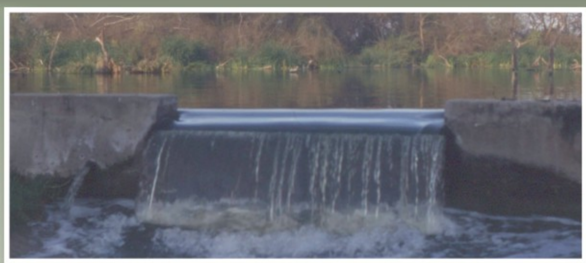
Artificial Groundwater Recharge: Recent Initiatives in Southern Africa



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ILISO Consulting (Pty) Ltd
Approved for ILISO Consulting (Pty) Ltd

____ ____

Director:
ILISO Consulting (Pty) Ltd
Dr Martin van Veelen

Project Manager:
Department of Water Affairs
Mr Fanus Fourie

Department of Water Affairs
Water Resource Planning Systems

____ ____

Director:
Water Resource Planning Systems
Dr Beason Mwaka

Deputy Director:
Water Resource Planning Systems
Mr Elias Nel

Published by
Department of Water Affairs
Private Bag X313
Pretoria
0001
Republic of South Africa
Tel: (012) 336-7500

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Professional Service Provider:

ILISO CONSULTING
ENGINEERS PROJECT MANAGERS

203 Witch-Hazel Avenue
Highveld Technopark
0157

PO Box 68735
Highveld
0169

Tel: 0861 245 476
Fax: (012) 665 1886

WATER GEOSCIENCES CONSULTING

Pentagon House
Cnr Cliffendale & Plettenberg Road
Faerie Glen

PO Box 40161
Faerie Glen
0043

Tel: 083 290 7253
Fax: 086 6842 611

GROUNDWATERAFRICA

54 Irene Avenue
Somerset West
7130

54 Irene Avenue
Somerset West
7130

Tel: (021) 852 0847
Fax: 0866165146

WRNA

Unit 126 Phase 4
Midrand Business Park

PO Box 218
Midrand
1685

Tel: (011) 315 6791
Fax: (011) 312 2148

Artificial Groundwater Recharge: Recent initiatives in Southern Africa

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Contents

1 Introduction

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

Artificial recharge is 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:

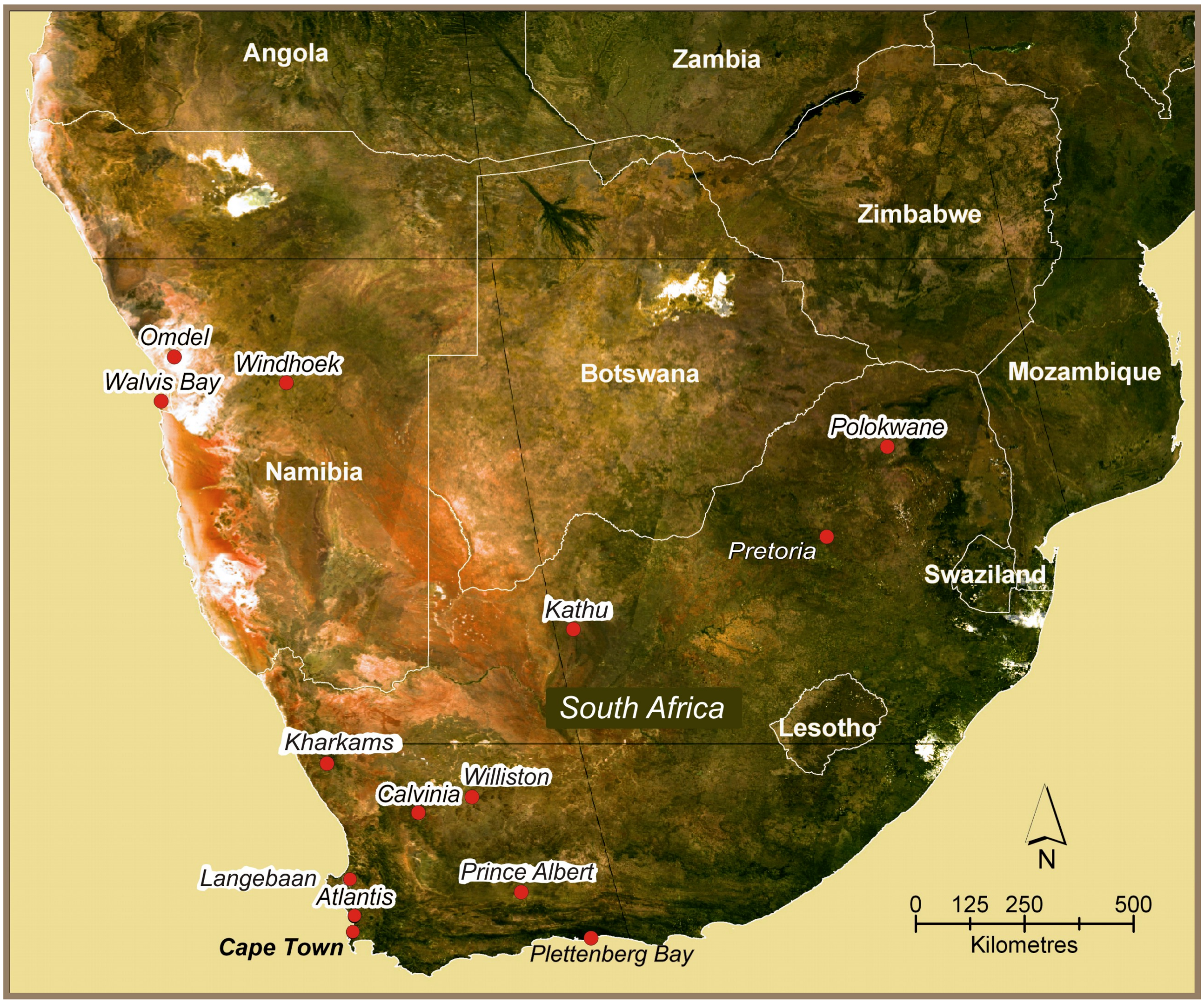
- artificial recharge is usually far cheaper than conventional surface water schemes;
- new surface water sources are often not available, or increasing supply from existing surface water sources is not an option, because local surface water resources are already stressed, and
- there is no possibility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

This booklet provides an overview of the status of artificial recharge in Southern Africa and lists resources that are easily accessible to anyone considering this water storage, treatment and conservation measure.

2 Benefits of Sub-surface

In Southern Africa, the main benefits of existing sub-surface storage schemes are:

- 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).



Location of existing and potential artificial recharge projects

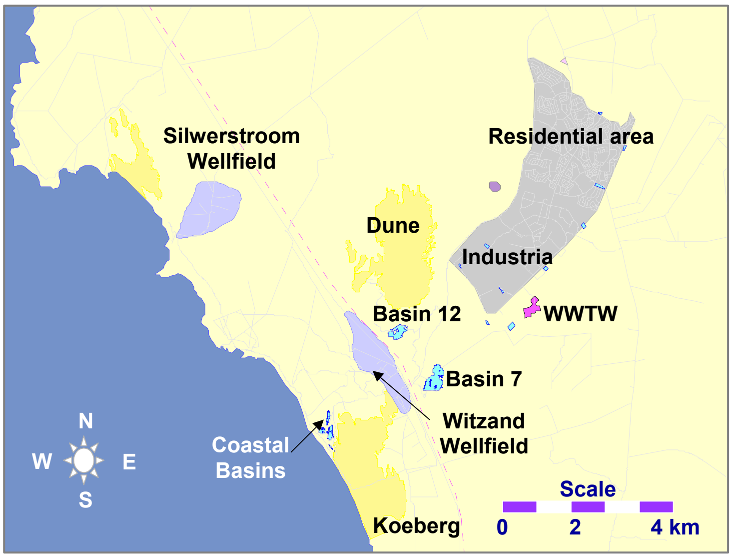
3 Existing Artificial Recharge Schemes

3.1 Atlantis: Storm and wastewater recharge of 7 500 m^3/day

The town of Atlantis, with a population in excess of 60 000, is 50 km north of the centre of the City of Cape Town on the dry west coast.

The Atlantis Water Resource Management Scheme has successfully recharged and recycled water for almost three decades. On average approximately 7 500 m^3/d of storm water and wastewater is currently recharged thereby augmenting the water supply by more than 2.7x10^6 m^3/a which means approximately 30% of Atlantis' groundwater supply is augmented through AR.

The relatively good quality, treated domestic waste water and storm water runoff is diverted into the main infiltration basins No's 7 and 12 up-gradient of the Witzand wellfield. Poorer quality, treated industrial waste water is diverted to the coastal basins. The aquifer is sandy with a saturated thickness of up to ~35 m. It is underlain by an impermeable layer of weathered shale.



Location of the main infiltration basins, 7 and 12, in relation to the Witzand wellfield

Atlantis Infiltration Basin 7

Sources of information:
DWA, 2009a
DWAF, 2007
Murray, 2004

3.2 Polokwane: Artificial recharge potential of 3-4 million m^3/a of treated waste water

Polokwane is largely dependent on surface water, however it also has an elaborate groundwater abstraction infrastructure that supplies domestic water to meet daily peak demands and also serves as a back-up during periods of surface water shortage.

The city has grown rapidly over the past decade and in 2007 had a estimated population in excess of 400 000 with water requirements of about 12 million m^3/a. Groundwater, which is fed by infiltrating treated waste water and natural runoff has been the saviour for the city in times of surface water shortages – especially during the 1992–1994 drought when groundwater supplied the bulk of the city's requirements.

The reliability of this source is largely due to the infiltration of treated municipal wastewater into the alluvial and gneissic aquifers. The water is used both by the municipality and by farmers for large-scale irrigation.

Polokwane's treated wastewater discharging into the Sand River

Source of information:
DWAF, 2007.
Murray, 2004.
Murray and Tredoux, 1998.

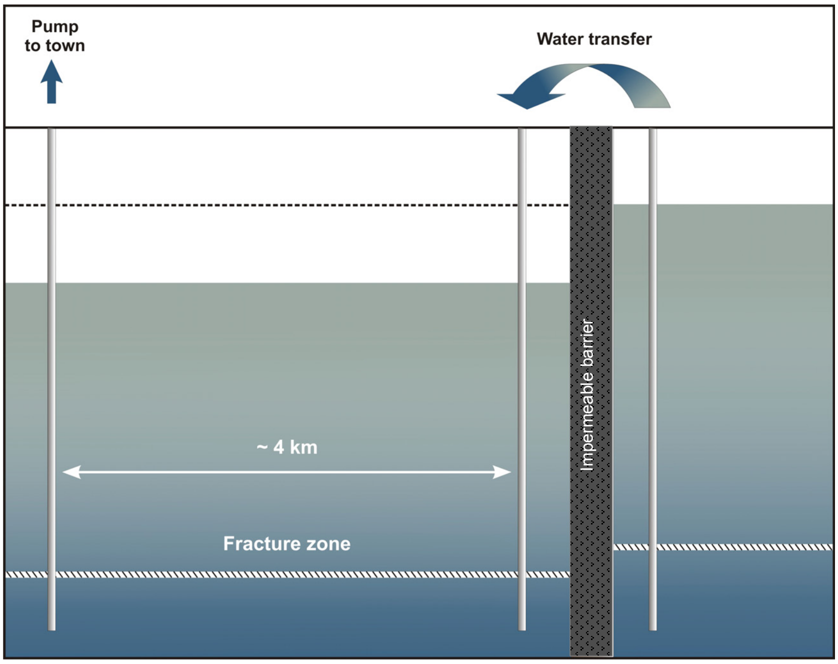
3.3 Williston: Doubling wellfield yield by transferring groundwater between aquifers

Williston, a small town in the western Karoo, relies on groundwater for its domestic supplies.

Abstraction over the years has been in excess of natural recharge and since intensive water level monitoring began in 1983, levels have steadily declined. 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. A groundwater transfer scheme has been constructed to pump water from the one compartment to the other.

The compartmentalising barrier is a narrow geological structure which allows the abstraction and injection boreholes to be located relatively close to one another (170 m apart), while the town's production boreholes are situated located 4 km away. This is possible because there is perfect hydraulic connection between the injection and production boreholes and no hydraulic connection across the two groundwater compartments. This is due to a horizontal fracture pattern which resulted from doleritic sill intrusions into Karoo sedimentary rocks. The compartmentalization, which is either a dyke or an impermeable fault, occurred after the horizontal fracturing and effectively divided the aquifer in half.

Water can now be transferred at 3 L/s or 260 m^3/day from the one compartment to the other and this doubles the yield of the town's wellfield.



Williston's groundwater transfer scheme

Sources of information:
Murray and Tredoux, 1998.
Mr Chris Esterhuyse, SRK Consulting Western Cape, personal communication.

3.4 Kharkams: Opportunistic artificial recharge triples borehole yield

Kharkams is a small village in the semi-arid Namaqualand region that depends solely on groundwater from a granitic aquifer.

The lowest yielding of the village's three production boreholes is artificially recharged whenever surface runoff is available. This has had the effect of tripling the borehole's yield and bringing the salinity of the water from virtually undrinkable (electrical conductivity of 300 mS/m) to good quality drinking water (<100 mS/m). The water used for artificial recharge is surface water runoff that would otherwise be lost to evaporation and evapotranspiration.

This scheme demonstrates the value of opportunistic artificial recharge in semi-arid areas, even if it is only practised on a small scale.

Unfortunately a lack of basic maintenance of the sand filter has resulted in the scheme not operating optimally over the past few seasons.

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

Sources of information:
DWAF, 2007.
Murray, 2004.
Murray and Tredoux, 1998.

3.5 Windhoek: Large-scale water banking

The Namibian capital Windhoek has a current water use of ~21 Mm^3/a most of which comes from three dams. The rest is sourced from a quartzite aquifer and reclaimed water (fully treated recycled water).

The city opted for artificial recharge over other options to increase their assurance of supply because it represented a significant cost saving. Surface water transfer from the Kavango River was estimated at R1.79 billion in comparison to the R242.5 million for the artificial recharge scheme with the same assurance of supply.

Artificial recharge in this case takes the form of water banking, whereby surface water is "banked" in the aquifer as security against droughts. This allows for the dams to be used at greater risk levels, as security lies in sub-surface storage where evaporation and aquifer losses are negligible. The overall aim of the scheme is for the aquifer 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.

In implementing the artificial recharge option Windhoek adopted a 4-phased approach.

Phases	Total injection capacity (million m^3/a)	Total abstraction capacity (million m^3/a)	Comment
Pre-artificial recharge ~50 abstraction boreholes	0	5.5	Natural recharge is ~1.7 Mm^3/a The boreholes can supply 5.5 Mm^3/a, but the aquifer would have to be rested for 3-4 years to replenish overdrawn storage if this volume was pumped in a single year.
Phase 1 Complete: 5 injection / abstraction boreholes	2.8	5.5	If 5.5 Mm^3 was pumped in a single year, the aquifer would have to be recharged (artificial and natural) for just over 1 year to replenish overdrawn storage.
Phase 2 Drilling completed in 2007. Boreholes still to be equipped. 4 additional injection / abstraction boreholes	8	11	If 11 Mm^3 was pumped in a single year, the aquifer would have to be recharged for just over 1 year to replenish overdrawn storage.
Phase 3 (2011) Drilling is complete: 6 additional abstraction boreholes	8	16.5	If 16.5 Mm^3 was pumped in a single year, the aquifer would have to be recharged for nearly 2 years to replenish overdrawn storage.
Phase 4 (2018) 4 – 8 additional abstraction boreholes	8	19	If 19 Mm^3 was pumped in a single year, the aquifer would have to be recharged for ~2 years to replenish overdrawn storage.

Borehole injection currently takes place in the five Phase 1 boreholes. The Phase 2 boreholes are being designed for injection and abstraction. These boreholes are on average 349 m deep (more than 150 m deeper than most older boreholes). The deeper drilling and interception of the water strikes at greater depths allows for a greater thickness of the aquifer to be used for storage.

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

Sources of information:
Central Areas JV Consultants, 2004.
DWAF, 2007.
Murray, 2002.
Murray and Tredoux, 1998.
Murray and Tredoux, 2002.

3.6 Omdel: Desert floods captured and stored underground

The artificial recharge scheme in the Omaruru River Delta (Omdel) in Namibia consists of the Omdel Dam and a series of infiltration basins in the riverbed 6 km down-stream.

Over 50% of desert flood waters have been recharged in this opportunistic infiltration scheme.

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. The aquifer provides water to the coastal towns of Walvis Bay, Swakopmund and Henties Bay, and a large open pit mine at Rössing.

In the two flood events since the scheme was constructed, over 9 Mm^3 of the flood water that was captured in the dam infiltrated the aquifer via seepage from the dam and basin recharge.

Omdel infiltration basin

Sources of information:
DWAF, 2007
Murray, 2004

4 Artificial Recharge Assessments

4.1 Langebaan Road Aquifer borehole injection test

The Saldanha Bay area is a fast growing industrial, business and holiday node in the Western Cape. Its water sources are the Berg River and the Langebaan Road aquifer.

The intention of this potential scheme is to transfer water from the Berg River during winter when surplus surface water is available, and when the water demand is low, into the Langebaan Road Aquifer.

The West Coast District Municipality with assistance from the CSIR conducted borehole injection tests on this sandy confined aquifer. In 2008 the first long-term test was completed after about 76 000 m^3 of treated surface water was injected at a rate of about 15 L/s into one borehole. Water levels and quality were monitored in a number of surrounding boreholes, as well as the fate of certain microorganisms.

The scheme is currently under consideration.

Injection borehole for pilot tests

Sources of information:
DWAF, 2007.
CSIR, 2009.

4.2 Prince Albert: Assessing the potential to top-up the aquifer before summer

The water demand in Prince Albert in the Karoo increases threefold over the summer months from about 1 000 to 3 000 m^3/day.

A small portion of the town's water comes from a furrow that is fed with excellent quality mountain runoff, and this is shared with local residents and farmers, the rest comes from boreholes in a sandstone aquifer which are all used to capacity to bridge the summer months.

Once a year the furrow is not used while its being cleaned, and this allows for water to be diverted into the aquifer. If the full flow of the furrow could be recharged during this period, it would amount to 120 000 m^3 which is equivalent to six weeks of the summer requirements and would provide a welcome water security system for the town.

Borehole injection tests are planned for 2010.

Planned Prince Albert injection borehole and source water (diverted runoff from the mountains)

Sources of information :
Murray, 2007a.

4.3 Plettenberg Bay: Large-scale storage potential

Every summer the holiday town of Plettenberg Bay 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.

The bulk of the supply comes from the Keurbooms River but during summer months groundwater abstraction from the quartzite aquifer can be high and borehole water levels drop by tens of metres.

Artificial recharge would rapidly replenish the aquifer and store a back-up volume of treated surface water underground for use during summer. The source water is surplus winter surface water that will be treated prior to borehole injection.

An advantage of this option over off-channel storage dams is that treated water would be stored in the aquifer and would then only require simple disinfection prior to supply to consumers. Another advantage is that the treatment plant can run to capacity during winter (as this is when artificial recharge would take place) thereby making it unnecessary to increase the size of the treatment plant to cope with the summer demand surge.

The artificial recharge option is currently being considered together with other water supply options.

Measuring water levels in one of the boreholes considered for artificial recharge

Sources of information :
Murray, 2007b.

4.4 Calvinia: Potential water banking as a back-up emergency supply

The town of Calvinia in the western Karoo has the potential to store 100 000 m^3 as a back-up supply in a highly mineralised and permeable sub-surface compartment similar in shape to Kimberlite pipes. Treated surface water from the Karee dam can be transferred to this compartment for safe storage. The 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 would need to be blended with the dam water prior to consumption. For this reason the scheme has not been in operation. Similar water quality problems could result from storing fresh water in disused mines.

Calvinia's injection and abstraction borehole

Source of information :
Murray and Tredoux, 1998.
Murray and Tredoux, 2002.

4.5 Kathu : The potential for enhancing groundwater resources

Water levels in the wellfield area of the Kathu Aquifer in the Northern Cape have dropped by over 20 m in 27 years and there is a general decrease in water levels of about 0.7m/a. This trend could be stopped or reversed by injecting water in the areas where the water table is depressed and in areas up-gradient of this.

The only available water source is groundwater from Khumba Mine. Although much of this water is used in the mining operation, any surplus could be transferred to the Kathu Aquifer.

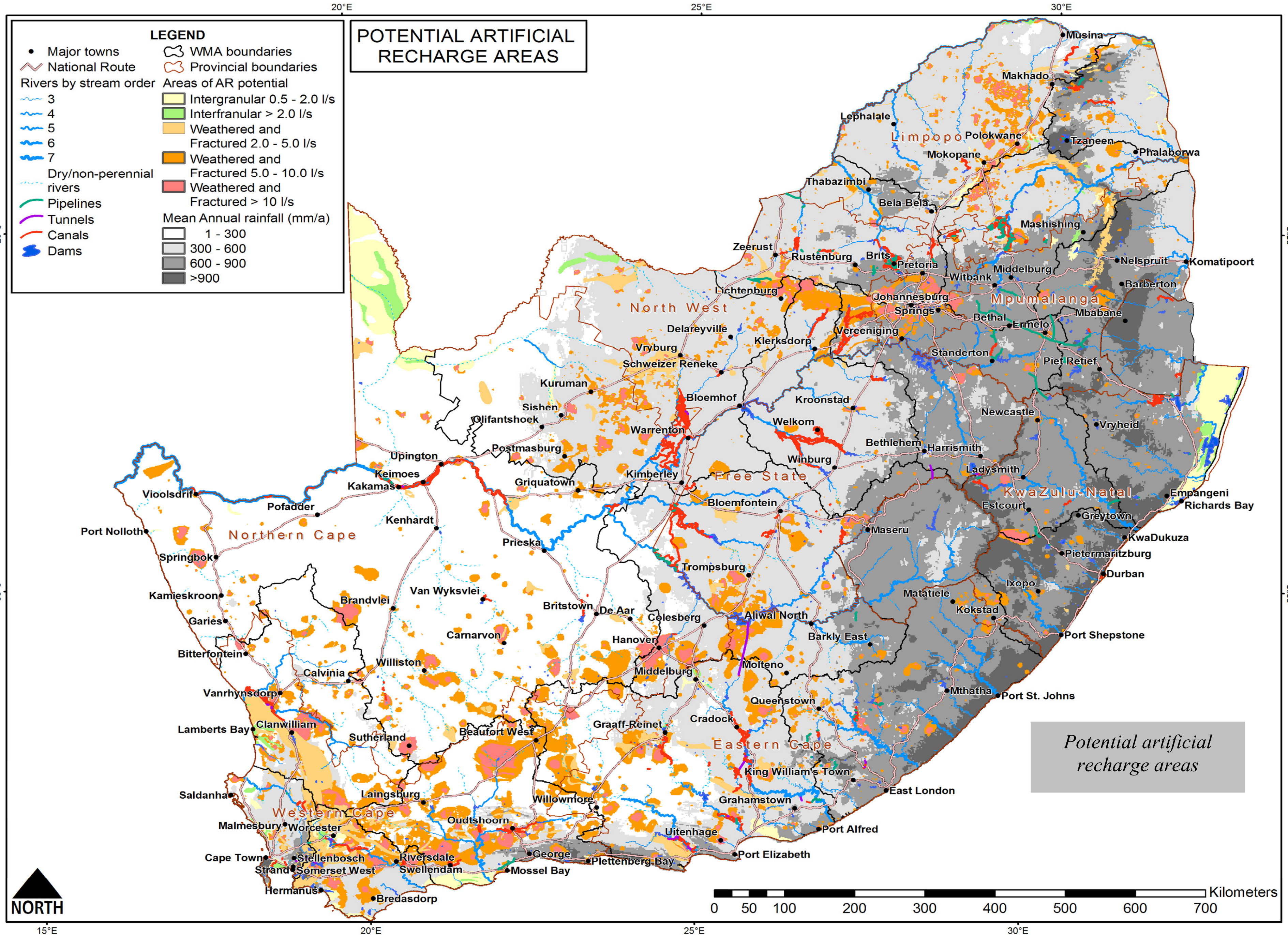
An artificial recharge pre-feasibility study has been undertaken for to Sishen Iron Ore Company (Pty) Ltd.

Sources of information :
Murray, 2006

5 Potential Artificial Recharge Areas

A nationwide assessment of potential artificial recharge areas was conducted as part of the roll-out of DWA's artificial recharge strategy. Favourable artificial recharge areas were identified as those areas which have known high aquifer permeability. See DWA (2009b) for detailed maps and a description of the methodology.

One of Kathu's production boreholes


POTENTIAL ARTIFICIAL RECHARGE AREAS
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
Limpopo
North West
Mpumalanga
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
Kilometers
0 50 100 200 300 400 500 600 700
NORTH
Potential artificial recharge areas

Potential artificial recharge areas maps have been made for each Water Management Area (WMA). These can be downloaded from the DWA artificial recharge website: www.artificialrecharge.co.za.

A detailed artificial recharge assessment of WMA 17 Olifants/Doorn was also conducted as an example of a WMA-level assessment and the accompanying maps can also be downloaded from the website.

6 Ideas For Potential AR Schemes

The following list gives some ideas for potential artificial recharge schemes. These are merely ideas to stimulate thought on possible AR applications.

In some cases there are no current water sources for recharging the aquifers and the potential for sub-surface storage may only be realisable once future canals or pipelines have been constructed (eg Kenhardt, Northern Cape).

Most of the best dam sites in South Africa have already been identified or built, so where will we store water in future? One option is in aquifers. This may require developing large-scale schemes that involve transferring water when available in the rainfall season to large-scale storage aquifers.

The list below consists of both small-scale localised options and schemes that would require large-scale sub-surface storage.

Vivo Dendron (Limpopo WMA): To replenish depressed water levels that have dropped by 80 m in places, farmers have built successful infiltration dams. Either the number of these needs to be increased or large-scale borehole injection is needed but there is no current water source for artificial recharge.

Lephalale/Ellisras (Limpopo WMA): To meet the need for water security for power stations, aquifers could possibly be used for large-scale storage.

Between the Klein & Groot Letaba Rivers (Luvubu & Letaba WMA): Groundwater usage is going to increase substantially due to growth in demand and poor surface water options. Artificial recharge could be built into water supply planning.

Springbok Flats – Settlers area (Olifants WMA): This heavily-pumped area is under stress - abstraction seems greater than recharge. It appears a very favourable area for borehole injection but there is no current water source. A long-term option would be to transfer surface water (where available in excess during the wet season or floods) to this area for large-scale sub-surface storage.

Pongola floodplain (Usutu to Mhlatuze WMA): This area is one of a few in South Africa where a sizeable alluvial aquifer could be used to maximise water storage. Intensive commercial agriculture only takes place over a small part of this area so the aquifer is under-utilised and full most of the time. Artificial recharge could be used to ensure the sustainability of large-scale groundwater abstraction if usage is to increase substantially in future.

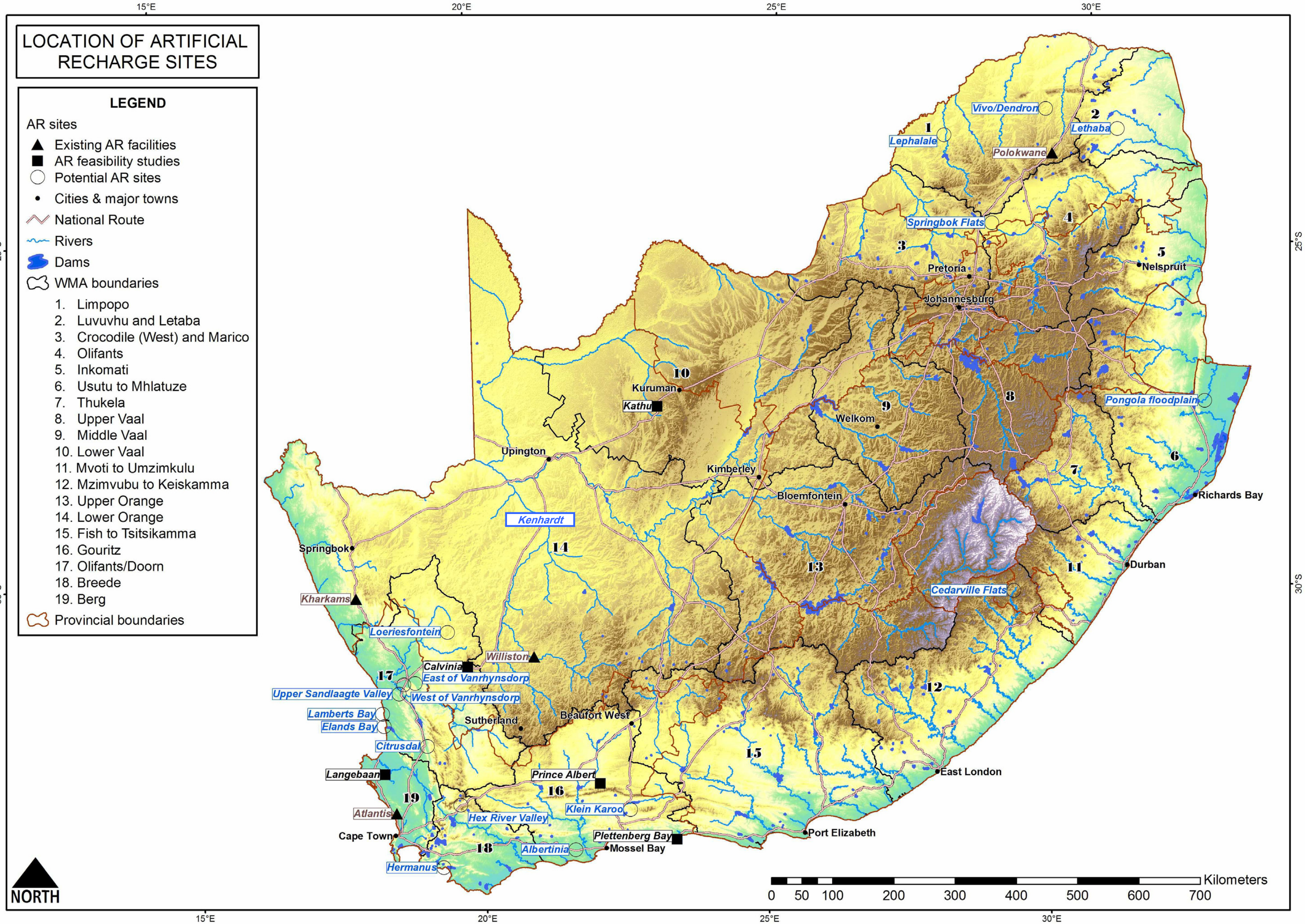
Cedarville Flats (Mzimvubu to Keiskamma WMA): This area forms one of the few deep alluvial basins in SA. Groundwater is being abstracted at significant rates by local farmers. The perennial Mzimvubu River flows through the area and could serve as a source for AR. There is potential to utilise the alluvial basin as a managed storage reservoir as opposed to the ad hoc pumping by farmers that currently takes place. Ultimately the aquifer's yield could be increased significantly with AR.

Kenhardt (Lower Orange WMA): Recently a water transfer from the Orange River was approved to supply the town of Kenhardt. Up until now it relied solely on groundwater. With Orange River water available it would be possible to store water in the aquifer to ensure it is full before summer.

Vanrhynsdorp (Olifants/Doorn WMA): Water levels have declined with high abstraction by farmers from the dolomitic marble aquifer. Runoff during high rainfall years in the catchment is a source option but this would be very irregular. A more reliable source would be surplus Doring River water the bulk of which, during winter, flows out to the sea. The scheme would require the costly transfer of water across a catchment divide but the potential storage volume could be huge.

Lamberts Bay (Olifants/Doorn WMA): The potential exits for large-scale storage in very thick sandy aquifers however the availability of suitable source water is severely limited. Options include: the Olifants River, sea water desalination and groundwater from the Table Mountain Group Aquifer. All these options would be costly. The benefit of artificial recharge in this case is that it can provide storage close to where the water is needed and fulfil a balancing function between winter and summer demands for any of the sources that may be developed.

Hermanus (Breede WMA): The plan requires diverting rain water from hard surfaces to infiltration basins and trenches wherever and whenever possible. This would increase recharge during the wet winter and would also extend the recharge period by capturing runoff from dry season rain events. For the municipality the main hard surfaces are roads and parking lots and the storm water from these surfaces would be captured in "leaky" storm water channels or, where possible, diverted to infiltration basins. For individual households the hard surfaces are roofs, driveways and paved areas and recharge can be achieved on a micro scale by discharging gutters into infiltration pits filled with crushed stone and diverting water from paved areas into vegetated infiltration areas.



Existing artificial recharge schemes and possible areas for artificial recharge assessments

7 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 impact 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, any artificial recharge scheme, 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.

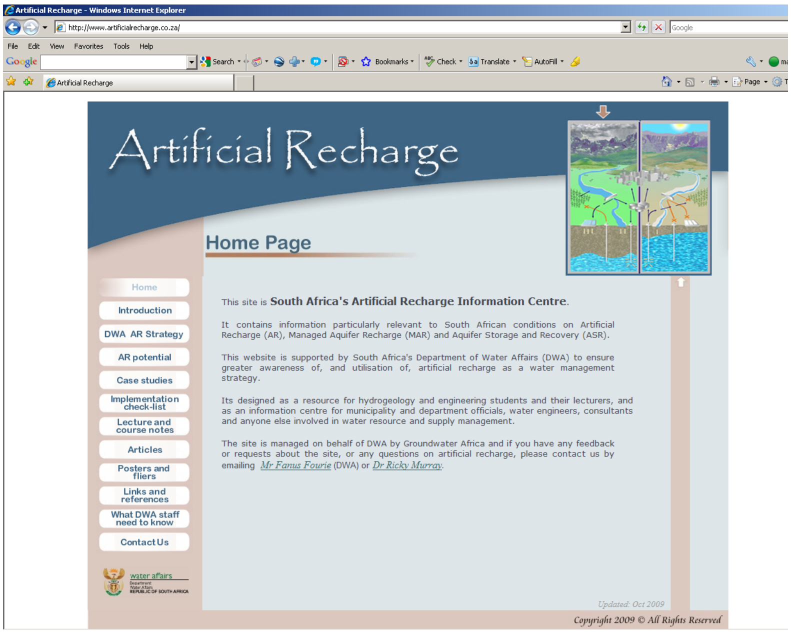
The department's Artificial Recharge Strategy (DWAF, 2007) outlines the ten key success criteria for artificial recharge.

1. **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?
2. **The source water:** What volume of water is available for recharge, and when is it available?
3. **Aquifer hydraulics:** Will the aquifer receive the water?
4. **Water quality:** Is the quality of the source water suitable for artificial recharge?
5. **The artificial recharge method and engineering issues:** How will the water be transferred into the aquifer?
6. **Environmental issues:** What are the potential environmental benefits, risks and constraints?
7. **Legal and regulatory issues:** What type of authorisation is required?
8. **Economics:** How much will the scheme cost, and what will the cost of supplied water per m^3 be?
9. **Management and technical capacity:** Are there the skills needed to operate the scheme?
10. **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?

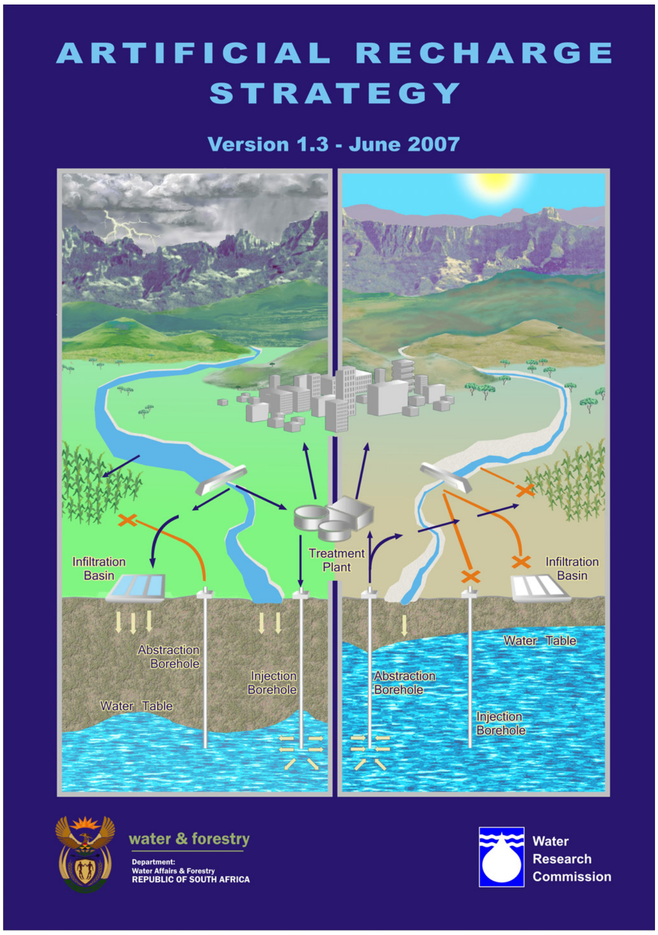
More information about these criteria, the key questions for each project stage and a detailed check-list for implementing successful artificial recharge projects are available in DWAF (2007) and DWA (2009c). See the Resource list below.

8 South African Artificial Recharge Resources

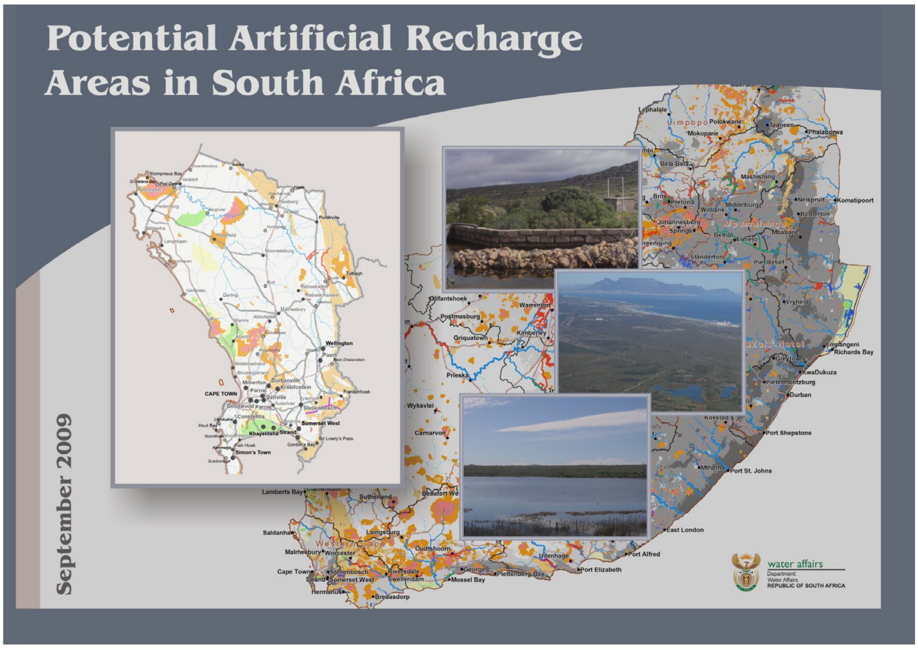
DWA's artificial recharge website
www.artificialrecharge.co.za: This website contains all the resources listed below, links to other relevant websites and more information on artificial recharge. All new resources developed under DWA's roll-out of the artificial recharge strategy have been posted on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

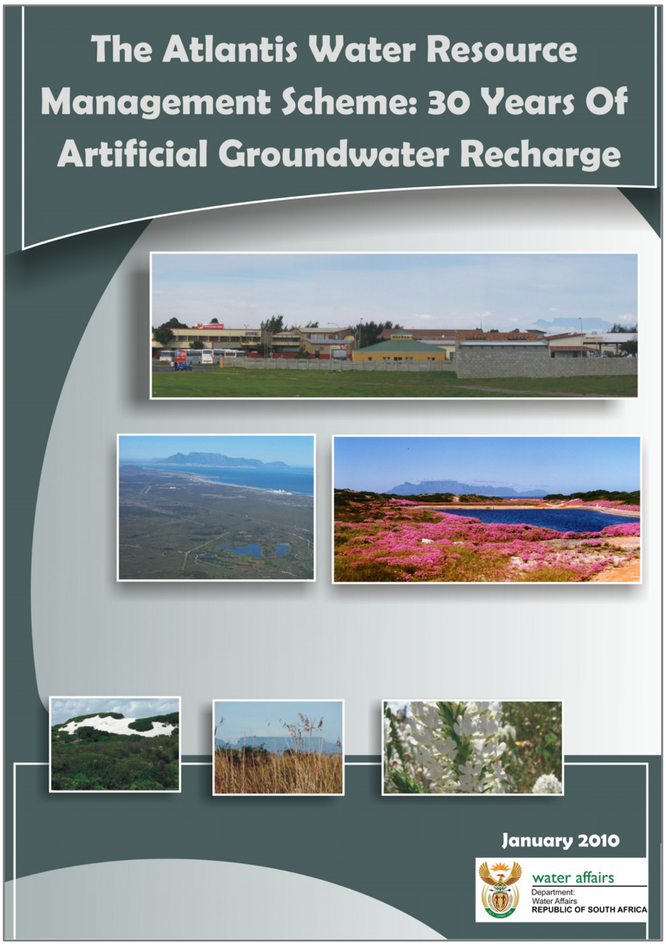


Potential Artificial Recharge Areas in South Africa *(DWA, 2009b): This report identifies potential recharge areas, identifies a number of places where artificial recharge should be considered, describes conceptual plans for artificial recharge at a few sites, and gives an artificial recharge assessment 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 WMA-scale studies.*

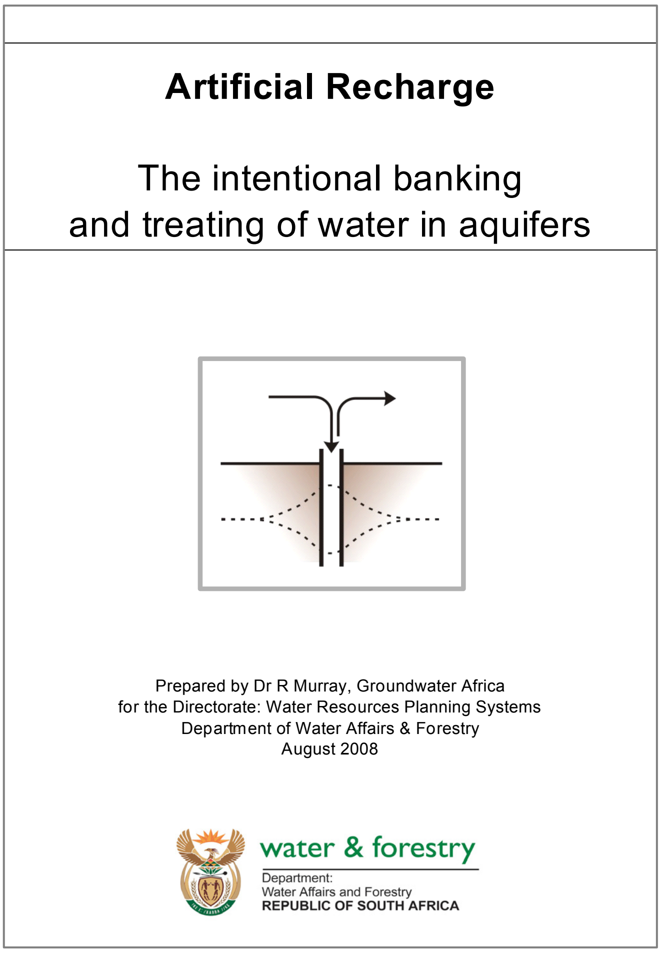


A check-list for implementing successful artificial recharge projects *(DWA, 2009c): This brief report covers: Artificial recharge project stages; the Pre-feasibility study check list; and the Feasibility study check list.*

The Atlantis Water Resource Management Scheme *(DWA, 2009a): This report describes the history, planning, implementation and operation of the Atlantis scheme which has been in operation for nearly 30 years. Linked to this is a field trip guide and a lecture on the scheme.*



Artificial Recharge lecture and lecture notes: *A lecture with lecture notes has been prepared for academic institutions. The lecture covers all key points on artificial recharge.*



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- Sishen Iron Ore Company (Pty) Ltd.

All photographs by R Murray except for Omdel which was taken by G Tredoux.

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