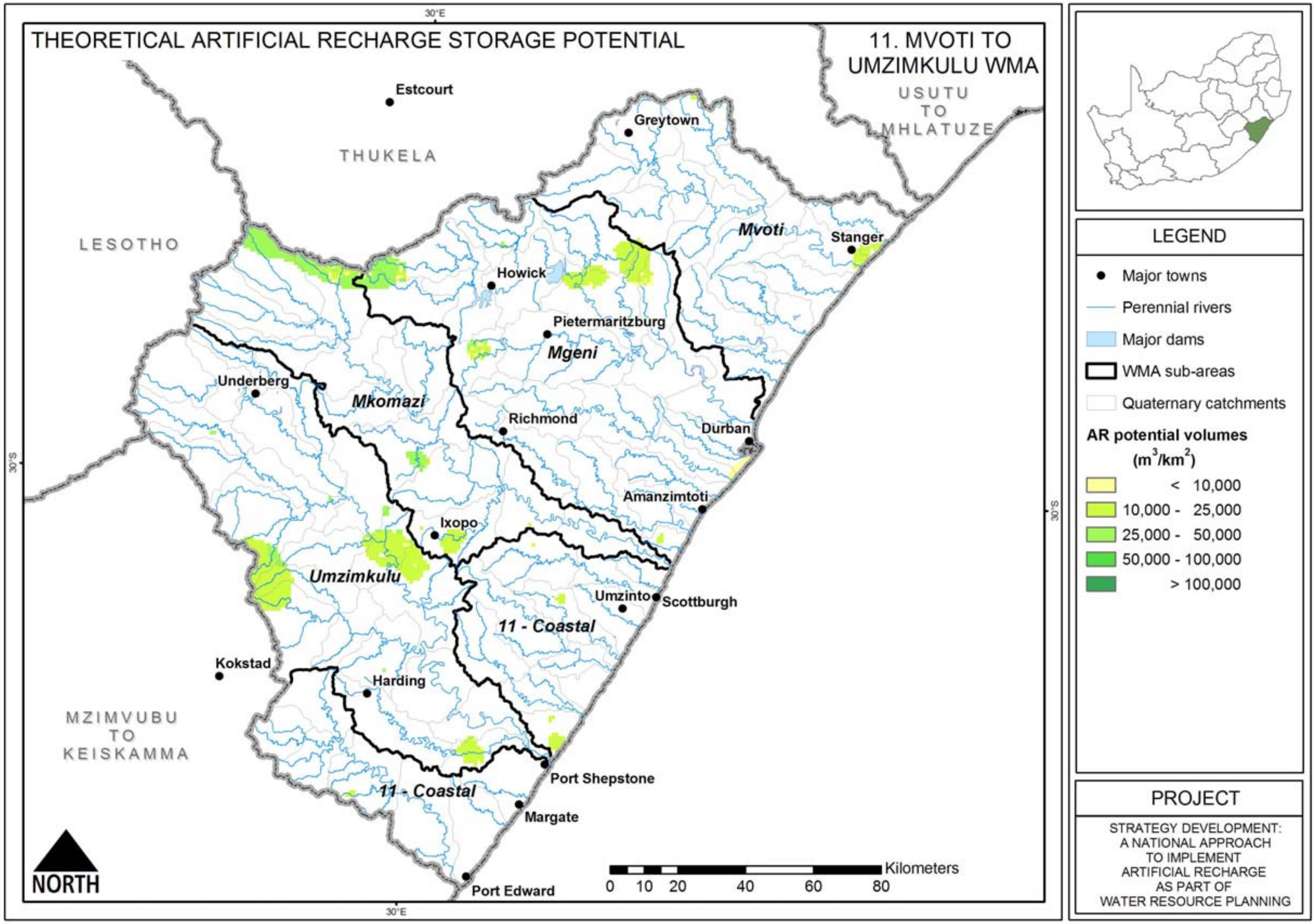
Water Management Area 11: Mvoti to Umzimkulu

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water require-ments for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
11 Mvoti-Umzimkulu	Mvoti	595	150		86	114	0	1	1
	Mgeni	992	187		376	504	3	7	11
	Mkomazi	1080	295		31	98	4	8	12
	Coastal	758	211		14	41	0	1	1
	Umzimkulu	1373	317		16	40	5	10	15
	Total for WMA11	**4798**	**1160**	**827**	**523**	**797**	**13**	**27**	**39**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*


THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL
11. MVOTI TO UMZIMKULU WMA
30°E
30°S
Estcourt
THUKELA
Greytown
USUTU TO MHLATUZE
LESOTHO
Mvoti
Stanger
Howick
Pietermaritzburg
Mgeni
Underberg
Mkomazi
Richmond
Durban
Amanzimtoti
Ixopo
Umzimkulu
Umzinto
Scottburgh
11 - Coastal
Kokstad
Harding
MZIMVUBU TO KEISKAMMA
Port Shepstone
11 - Coastal
Margate
Port Edward
NORTH
0 10 20 40 60 80 Kilometers
LEGEND
Major towns
Perennial rivers
Major dams
WMA sub-areas
Quaternary catchments
AR potential volumes (m³/km²)
< 10,000
10,000 - 25,000
25,000 - 50,000
50,000 - 100,000
> 100,000
PROJECT
STRATEGY DEVELOPMENT: A NATIONAL APPROACH TO IMPLEMENT ARTIFICIAL RECHARGE AS PART OF WATER RESOURCE PLANNING

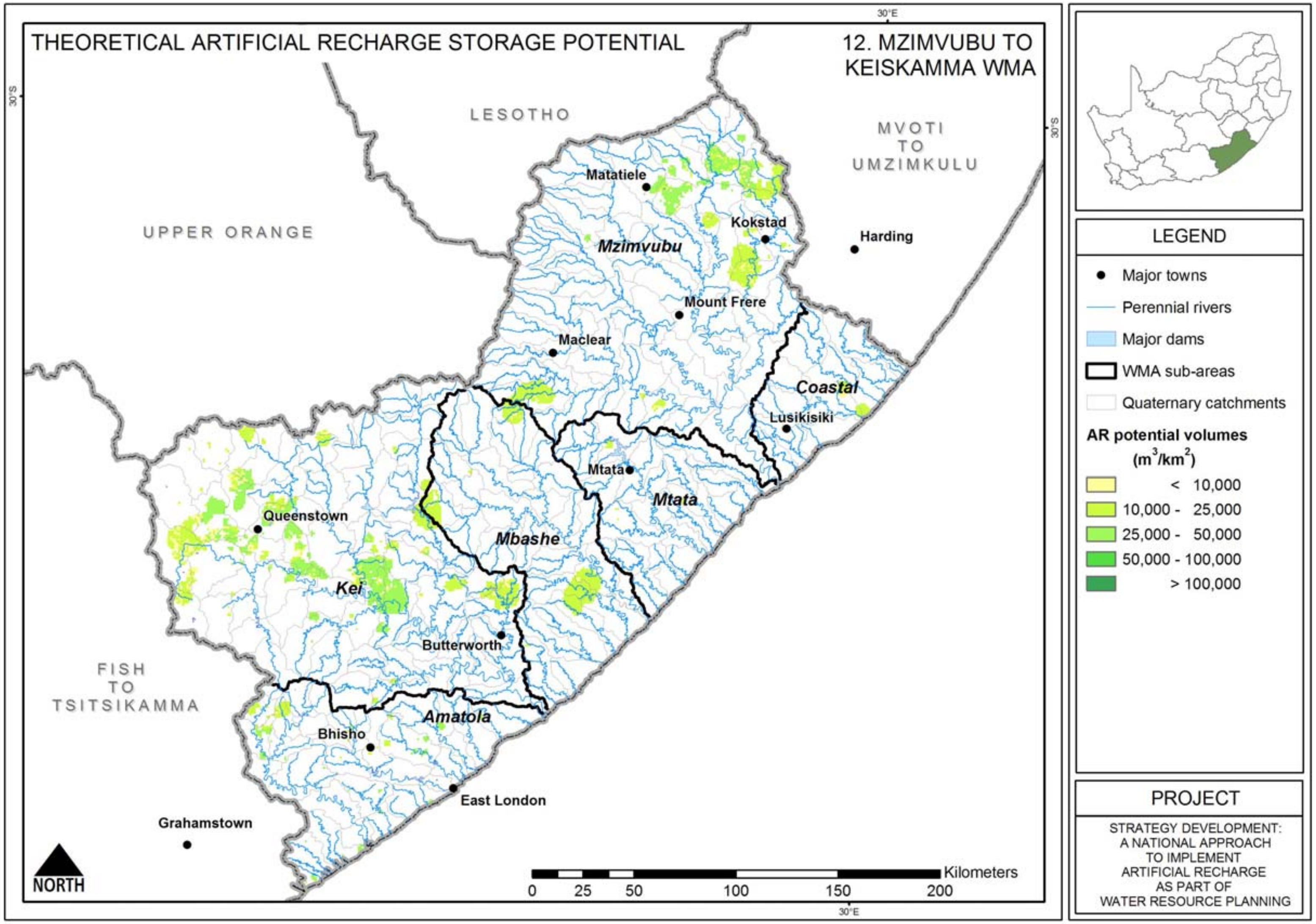
Water Management Area 12: Mzimvubu to Keiskamma

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water requirements for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
12 Mzimvubu-Keiskamma	Mzimvubu	2897	338		91	33	16	30	46
	Mtata	836	163		136	53	0	0	1
	Mbashe	1126	203		114	11	7	8	15
	Kei	1027	154		359	174	39	52	91
	Amatola	559	116		149	99	4	1	5
	Wild Coast	796	148		5	4	1	6	7
	Total for WMA12	**7241**	**1122**	**1115**	**854**	**374**	**67**	**98**	**165**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*


THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL
12. MZIMVUBU TO KEISKAMMA WMA
30°E
30°S
LESOTHO
MVOTI TO UMZIMKULU
UPPER ORANGE
FISH TO TSITSIKAMMA
Matatiele
Kokstad
Harding
Mzimvubu
Mount Frere
Maclear
Coastal
Lusikisiki
Mtata
Mtata
Queenstown
Mbashe
Kei
Butterworth
Amatola
Bhisho
East London
Grahamstown
NORTH
0 25 50 100 150 200
Kilometers
LEGEND
Major towns
Perennial rivers
Major dams
WMA sub-areas
Quaternary catchments
AR potential volumes (m³/km²)
< 10,000
10,000 - 25,000
25,000 - 50,000
50,000 - 100,000
> 100,000
PROJECT
STRATEGY DEVELOPMENT: A NATIONAL APPROACH TO IMPLEMENT ARTIFICIAL RECHARGE AS PART OF WATER RESOURCE PLANNING

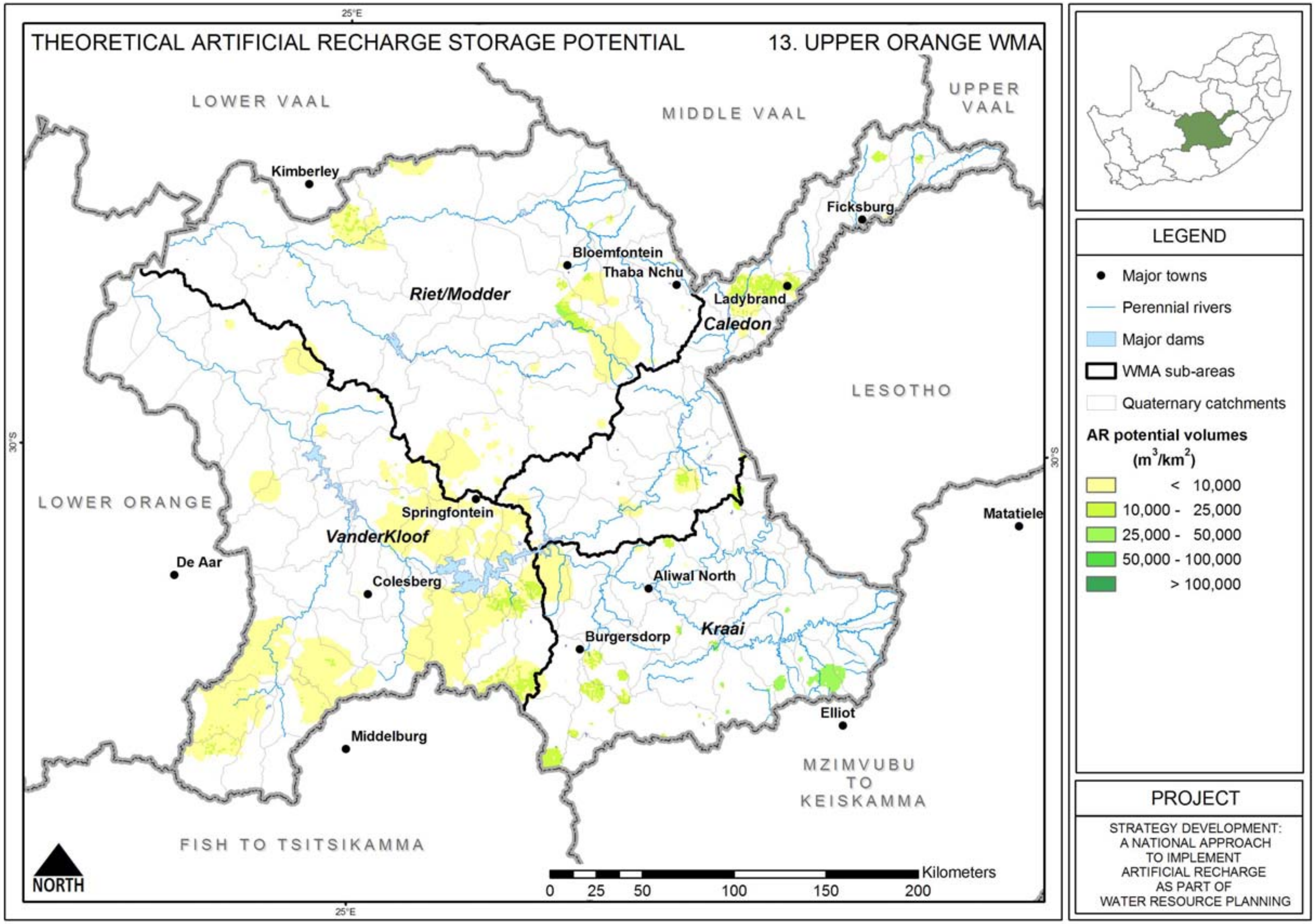
Water Management Area 13: Upper Orange

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water require-ments for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
13 Upper Orange	Senqu Lesotho	4012	933		523	23	N/A	N/A	N/A
	Caledon Lesotho	753	92		31	40	N/A	N/A	N/A
	Caledon RSA	650	90		178	105	11	10	20
	Kraai	956	158		44	103	16	20	36
	Riet / Modder	407	45		137	351	16	16	31
	Vanderkloof	203	31		3534	346	77	54	132
	Total for WMA13	**6981**	**1349**	**11711**	**4447**	**968**	**119**	**100**	**219**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*


THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL
13. UPPER ORANGE WMA
25°E
30°S
LOWER VAAL
MIDDLE VAAL
UPPER VAAL
LOWER ORANGE
LESOTHO
FISH TO TSITSIKAMMA
MZIMVUBU TO KEISKAMMA
Kimberley
Ficksburg
Bloemfontein
Thaba Nchu
Ladybrand
Riet/Modder
Caledon
Springfontein
VanderKloof
De Aar
Colesberg
Aliwal North
Matatiele
Burgersdorp
Kraai
Elliot
Middelburg
NORTH
0 25 50 100 150 200
Kilometers
LEGEND
● Major towns
Perennial rivers
Major dams
WMA sub-areas
Quaternary catchments
AR potential volumes (m^3/km^2)
< 10,000
10,000 - 25,000
25,000 - 50,000
50,000 - 100,000
> 100,000
PROJECT
STRATEGY DEVELOPMENT: A NATIONAL APPROACH TO IMPLEMENT ARTIFICIAL RECHARGE AS PART OF WATER RESOURCE PLANNING

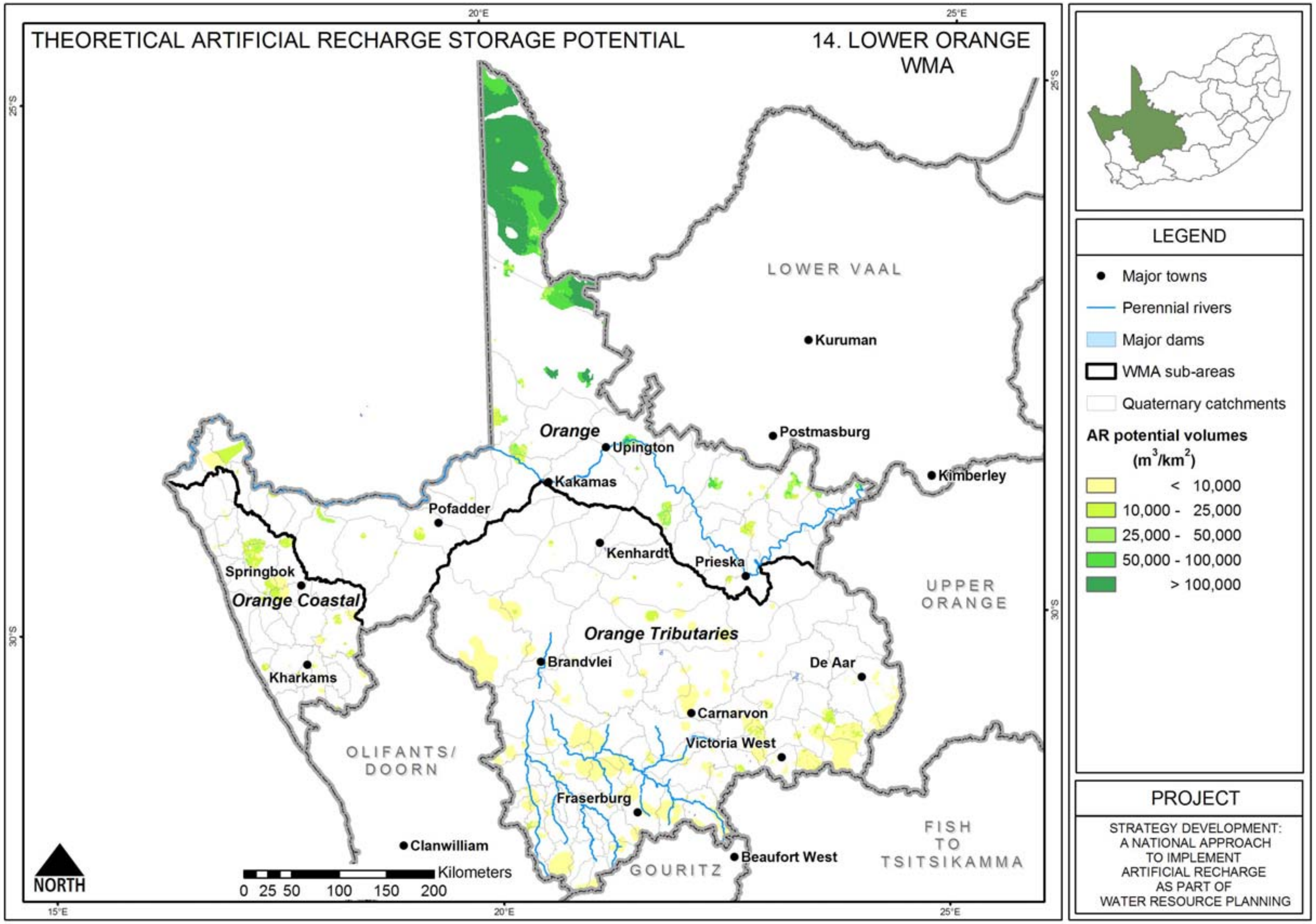
Water Management Area 14: Lower Orange

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water require-ments for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
14 Lower Orange	Orange	198	32		-986	989	289	1514	1802
	Orange Tributaries	280	35		22	31	94	83	177
	Orange Coastal	24	2		3	8	14	24	38
	Total for WMA14	**502**	**69**	**298**	**-961**	**1028**	**397**	**1620**	**2017**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*


THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL
14. LOWER ORANGE WMA
20°E
25°E
15°E
25°S
30°S
LOWER VAAL
Kuruman
Postmasburg
Kimberley
Orange
Upington
Kakamas
Pofadder
Kenhardt
Prieska
Springbok
Orange Coastal
UPPER ORANGE
Orange Tributaries
Brandvlei
De Aar
Kharkams
Carnarvon
Victoria West
OLIFANTS/ DOORN
Fraserburg
FISH TO TSITSIKAMMA
Clanwilliam
Beaufort West
GOURITZ
NORTH
0 25 50 100 150 200
Kilometers
LEGEND
● Major towns
Perennial rivers
Major dams
WMA sub-areas
Quaternary catchments
AR potential volumes (m^3/km^2)
< 10,000
10,000 - 25,000
25,000 - 50,000
50,000 - 100,000
> 100,000
PROJECT
STRATEGY DEVELOPMENT: A NATIONAL APPROACH TO IMPLEMENT ARTIFICIAL RECHARGE AS PART OF WATER RESOURCE PLANNING

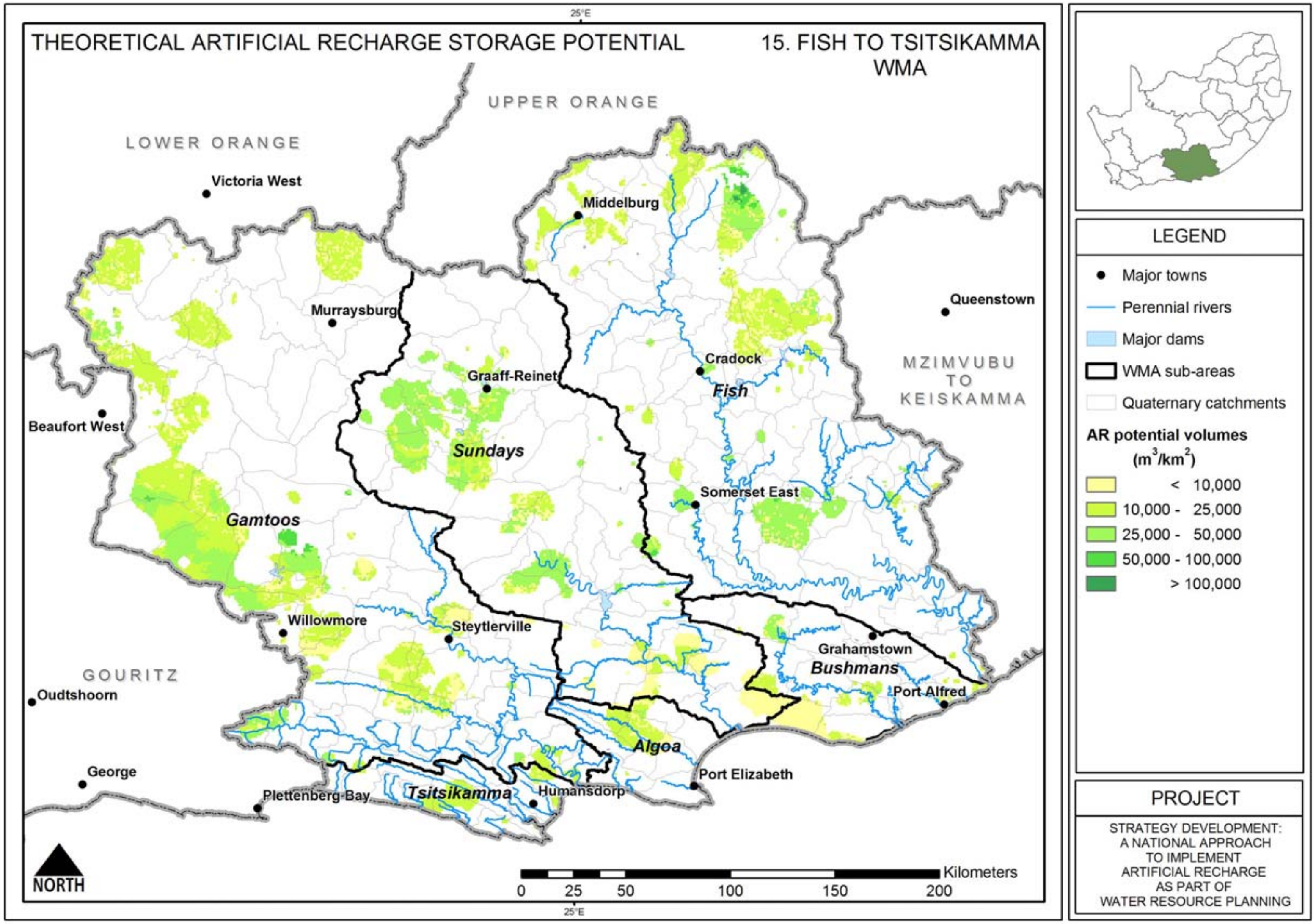
Water Management Area 15: Fish to Tsitsikamma

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water requirements for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
15 Fish-Tsitsikamma	Fish	518	47		84	473	66	91	157
	Bushmans	174	15		21	22	3	9	12
	Sundays	280	20		101	182	54	77	131
	Gamtoos	491	39		145	111	119	145	264
	Algoa	147	15		23	91	3	7	11
	Tsitsikamma	544	107		49	22	4	7	11
	Total for WMA15	**2154**	**243**	**739**	**423**	**901**	**249**	**337**	**586**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*


THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL
15. FISH TO TSITSIKAMMA WMA
25°E
UPPER ORANGE
LOWER ORANGE
Victoria West
Middelburg
Queenstown
Murraysburg
Cradock
Graaff-Reinet
Fish
MZIMVUBU TO KEISKAMMA
Beaufort West
Sundays
Somerset East
Gamtoos
Willowmore
Steytlerville
Grahamstown
Bushmans
GOURITZ
Oudtshoorn
Port Alfred
Algoa
George
Port Elizabeth
Plettenberg Bay
Tsitsikamma
Humansdorp
NORTH
0
25
50
100
150
200
Kilometers
LEGEND
● Major towns
Perennial rivers
Major dams
WMA sub-areas
Quaternary catchments
AR potential volumes (m^3/km^2)
< 10,000
10,000 - 25,000
25,000 - 50,000
50,000 - 100,000
> 100,000
PROJECT
STRATEGY DEVELOPMENT: A NATIONAL APPROACH TO IMPLEMENT ARTIFICIAL RECHARGE AS PART OF WATER RESOURCE PLANNING

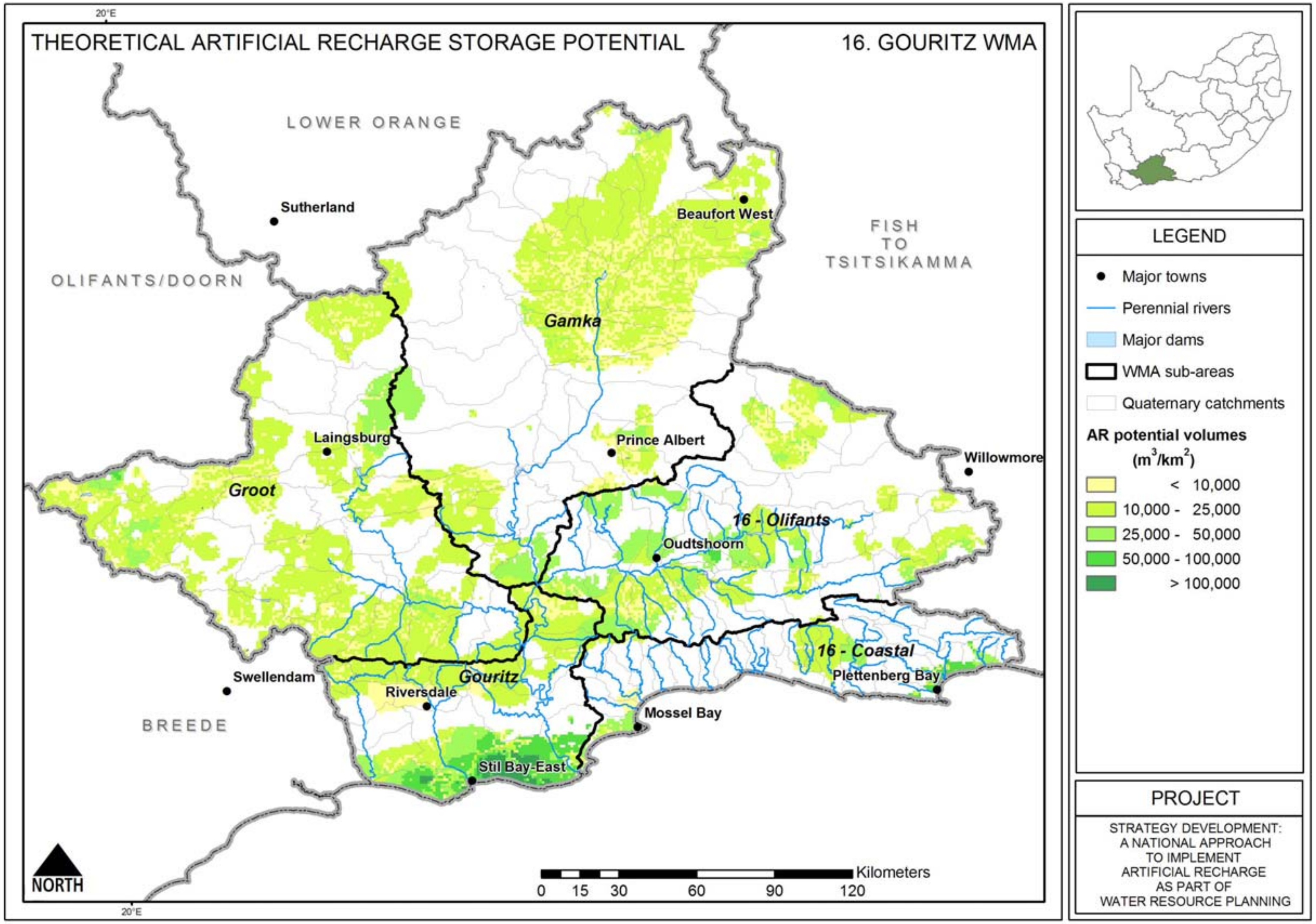
Water Management Area 16: Gouritz

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water require-ments for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
16 Gouritz	Gamka	227	19		48	55	113	110	223
	Groot	105	5		42	53	86	119	205
	Olifants	229	17		71	74	57	79	136
	Gouritz	347	56		59	58	49	122	171
	Coastal	771	228		55	98	7	21	28
	Total for WMA16	**1679**	**325**	**301**	**275**	**338**	**313**	**451**	**763**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*



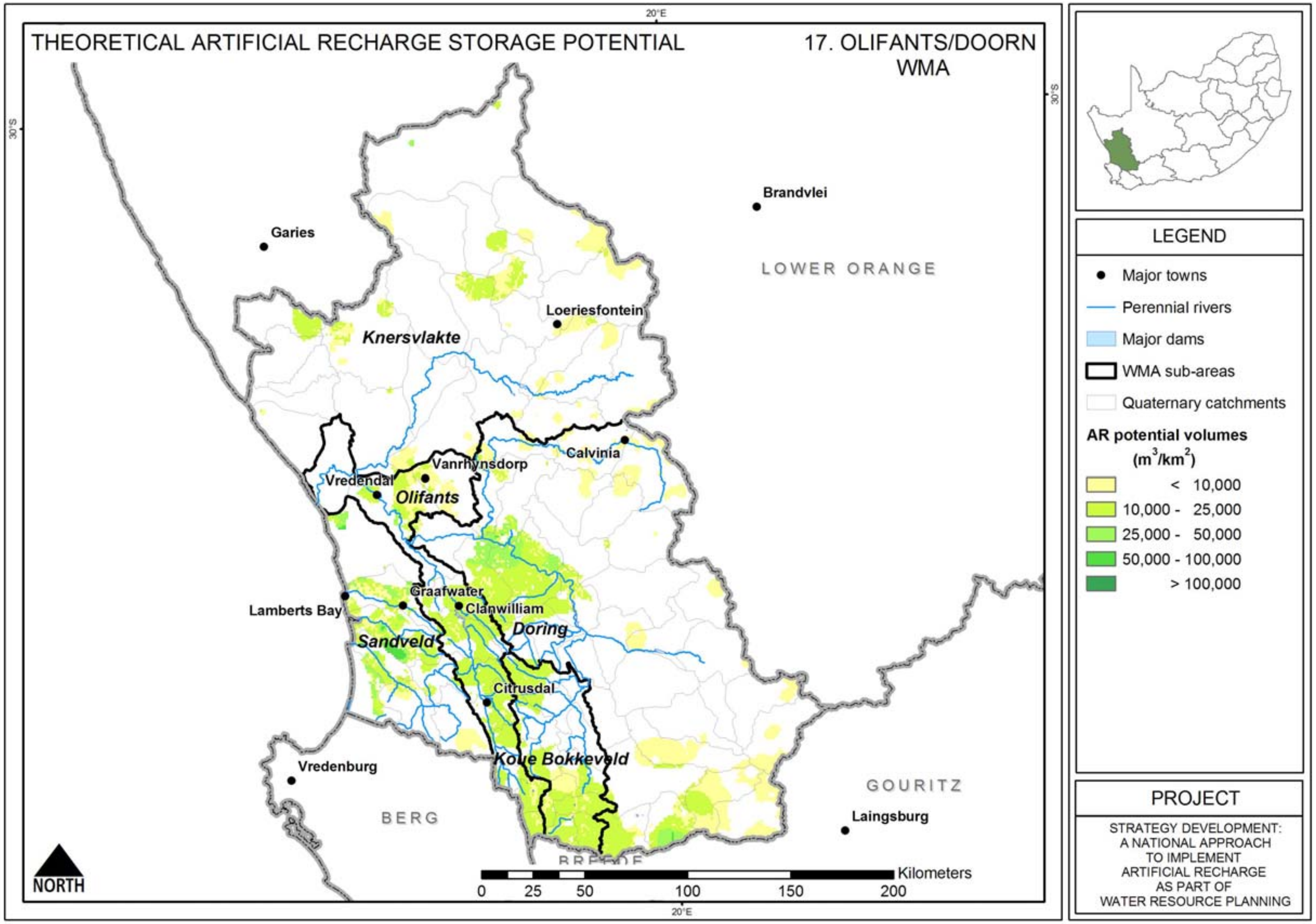
THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL

16. GOURITZ WMA

Water Management Area 17: Olifants/Doorn

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water requirements for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
17 Olifants-Doorn	Koue Bokkeveld	279	29		67	66	18	22	40
	Sandveld	60	8		32	38	15	27	42
	Olifants	514	77		221	247	22	30	52
	Knersvlakte	27	3		4	7	10	15	26
	Doring	228	39		11	15	39	61	100
	Total for WMA17	**1108**	**156**	**132**	**335**	**373**	**104**	**155**	**259**

MAR: Mean Annual Runoff
The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.
* *Derived from GRAII data sets (refer to Section B.4)*


THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL
17. OLIFANTS/DOORN WMA
20°E
30°S
Brandvlei
Garies
LOWER ORANGE
Loeriesfontein
Knersvlakte
Calvinia
Vanrhynsdorp
Vredendal
Olifants
Graafwater
Lamberts Bay
Clanwilliam
Doring
Sandveld
Citrusdal
Koue Bokkeveld
Vredenburg
GOURITZ
Laingsburg
BERG
BREEDE
NORTH
0
25
50
100
150
200
Kilometers
LEGEND
● Major towns
Perennial rivers
Major dams
WMA sub-areas
Quaternary catchments
AR potential volumes (m³/km²)
< 10,000
10,000 - 25,000
25,000 - 50,000
50,000 - 100,000
> 100,000
PROJECT
STRATEGY DEVELOPMENT: A NATIONAL APPROACH TO IMPLEMENT ARTIFICIAL RECHARGE AS PART OF WATER RESOURCE PLANNING

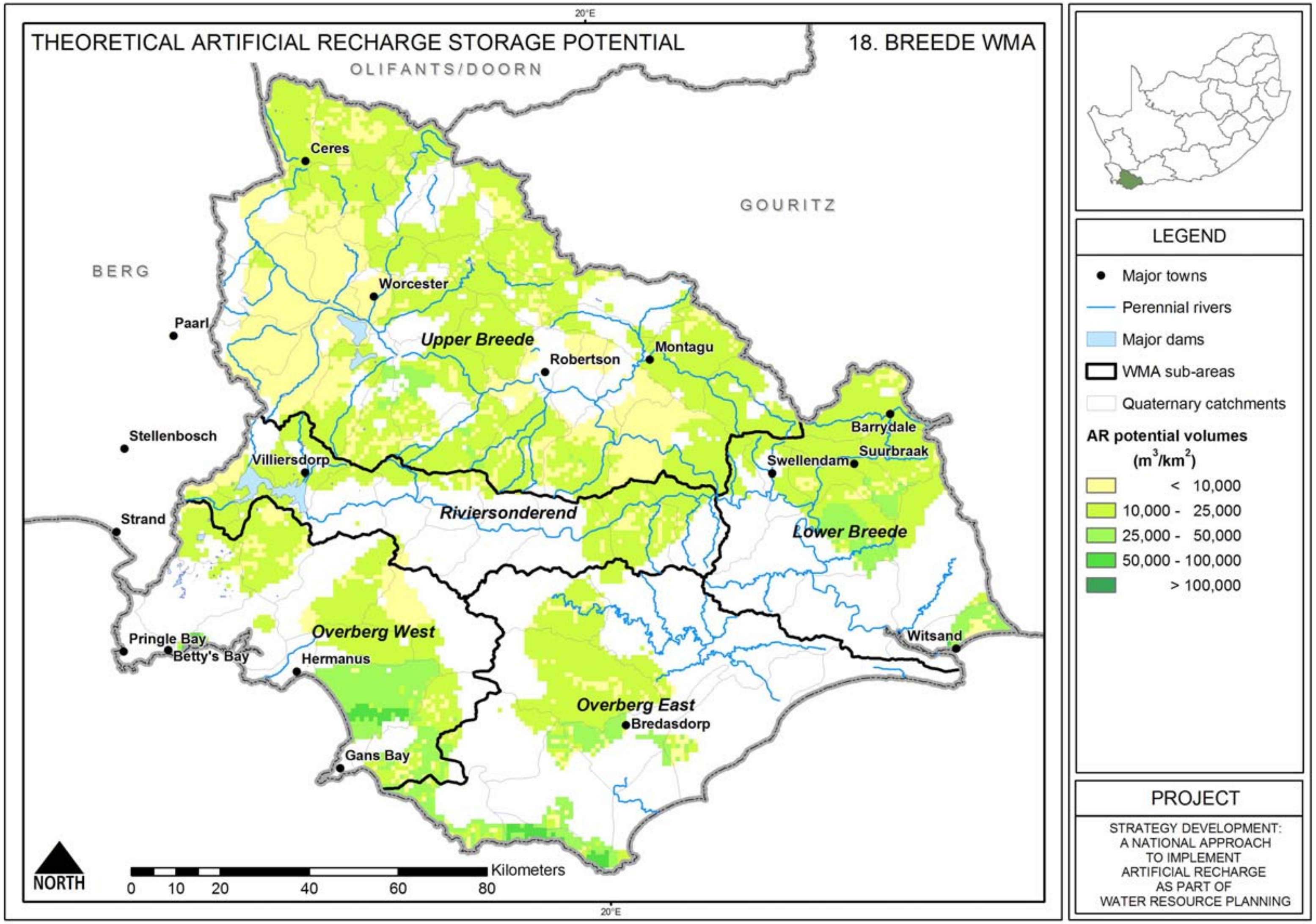
Water Management Area 18: Breede

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m^3/a)**	**Ecological Reserve (million m^3/a)**	**Storage in major dams (million m^3)**	**Total local yield for year 2000 (million m^3/a)**	**Total local water requirements for year 2000 (million m^3/a)**	**Groundwater: 5m drawdown storage (million m^3)**	**Potential AR storage (million m^3)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m^3)**
18 Breede	Upper Breede	1212	178		501	465	54	71	124
	Riviersonderend	460	65		226	53	8	11	19
	Lower Breede	210	34		36	31	12	26	37
	Overberg East	110	13		2	4	11	22	33
	Overberg West	480	94		99	79	17	28	44
	Total for WMA18	**2472**	**384**	**1060**	**864**	**632**	**101**	**157**	**258**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*


THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL
18. BREEDE WMA
20°E
OLIFANTS/DOORN
GOURITZ
BERG
Ceres
Worcester
Paarl
Upper Breede
Robertson
Montagu
Stellenbosch
Villiersdorp
Barrydale
Suurbraak
Swellendam
Strand
Riviersonderend
Lower Breede
Overberg West
Pringle Bay
Betty's Bay
Hermanus
Witsand
Overberg East
Bredasdorp
Gans Bay
NORTH
Kilometers
0
10
20
40
60
80
20°E
LEGEND
Major towns
Perennial rivers
Major dams
WMA sub-areas
Quaternary catchments
AR potential volumes
(m³/km²)
< 10,000
10,000 - 25,000
25,000 - 50,000
50,000 - 100,000
> 100,000
PROJECT
STRATEGY DEVELOPMENT:
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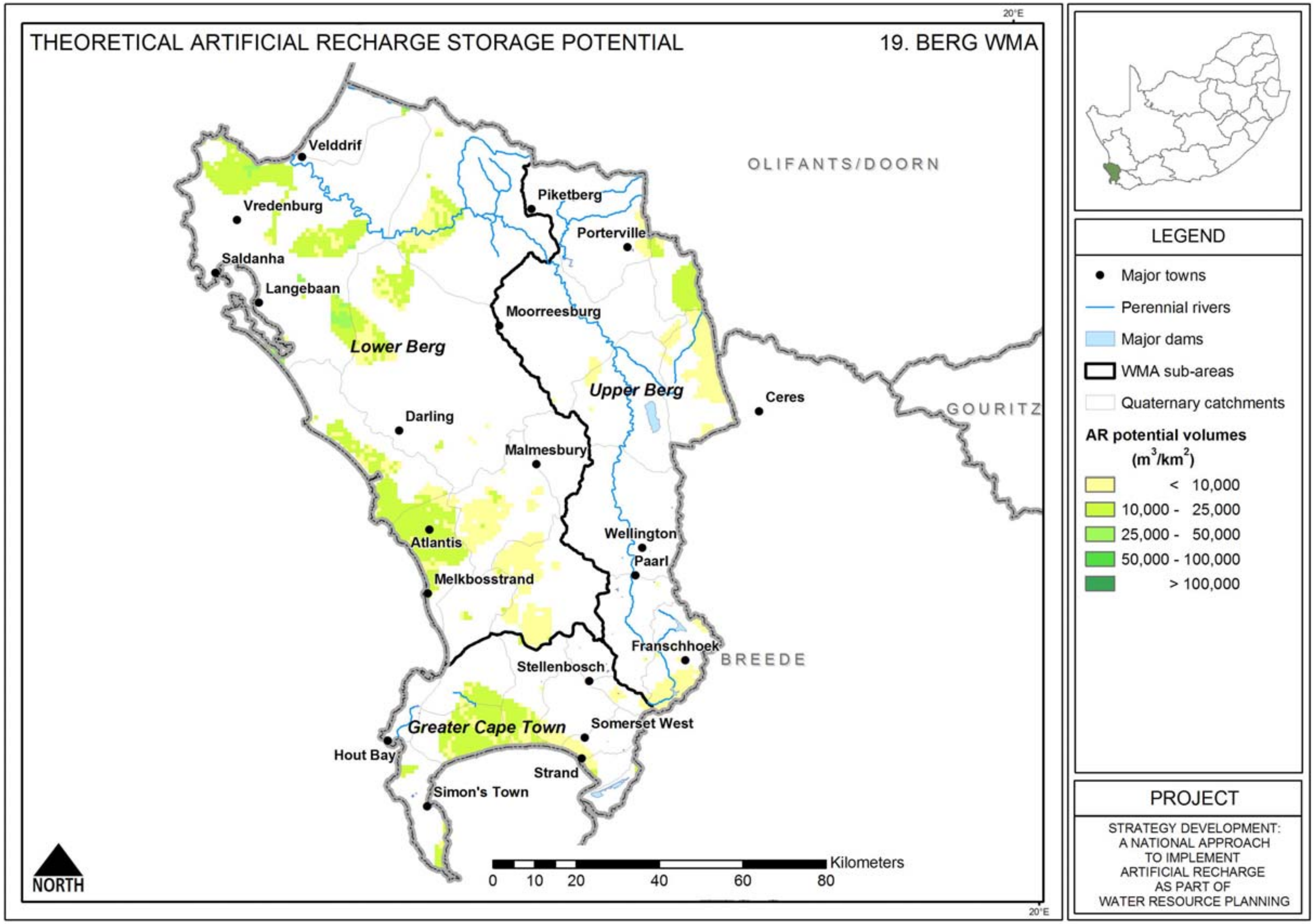
Water Management Area 19: Berg

WMA data taken from NWRS, 2004							Groundwater storage in AR favourable areas*		
WMA	**Component Sub-Area**	**Natural MAR (million m³/a)**	**Ecological Reserve (million m³/a)**	**Storage in major dams (million m³)**	**Total local yield for year 2000 (million m³/a)**	**Total local water require-ments for year 2000 (million m³/a)**	**Groundwater: 5m drawdown storage (million m³)**	**Potential AR storage (million m³)**	**Combined potential groundwater storage (AR + 5m drawdown) (million m³)**
19 Berg	Greater Cape Town	373	61		108	394	10	5	15
	Upper Berg	849	124		322	229	3	3	6
	Lower Berg	207	32		52	81	29	17	46
	Total for WMA19	**1429**	**217**	**295**	**482**	**704**	**42**	**25**	**68**

MAR: Mean Annual Runoff

The total local yield is the sum of useable surface water, existing groundwater use and useable return flows, as defined in the NWRS, 2004.

* *Derived from GRAII data sets (refer to Section B.4)*


THEORETICAL ARTIFICIAL RECHARGE STORAGE POTENTIAL
19. BERG WMA
20°E
OLIFANTS/DOORN
GOURITZ
BREEDE
Velddrif
Vredenburg
Saldanha
Langebaan
Lower Berg
Piketberg
Porterville
Moorreesburg
Upper Berg
Ceres
Darling
Malmesbury
Wellington
Paarl
Atlantis
Melkbosstrand
Franschhoek
Stellenbosch
Somerset West
Greater Cape Town
Hout Bay
Strand
Simon's Town
NORTH
0
10
20
40
60
80
Kilometers
LEGEND
● Major towns
Perennial rivers
Major dams
WMA sub-areas
Quaternary catchments
AR potential volumes
(m³/km²)
< 10,000
10,000 - 25,000
25,000 - 50,000
50,000 - 100,000
> 100,000
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