Water Banking – A Practical Guide to Using Artificial Groundwater Recharge

Artificial Groundwater Recharge

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1. INTRODUCTION

In the past four years there have been many significant and exciting developments in the field of artificial recharge.

Water banking is the process of storing surplus water to help maintain sufficient water for our needs, to be drawn on when demand requires. Artificial recharge can be defined as the process whereby surface water is transferred underground to be stored in an aquifer. The most common methods used involve injecting water into boreholes or 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.

The Department of Water Affairs (DWA) published its artificial recharge strategy in June 2007 and in November of that year began implementing it. Potential artificial recharge areas have been identified for the whole country and a detailed artificial recharge assessment has been conducted in one Water Management Area – the Olifants/Doorn.WMA.

Some recent initiatives include:

- conducting feasibility studies for the towns of Plettenberg Bay and Prince Albert;
- transferring groundwater from one aquifer to another in Williston (western Karoo);
- conducting trial borehole injection tests in Langebaan;
- substantially increasing the artificial recharge and abstraction capacity in Windhoek by drilling new injection boreholes and deep abstraction boreholes;
- developing a website (www.artificialrecharge.co.za) as South Africa's artificial recharge resource centre;
- developing university course material (presentation and notes) on artificial recharge, and
- writing up the history and operation of the Atlantis scheme near Cape Town.

The three main reasons for the recent interest in artificial recharge are:

- artificial recharge is usually far cheaper than conventional surface water schemes;
- new surface water sources are often not available, or increasing supply from existing surface water sources is not an option, because local surface water resources are already stressed, and
- there is no possibility for expanding existing groundwater supplies.

This booklet provides a practical guide for the appropriate application of artificial recharge in Southern Africa and is intended to assist the reader in the preliminary identification of potential artificial recharge options as method of achieving sustainable water management practices.

2. BENEFITS OF SUB-SURFACE STORAGE

Artificial recharge presents the opportunity for strategic water management for water stressed communities. This is particularly relevant to Southern Africa, where artificial recharge can provide a sustainable solution to managing the limited water resources. The proven benefits of existing sub-surface storage schemes are given below:

- The on-going enhancing of aquifer yields using treated waste water and storm water (Atlantis) and treated waste water only (Polokwane);
- Enhancing aquifer yields by transferring groundwater from one aquifer to another (Williston);
- Enhancing aquifer yields through opportunistic artificial recharge whenever surface water is available (Kharkams in Namaqualand and Omdel in Namibia);
- Enhancing the security of supply by large-scale sub-surface water banking from treated dam water for long-term and seasonal storage, and for emergency requirements (Windhoek), and
- Improving water quality (Atlantis and Kharkams).

See DWA (2010a) for more detailed information regarding the referenced schemes.

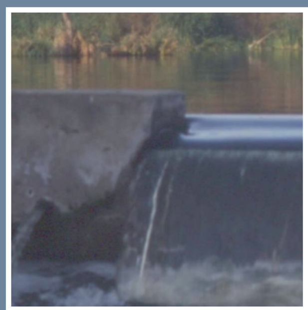
3. APPROPRIATE APPLICATIONS

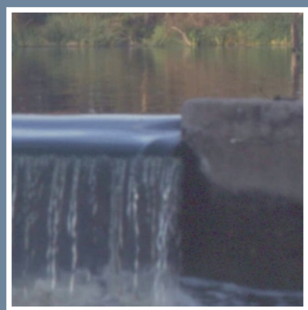
Introduction

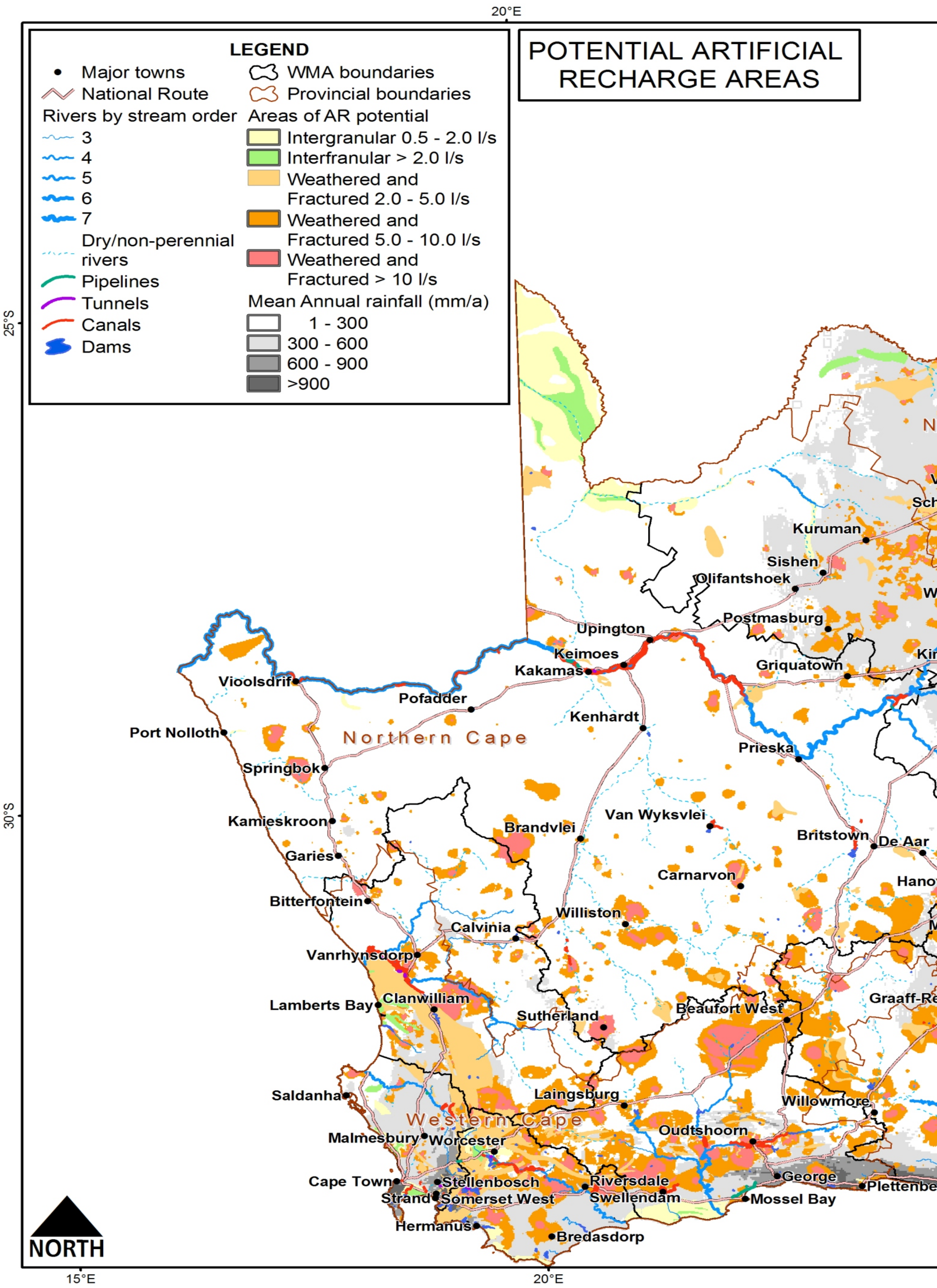
Where water demand exceeds the availability of existing surface water and groundwater resources, artificial recharge may present the means to bank surplus water times of plenty for subsequent extraction. The identification of potential artificial recharge schemes is fundamentally driven by two main factors, namely; the presence of a suitable aquifer, and the availability of a suitable water source. Where there is no suitable aquifer, it may be possible to create an “aquifer' in the form of a sand dam. The artificial recharge selection procedure is discussed below.

Artificial Recharge Areas

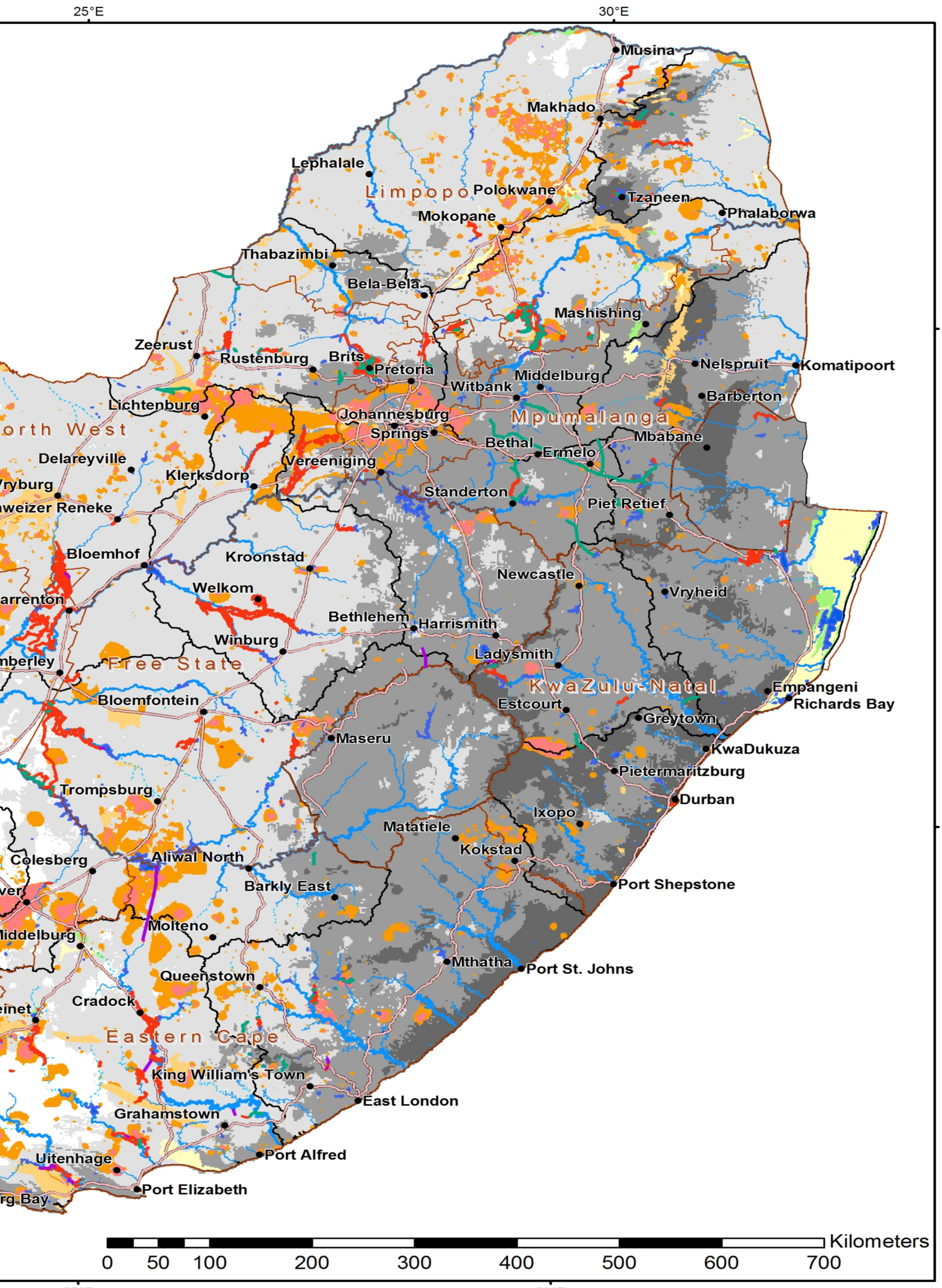
Artificial recharge schemes and favourable aquifers usually emerge after it becomes apparent that groundwater levels have dropped over time as a result of pumping; or additional storage is required and sub-surface storage is the cheapest large-scale reservoir option. However, it can also be advantageous to plan a groundwater scheme that incorporates artificial recharge from the outset, and to pro-actively identify areas where artificial recharge opportunities exist. With this in mind, a nationwide assessment of potential artificial recharge areas was conducted as part of the roll-out of DWA's artificial recharge strategy (see DWA 2009b). Favourable artificial recharge areas were identified as those areas which have known high aquifer permeability (see the map of South Africa overleaf). Potential artificial recharge area maps have been made for each Water Management Area (WMA). These can be downloaded from the DWA artificial recharge website: www.artificialrecharge.co.za.







LEGEND
Major towns
National Route
Rivers by stream order
3
4
5
6
7
Dry/non-perennial rivers
Pipelines
Tunnels
Canals
Dams
WMA boundaries
Provincial boundaries
Areas of AR potential
Intergranular 0.5 - 2.0 l/s
Interfranular > 2.0 l/s
Weathered and Fractured 2.0 - 5.0 l/s
Weathered and Fractured 5.0 - 10.0 l/s
Weathered and Fractured > 10 l/s
Mean Annual rainfall (mm/a)
1 - 300
300 - 600
600 - 900
>900
POTENTIAL ARTIFICIAL RECHARGE AREAS
20°E
25°S
30°S
15°E
20°E
NORTH
Northern Cape
Western Cape
Kuruman
Sishen
Olifantshoek
Postmasburg
Upington
Keimoes
Kakamas
Griquatown
Vioolsdrif
Pofadder
Kenhardt
Port Nolloth
Springbok
Prieska
Kamieskroon
Brandvlei
Van Wyksvlei
Britstown
De Aar
Garies
Carnarvon
Bitterfontein
Williston
Calvinia
Vanrhynsdorp
Lamberts Bay
Clanwilliam
Sutherland
Beaufort West
Saldanha
Laingsburg
Willowmore
Malmesbury
Worcester
Oudtshoorn
Cape Town
Stellenbosch
Riversdale
George
Strand
Somerset West
Swellendam
Mossel Bay
Hermanus
Bredasdorp


25°E
30°E
25°S
30°S
Musina
Makhado
Lephalale
Limpopo
Polokwane
Tzaneen
Phalaborwa
Mokopane
Thabazimbi
Bela-Bela
Mashishing
Zeerust
Rustenburg
Brits
Pretoria
Nelspruit
Komatipoort
Middelburg
Witbank
Barberton
Lichtenburg
Johannesburg
Mpumalanga
orth West
Springs
Mbabane
Bethal
Ermelo
Delareyville
Klerksdorp
Vereeniging
ryburg
weizer Reneke
Standerton
Piet Retief
Bloemhof
Kroonstad
Newcastle
Welkom
Vryheid
arrenton
Bethlehem
Harrismith
Winburg
Ladysmith
nberley
Free State
KwaZulu-Natal
Empangeni
Richards Bay
Estcourt
Bloemfontein
Greytown
Maseru
KwaDukuza
Pietermaritzburg
Trompsburg
Durban
Ixopo
Matatiele
Kokstad
Colesberg
Aliwal North
Barkly East
Port Shepstone
ver
Molteno
iddelburg
Mthatha
Port St. Johns
Queenstown
Cradock
einet
Eastern Cape
King William's Town
East London
Grahamstown
Port Alfred
Uitenhage
Port Elizabeth
rg Bay
0
50
100
200
300
400
500
600
700
Kilometers

Water Source

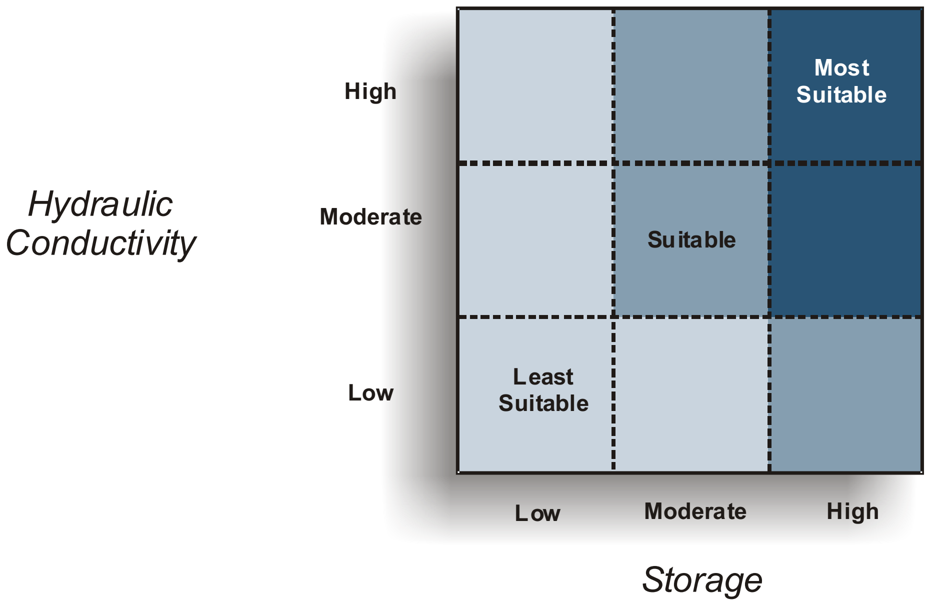
The availability of surplus water is essential to provide a source of water for aquifer recharge. This water may be in the form of rivers, dams, treated effluent, urban run-off and rainwater harvesting. The physical property of the different water sources will influence the design of the artificial recharge scheme.

Water sources for artificial recharge

Source water	Quantity	Reliability	Quality
Perennial Rivers	Variable	Variable	Variable
Ephemeral Streams	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 stormwater runoff	Variable	Variable	Variable
Run-off from roofs and driveways	Variable	Variable	High
Agricultural return flows	Variable	High	Low

Aquifer Hydraulics

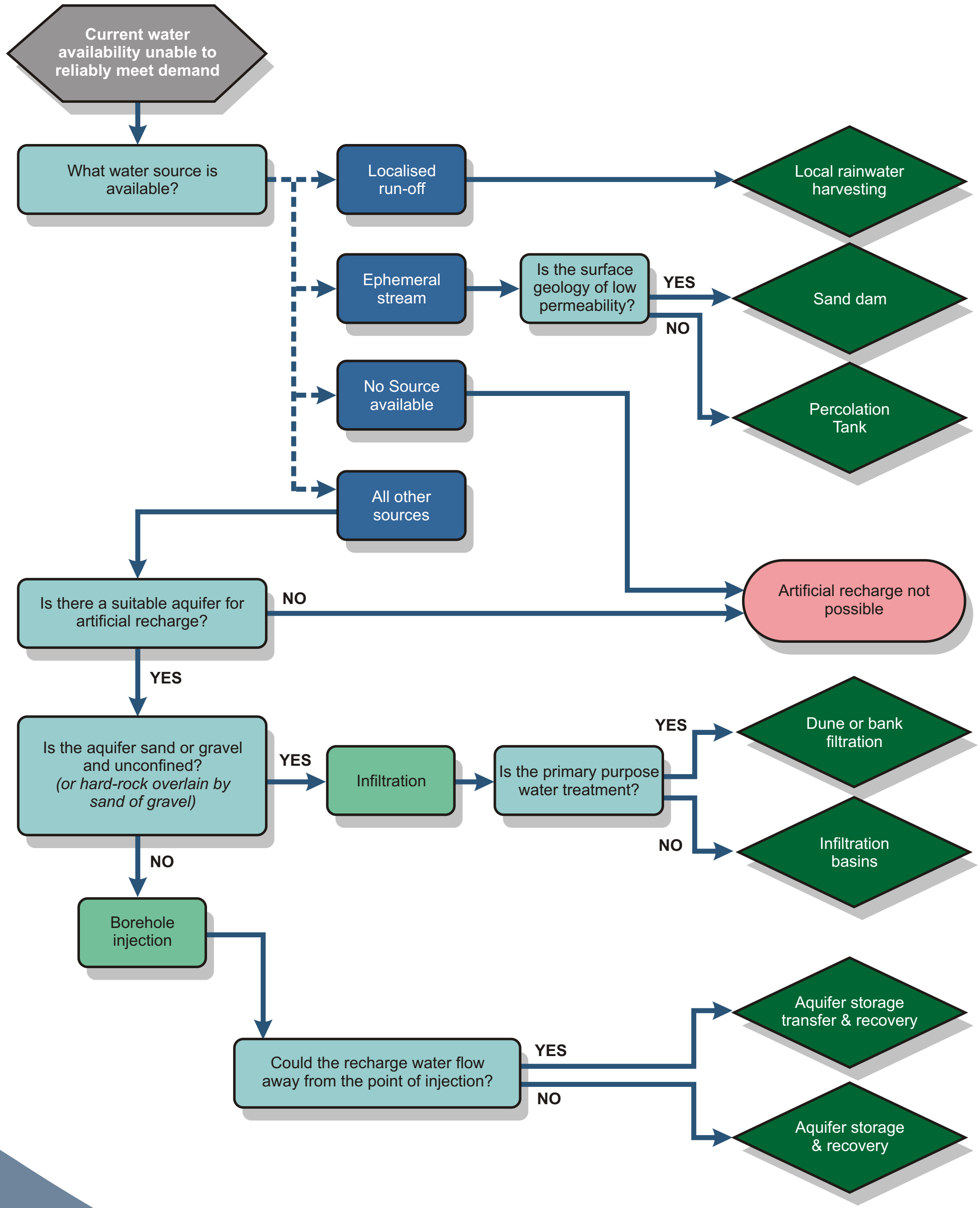
The potential artificial recharge areas presented in the map of South Africa identify aquifers which are expected to have suitable hydraulic properties for the purpose of artificial recharge. Local variations in the hydrogeology may impact on the suitability of a particular aquifer. Where potential aquifers have been identified a hydrogeologist should evaluate the storage capacity and hydraulic conductivity of the aquifer. This information will inform the suitability of the aquifer for artificial recharge as illustrated below.



Suitability of an aquifer to receive artificially recharged water (Murray and Tredoux, 1998)

Scheme Selection

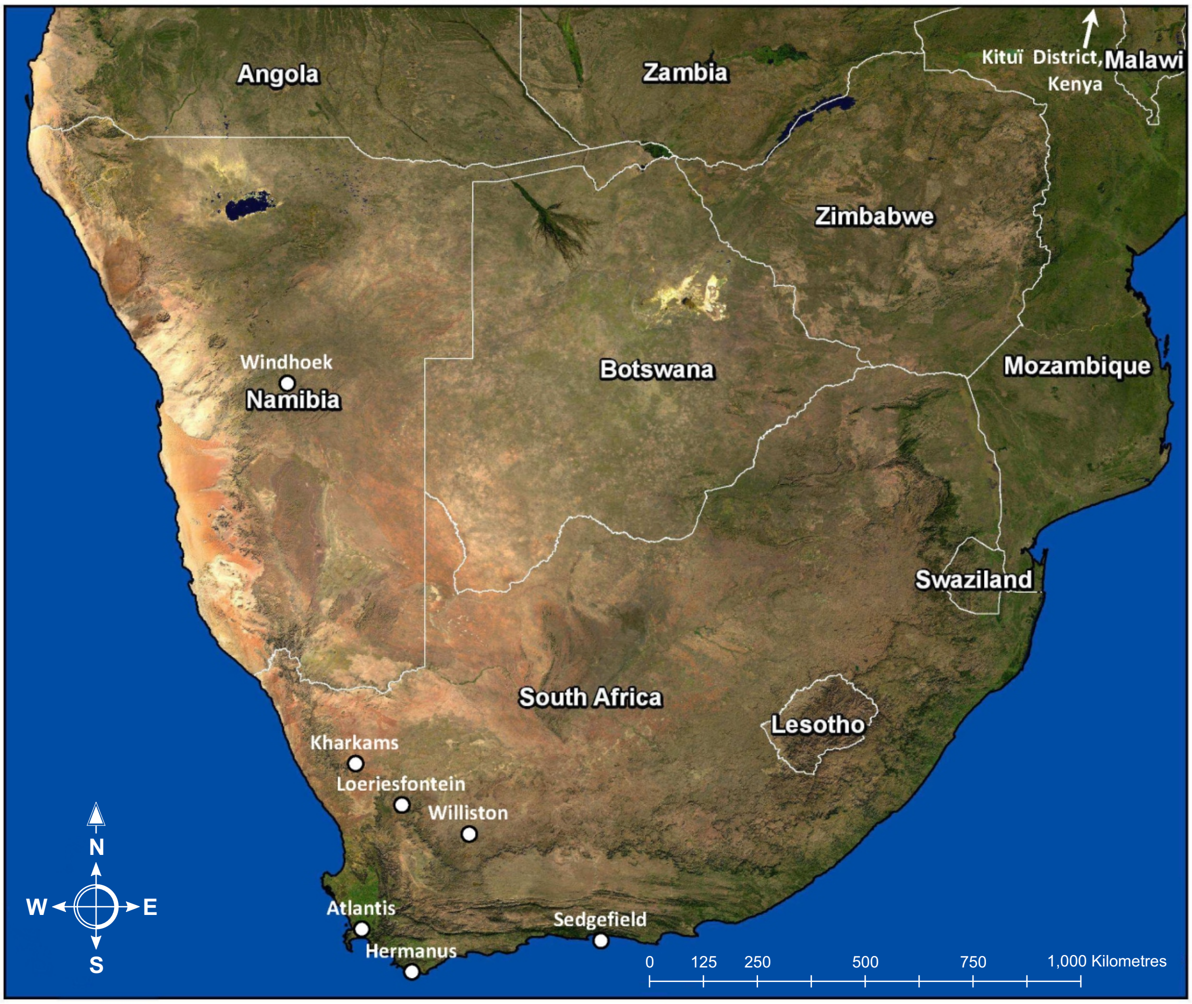
The flow chart below is intended to guide the selection of potential artificial recharge methods. Examples of each method are presented in the following section.



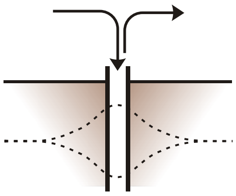
Flow chart to identify artificial recharge method

4. RECHARGE OPTIONS

The different artificial recharge methods are presented below together with case studies. The location of the case studies are shown on the map below.



Case Study Locations



Aquifer Storage and Recovery (ASR)

The injection of water into a borehole for storage and recovery from the same borehole

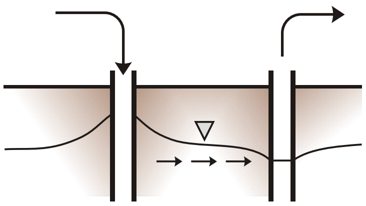
Hydrogeological Conditions	Suitable in both confined and unconfined aquifers. Optimal in areas where groundwater has a shallow hydraulic gradient.
Typical Scale	Village / Town (10^4 – 10^6 m^3 per annum)
Relative Cost	Low to Moderate (*can be retrofitted to existing boreholes*)
Treatment	Usually high. Sediment load and debris must be removed to minimise borehole clogging.
Other Considerations	Requires abstraction and recharge pipe and fittings in the same borehole.

CASE STUDY

Kharkams, Namaqualand

Background	Kharkams is a small village in the semi-arid Namaqualand region that depends solely on groundwater.
Purpose	Increase yield and reduce salinity of groundwater
Water Source	Surface water run-off
Treatment	Sand filtration
Target Aquifer	Fractured granite
Typical Yield	Yield increased by three times. Salinity reduced from undrinkable (EC = 300mS/m) to good quality potable water (EC < 100mS/m).
Challenges / Lessons	Poor maintenance of the sand filter has reduced the operational efficiency.

Sand filter with injection and abstraction borehole (pump house) in the background

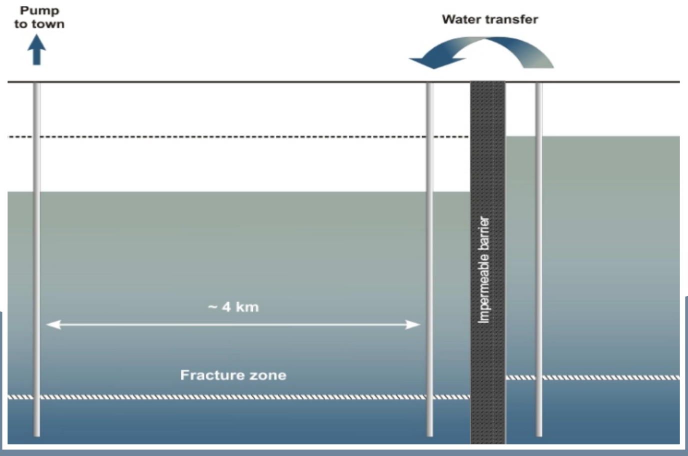


Aquifer Storage Transfer & Recovery (ASTR)

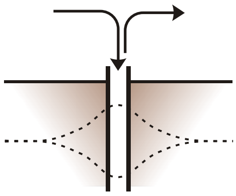
The injection of water into a borehole for storage and recovery from a different borehole

Hydrogeological Conditions	Suitable in both confined and unconfined aquifers
Typical Scale	Village / Town (10^4 – 10^6 m^3 per annum)
Relative Cost	Moderate to High (*recharge up-gradient of existing boreholes*)
Treatment	Usually high. Sediment load and debris must be removed to minimise borehole clogging. Transfer process can improve the quality of the recharge water.

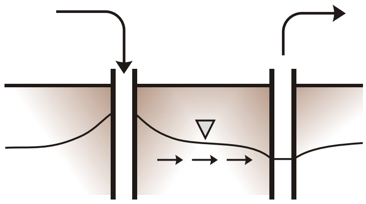
CASE STUDY	***Williston, western Karoo***
Background	This small town relies on groundwater for its domestic supplies. Abstraction over the years has been in excess of natural recharge. The aquifer is divided by an impermeable barrier and the levels in the adjacent compartment have not shown the decline evident in the pumped compartment.
Purpose	To increase yield of existing production boreholes
Water Source	Adjacent aquifer compartment
Treatment	None required
Target Aquifer	Fractured sandstones (dolerite sill intrusion in sedimentary rocks)
Typical Yield	260m^3/day (effectively doubling the available yield)
Challenges / Lessons	Historic monitoring was essential to establish the groundwater levels in the two aquifer compartments.



Schematic diagram of Williston ASTR scheme



ASR & ASTR Combined



CASE STUDY

Windhoek, Namibia

Background

The Namibian capital Windhoek has a current water use of ~21 Mm^3/ annum, most of which comes from three dams. The remainder is sourced from a groundwater and reclaimed water.

To improve water assurance, the city opted for artificial recharge over other options because it represented a significant cost saving with the same assurance of supply.

Purpose

To improve water security by 'banking' surface water underground, where evaporation and aquifer losses are negligible. To be able to supply virtually the entire city's current use when the aquifer is full, and then for it to be able to be rapidly and fully recharged afterwards.

Water Source

Surface water

Treatment

Full treatment to potable standards prior to injection

Target Aquifer

Fractured quartzite

Typical Yield

Sand filtration

Target Aquifer

Fractured granite

Typical Yield

Aquifer's sustainable yield: 1.7 Mm^3/annum (without artificial recharge)

Current artificial recharge capacity: 2.8 Mm^3/annum (5 injection boreholes)

Target artificial recharge capacity: 8 Mm^3/annum (8 new injection boreholes have been drilled)

Current maximum yield: 11Mm^3/annum (with artificial recharge)

Target yield: 19 Mm^3/annum (with artificial recharge)

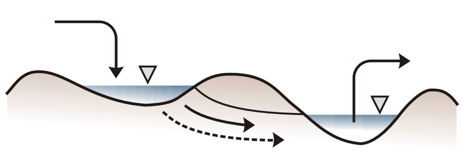
Challenges / Lessons

Artificial Recharge can be the most cost-effective option for enhancing a city's water security and supply system.

Complex, fractured aquifers can be used for artificial recharge provided detailed hydrogeological assessments are undertaken to understand the groundwater flow system.

Finalising agreements between the source water supplier (NamWater) and the scheme operator (City of Windhoek) delayed the initial operation of the scheme. Institutional agreements are commonly the greatest impediment to implementing artificial recharge schemes.

One of Windhoek's injection boreholes (below the tripod) and the water treatment building where further treatment is given through Granular Activated Carbon and chlorination



Dune Filtration

The infiltration of water through a sand dune and extraction from boreholes, wells or ponds at a lower elevation for water quality improvement and to balance supply and demand.

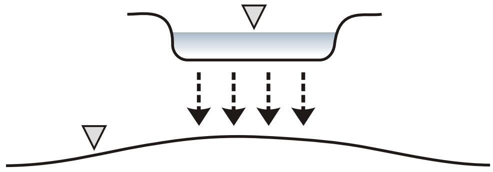
Hydrogeological Conditions	Unconfined sedimentary aquifer (sand dune)
Typical Scale	Village / Town (10^4 – 10^6 m^3 per annum)
Relative Cost	Low (*only shallow wells / excavations required*)
Treatment	Minimal pre-treatment is usually required. Source water should be reasonably clear to avoid clogging. Dune infiltration is effective for the removal of sediments and micro-organisms.
Other Considerations	Requires water source near to dune system (commonly wastewater treatment works or stormwater outfalls). Residence time in the aquifer will determine how effective it is for removing micro-organisms.

CASE STUDY

Sedgefield

Background	This coastal town has a current water demand of 2000m^3/day. Water is supplied from the Karatara River which is supplemented by groundwater and sea water desalination in the summer. Future demand is expected to increase to 4500m^3/day.
Purpose	Increase water supply to meet future demand
Water Source	Treated effluent from Waste Water Treatment Works
Treatment	Natural polishing will occur in aquifer before abstraction
Target Aquifer	Sand
Typical Yield	Potential yield – 1300m^3/day (and can increase as more water is treated at the Waste Water Treatment Works)
Challenges / Lessons	Project to be implemented. Post treatment requirements (eg chlorination) will only be known after abstraction boreholes have been drilled.

Aerial photograph of Sedgefield WWTW in the sand dunes and proposed abstraction boreholes (Google Earth, 2010)



Infiltration Basins

Basins constructed in sand or gravel aquifers. Surface water is diverted to the basins and allowed to infiltrate through an unsaturated zone to the underlying unconfined aquifer.

Hydrogeological Conditions	Sandy unconfined aquifers. This method is not suited to clayey soils
Typical Scale	Village / Town (10^4 – 10^6 m^3 per annum)
Relative Cost	Moderate *(can recharge up-gradient of existing boreholes)*
Treatment	Infiltration is more rapid with clean water than turbid water, and the cleaner the water the longer the infiltration "runs" before having to scrape the basin to remove fine material. Natural treatment is provided by filtration through the unsaturated zone.
Other Considerations	The water table should be at least a few metres below ground level. Residence time in the aquifer will determine how effective it is for removing micro-organisms.

CASE STUDY

Atlantis

Background	Atlantis is 50 km north of the Cape Town and has a population in excess of 60 000. The artificial recharge scheme is operated by the City of Cape Town and has successfully recharged and recycled treated waste water and storm water for three decades. The recycled water is used for domestic supplies. In addition to the recharge scheme, treated industrial waste water is diverted to coastal basins to provide a subsurface barrier to contain the recharge water and prevent ingress of saline water.
Purpose	To enhance groundwater yields and deal with industrial wastewater
Water Source	Treated domestic waste water and storm water runoff
Treatment	Domestic waste water and "clean" industrial waste water is treated prior to infiltration, and urban runoff is allowed to settle prior to being fed to the recharge basins. The poorer quality industrial waste water is treated prior to being used as a barrier between the relatively clean recharge water and saline water.
Target Aquifer	Sandy with a saturated thickness of up to ~35 m. It is underlain by an impermeable layer of weathered shale.
Typical Yield	2.7×10^6 m^3/annum water recharged (approximately 30% of Atlantis' groundwater supply)

The main infiltration basin, Basin 7

CASE STUDY

Atlantis (continued)

The Atlantis Water Resource Management Scheme has proven itself as an innovative and highly successful scheme. It has shown that that it is possible to separate different types of wastewater and storm water and manage them all. The performance of the water recycling system has shown itself to be robust with respect to the elimination of contaminants.

A monitoring system has been in place since project inception. This needs to be continuously upgraded to improve the understanding, management and performance of the scheme.

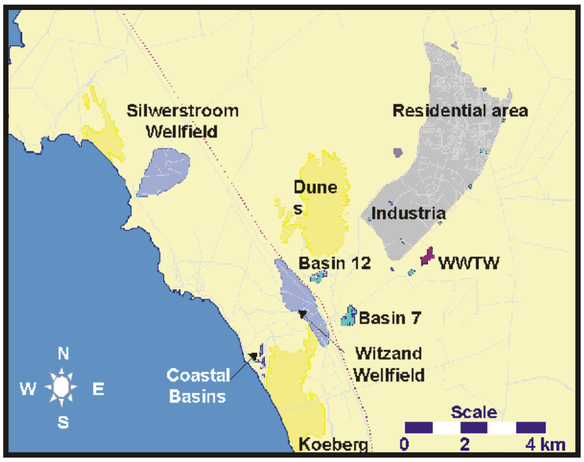
Challenges / Lessons

An integrated scheme requires integrated management to ensure optimal efficiency of the scheme. This is a challenge as different responsibilities currently rest with three separate departments in the City of Cape Town.

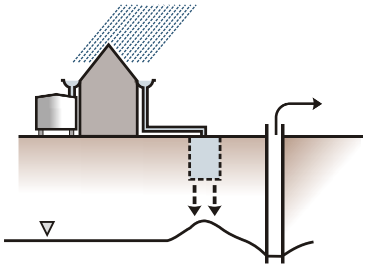
Most of the infiltration is via one basin. This limits the scheme's infiltration and attenuation capacity. By redesigning the basin into a number of sub-basins, it would allow for alternate wetting and drying cycles. This would allow for regular scraping of the basins to increase infiltration efficiencies, and it would increase the thickness of the unsaturated zone which would improve the attenuation capacity.

Regular litter and sediment removal is required to optimise the efficiency of the scheme.

Aerial photo of Basin 7



Basin location plan



Local Rainwater Harvesting

Surface water runoff from roofs or localised paving is diverted into a borehole, well or a soakaway filled with sand or gravel and allowed to percolate to the water table where it is collected by pumping from wellpoints, wells or boreholes.

Hydrogeological Conditions Sandy aquifers: Wells, soakaways or boreholes

Hard-rock aquifers: Boreholes

Typical Scale Family / Village (10^2 – 10^3 m^3 per annum)

Relative Cost Low to Moderate, *(can be retrofitted to existing boreholes)*

Pre-Treatment Not usually required, first few millimetres of rain can be diverted away from infiltration to flush debris collected on the roof. Storm runoff can be diverted to reed beds prior to artificial recharge. These “water features” linked to artificial recharge schemes are becoming increasingly popular as part of urban design.

Other Considerations Diverting roof water into the ground can be beneficial by offsetting the impact of urbanisation on the aquifer.

CASE STUDY

Hermanus

Background Two out of every three houses in the suburbs of Northcliff and Eastcliff in Hermanus have well points. This places a sizable demand on the existing shallow groundwater source.

Purpose Household rain water which falls onto roofs and hard surfaces can be captured and diverted into the aquifer rather than being lost to storm water drainage.

Water Source Rainwater falling on local properties

Pre-Treatment None

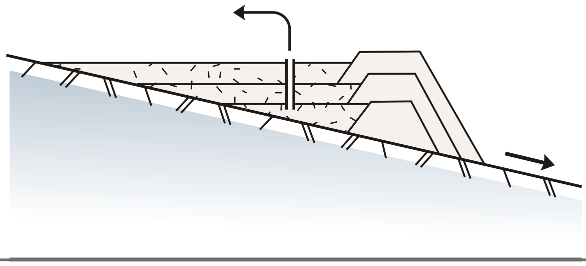
Target Aquifer Shallow sands 5-10m thick with an average groundwater depth of 2.5m below ground level.

Typical Yield Artificial recharge will help sustain yields sufficient to meet garden irrigation demands.

Challenges / Lessons To raise awareness of the financial benefit of harvesting rainwater for household irrigation, rather than using clean municipal water.

Aerial photograph of Hermanus

(Google Earth, 2010)



Sand Dam

Built in ephemeral streams in arid areas on low permeability lithology. They trap sediment when flow occurs and following successive floods, the sand dam is raised to create an "aquifer". Vertical boreholes or horizontal outlets to the face of the dam can be used to extract water in dry seasons.

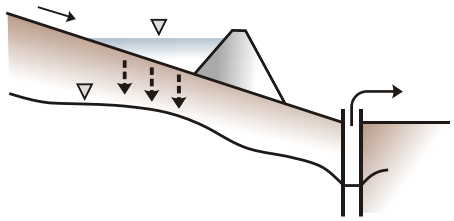
Hydrogeological Conditions	Low permeability surface geology
Typical Scale	Family / Village (10^3 – 10^4 m^3 per annum)
Relative Cost	Low to moderate, depends on size of dam
Pre-Treatment	Silt traps may be required to prevent surface clogging
Other Considerations	Generally not suitable where very fine sediment loads occur, however dam can be designed to trap the coarser sediment that occurs as bed load. Best in areas where the river flows over coarse sand such as granitic sands.

CASE STUDY

Kituï District, Kenya *(Borst & de Haas, 2006)*

Background	Sand Dams have been constructed in the Kituï District for the last 25 years, constructed by communities with local materials.
Purpose	Domestic use, livestock and agriculture
Water Source	Ephemeral stream
Pre-Treatment	None, but stored water is protected from contamination
Target Aquifer	Series of Sand Dams, ranging between 2m - 4m high and 20m long
Typical Yield	$2000m^3$ (per dam)
Challenges / Lessons	Low maintenance requirements make the Sand Dam a sustainable technology for remote communities.

Typical Sand Dam
(Borst & de Haas, 2006)



Percolation Tank

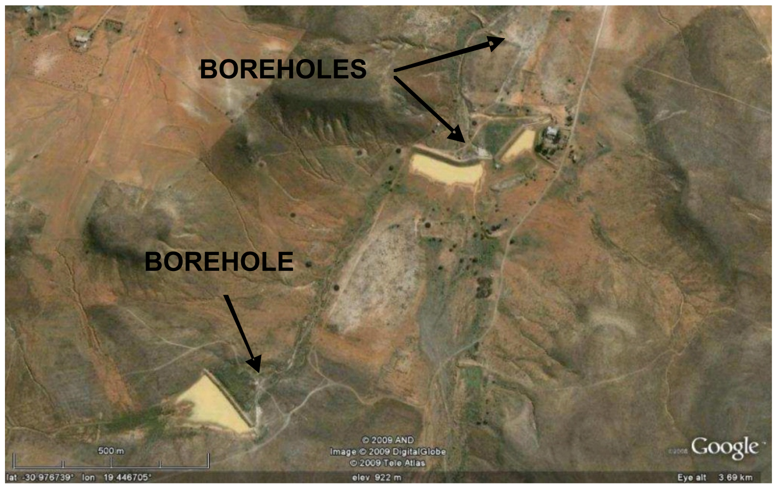
Normally built in ephemeral streams, the percolation tank stores surface water allowing it to infiltrate into the underlying unconfined aquifers. The recharged water is then extracted down-gradient via wells or boreholes.

Hydrogeological Conditions	Unconfined aquifers
Typical Scale	Village / Town (10^4 – 10^5 m^3 per annum)
Relative Cost	Low to Moderate, depending on size of dam
Pre-Treatment	Silt Traps may help to prevent surface clogging and siltation of the percolation tank.
Other Considerations	Effective where surface geology is permeable (ie in areas where the construction of a water-tight dam would require the importation of lining material).

CASE STUDY

Loeriesfontein, Northern Cape

Background	Loeriesfontein is a small town in the semi-arid Namakwa District. The average rainfall is less than 250 mm per year and the average evaporation is about 2200 mm per year. The town's water is from five production boreholes.
Purpose	Municipal water supply and irrigation.
Water Source	Ephemeral Stream
Pre-Treatment	None
Target Aquifer	Alluvium
Typical Yield	Recharge increases the productivity of the boreholes which yield approximately 0.15Ml/d.
Challenges / Lessons	Siltation will reduce the storage capacity and therefore the potential recharge volume. Sub-surface storage is preferable due to high evaporation.
Replication Opportunities	Widely used across South Africa and can be retrofitted to existing 'leaky' dams to harvest water lost to infiltration.



Loeriesfontein boreholes located below earth dam walls.

5. ARTIFICIAL RECHARGE SUCCESS CRITERIA

There is a range of important criteria to be assessed before undertaking an artificial recharge project. Many of these relate to the geology and hydrology of the area; some concern environmental impacts and others are about cost/benefit ratios and the appropriate scale and design of the scheme.

But even if all these criteria are correctly considered, all artificial recharge schemes, irrespective of size, will fail without proper monitoring and maintenance. The demands vary - the small Kharkams project only requires yearly scraping of the sand filter and cleaning of the in-line filters, whereas the more complex Atlantis scheme needs dedicated staff to operate it along with the treatment plant and other infrastructure – but the requirement for on-going maintenance is constant.

The department's Artificial Recharge Strategy (DWAF, 2007) outlines the ten key “success criteria” for artificial recharge. The top four of these criteria were discussed in Chapter 3 with reference to the selection of an appropriate application for artificial recharge; the latter criteria consider potential regulatory, financial and capacity constraints. The ten “success criteria” are summarised below:

I. **The need for an artificial recharge scheme:** Is artificial recharge really necessary – could you not increase your groundwater yield by expanding the wellfield or by managing the existing wellfield better?

II. **The source water:** What volume of water is available for recharge, and when is it available?

III. **Aquifer hydraulics:** Will the aquifer receive and hold the water in storage?

IV. **Water quality:** Is the quality of the source water suitable for artificial recharge?

V. **Engineering issues:** How will the water be treated and transferred into the aquifer?

VI. **Environmental issues:** What are the potential environmental benefits, risks and constraints?

VII. **Legal and regulatory issues:** What type of authorisation is required?

VIII. **Economics:** How much will the scheme cost, and what will the cost of supplied water per m^3 be?

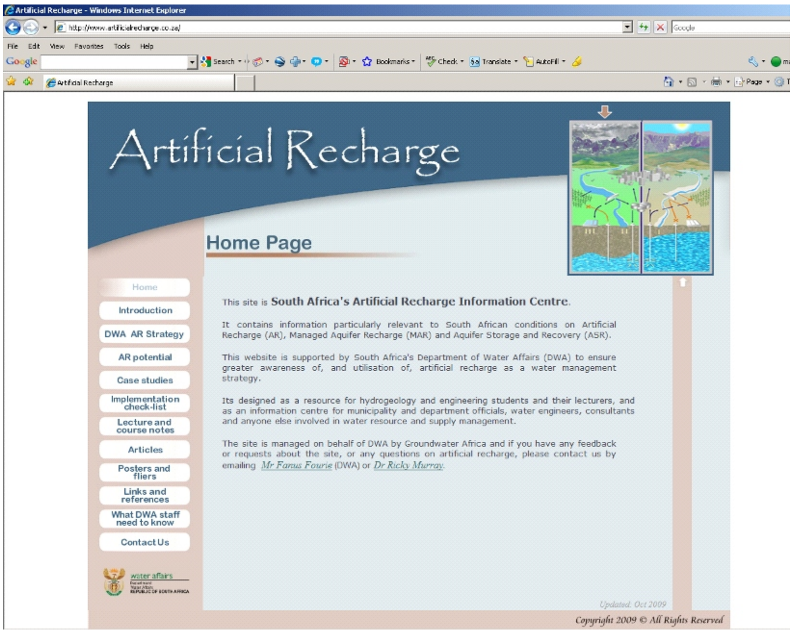
IX. **Management and technical capacity:** Are the skills available to operate the scheme?

X. **Institutional arrangements:** Who will be responsible for supplying the source water and ensuring its quality is suitable; are there other users of the aquifer; who will regulate the use of the scheme?

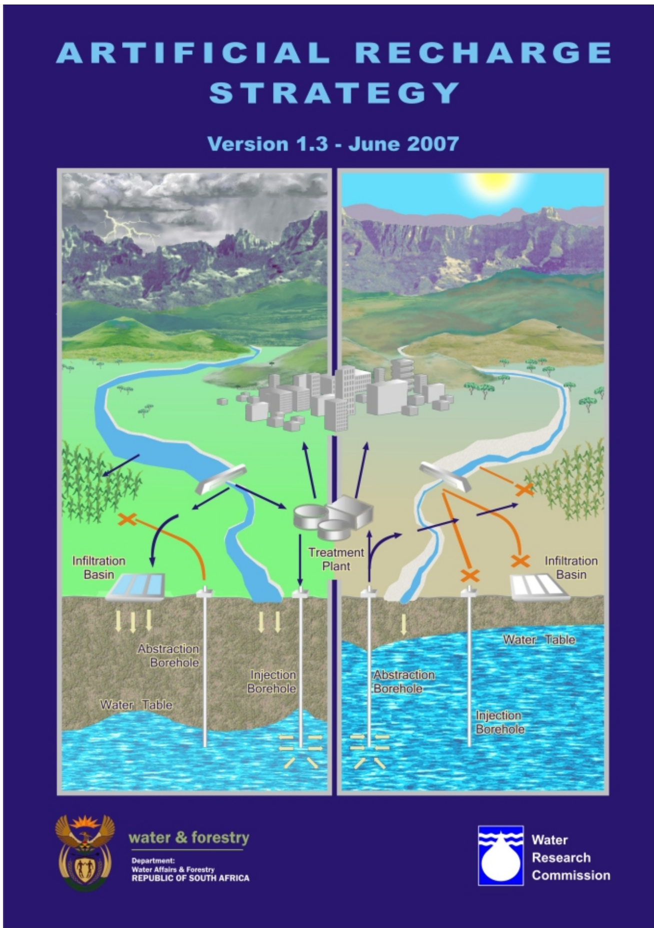
More information about these criteria, the key questions for each project stage and a detailed check-list for implementing successful artificial recharge projects is available in DWAF (2007) and DWA (2009a).

6. SOUTH AFRICAN ARTIFICIAL RECHARGE RESOURCES

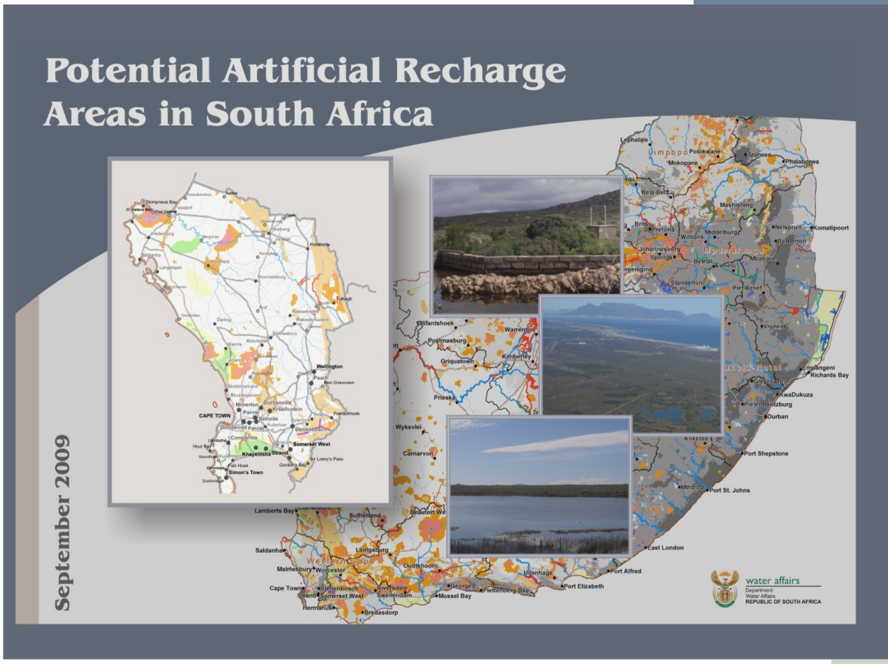
DWA's artificial recharge website
www.artificialrecharge.co.za
This website contains all the resources listed below, links to other relevant websites and more information on artificial recharge. All new resources developed under DWA's roll-out of the artificial recharge strategy have been posted on the website.



Artificial Recharge Strategy: Version 1.3 (DWAF, 2007): This document is mostly a handbook on artificial recharge. It contains a wealth of information, including the types of schemes, details on the "success criteria", authorisation and regulatory issues and the Artificial Recharge Strategy.

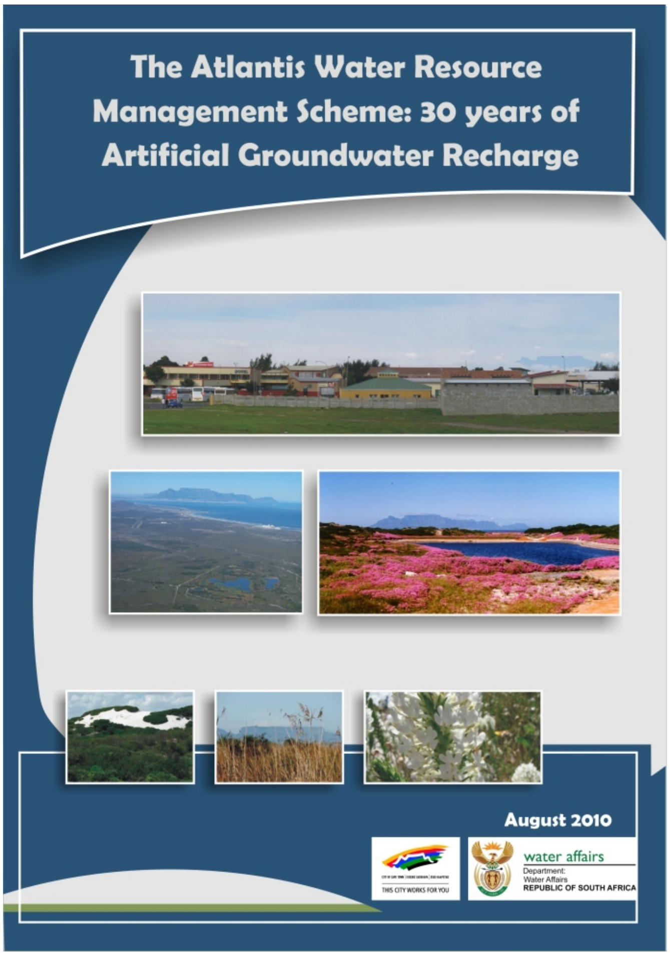


Potential Artificial Recharge Areas in South Africa (DWA, 2009b): This report identifies potential recharge areas, identifies a number of places where artificial recharge should be considered, describes conceptual plans for artificial recharge at a few sites, and gives an artificial recharge assessment of WMA 19. The methodology for the WMA 19 study is written up in detail and can be used as an example or template for other WMA-scale studie

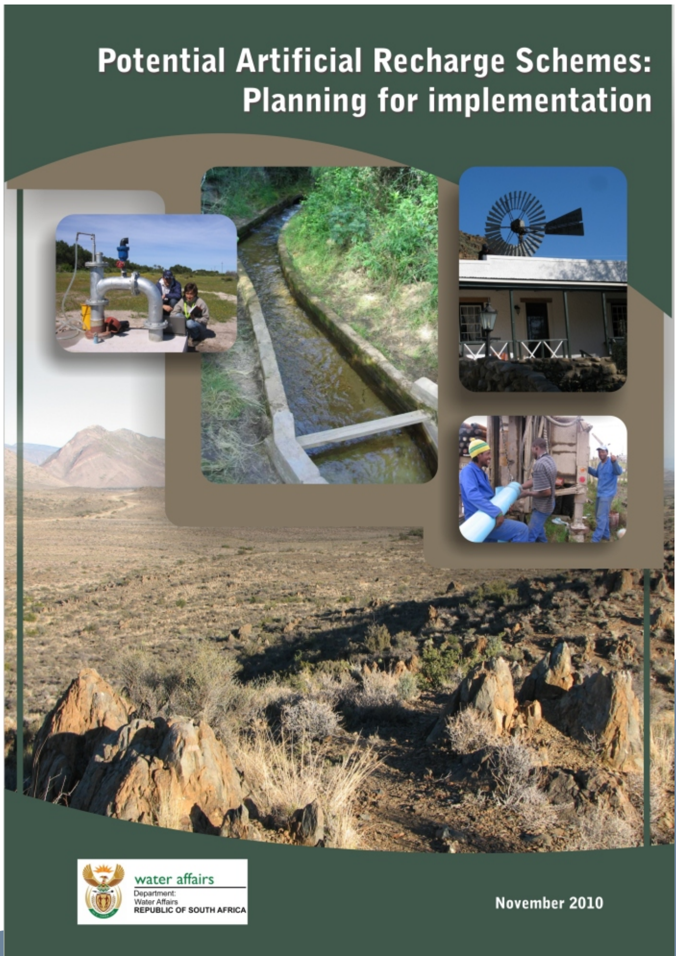


A check-list for implementing successful artificial recharge projects (DWA, 2009a): This brief report covers: Artificial recharge project stages; the Pre-feasibility study check list; and the Feasibility study check list (see the inside back cover of this booklet).

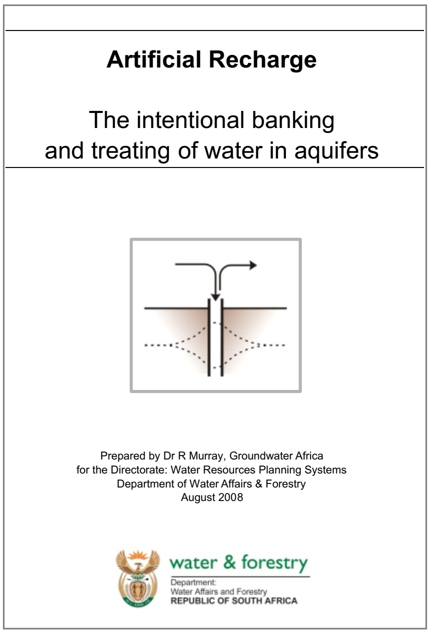
The Atlantis Water Resource Management Scheme (DWA, 2010b): This report describes the history, planning, implementation and operation of the Atlantis scheme which has been in operation for nearly 30 years.

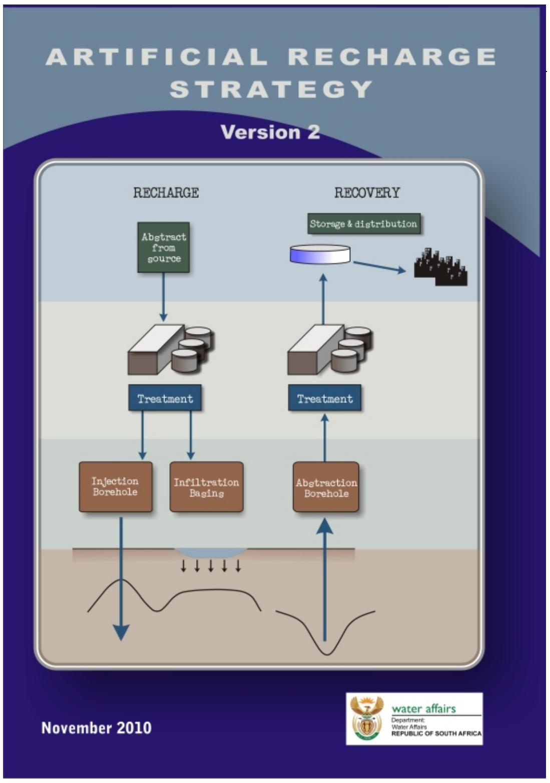


Potential Artificial Recharge schemes: Planning for Implementation (DWA, 2010c): This report presents different levels of feasibility studies for a number of potential artificial recharge projects.



Artificial Recharge lecture and lecture notes (DWA, 2009c): A lecture with lecture notes has been prepared for academic institutions. The lecture covers all key points on artificial recharge.





Artificial Recharge Strategy Version 2 (DWA, 2010d): An update of the 2007 Artificial Recharge Strategy.

Planning and Authorising Artificial Recharge Schemes (DWA, 2010e): This brief report outlines project implementation stages, legal and regulatory issues and the authorisation process.

7. ACKNOWLEDGEMENTS

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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.	None
	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.	
	Establish existing water use licence conditions and authorisation requirements from DWA.	
Feasibility Stage	If needed, obtain a water use licence and environmental authorisation for the recharge tests.	None, or a short-term water use licence for AR testing and possibly environmental authorisation for AR testing
	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.	
Implementation Stage	Obtain the necessary water use licence and environmental authorisation for the AR scheme.	Water use licence and possibly environmental authorisation
	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.	
Operation and Maintenance Stage	Carry out performance monitoring during production.	Compliance monitoring and reporting.
	Modify operation & maintenance procedures based on scheme performance.	
	Develop final monitoring and reporting system.