Potential Artificial Recharge Areas in South Africa

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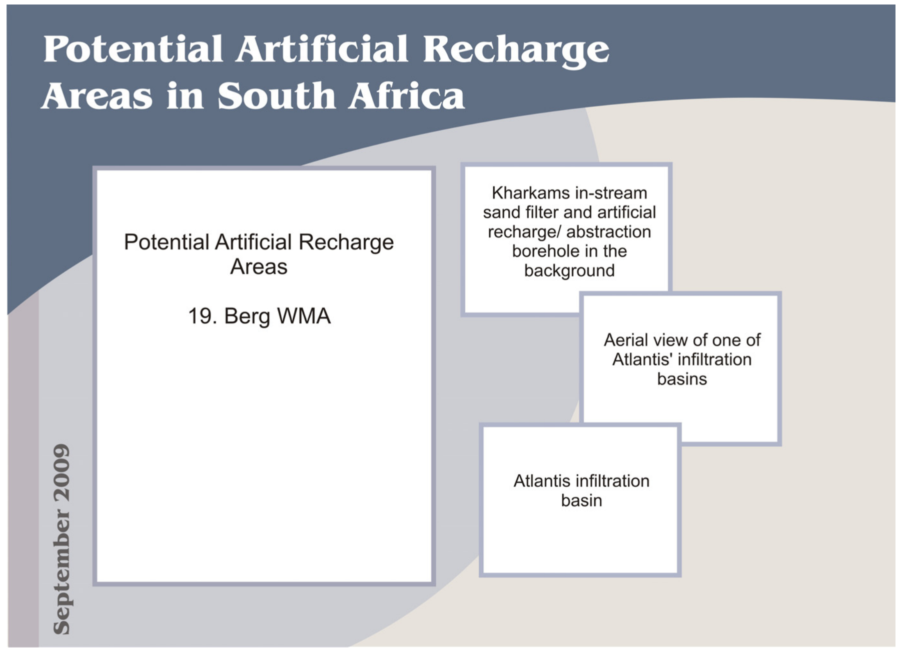

Figures

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This report can be downloaded from

www.artificialrecharge.co.za or www.dwa.gov.za/groundwater

1. Introduction

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.

The Artificial Recharge Strategy of the Department of Water Affairs (DWA) (DWAF, 2007), lists seven areas or themes that need to be addressed in order to make artificial recharge "accessible". The overall aim is to implement artificial recharge schemes wherever it is technologically, economically, environmentally and socially feasible. One of the seven themes is the Planning Theme.

To date, maximising sub-surface storage through artificial recharge has not been considered by water sector planners. 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).

The Artificial Recharge Strategy (DWAF, 2007), identified two key areas in the Planning sphere that needed attention:

i) To incorporate artificial recharge in key planning documents such as the National Water Resource Strategy
ii) To identify areas where artificial recharge could help solve the water resource problems

This report deals with the second item, and aims to provide those involved with water resource and supply planning with ideas on how artificial recharge could help solve a water supply problem. It also gives examples of how artificial recharge can be used to reverse the environmental effects of historical large-scale groundwater abstraction.

This report's main aim is to feed planners with ideas and concepts on how subsurface storage can be used as an alternative way to solve particular water resource problems. It is broken into two main sections:

i) A broad assessment of areas where artificial recharge may be feasible. This is divided into:
    a. National Study
    b. A Water Management Area Study

    A GIS approach was taken for both the National and WMA studies, and they build on the GIS assessment that is presented in the Artificial Recharge Strategy (DWAF, 2007). In the WMA study, more data sets were used and local knowledge was taken into account. One WMA was selected, WMA 17, Olifants/Doorn, and the main intention of this study is to serve as a guide for WMA-scale studies in other areas.

ii) A list of possible areas where artificial recharge may be able to help sort out water resource problems. This consists of both summary and more detailed descriptions of conceptual artificial recharge plans. These areas are either "problem" areas or "opportunities" that were identified by a number people in the water sector, and in particular DWA staff.

2. Key criteria for identifying artificial recharge areas

The two key factors in identifying potential artificial recharge areas are:

i) Can the aquifer accept artificially recharged water?
ii) Is there a water source available for recharging the aquifer?

Can the aquifer accept artificially recharged water?

The two key questions are:

i) Is there space in the aquifer?
ii) Can the water get in there rapidly enough?

Is there space?

Regarding the space issue, if groundwater levels have been lowered in and around a wellfield or over the aquifer as a whole, or if the groundwater levels are generally dropping after years of abstraction, then the aquifer has space to be refilled. Good examples of this are the Dendron area in the Limpopo Province where groundwater levels have dropped by tens of metres over large areas as a result of abstraction that is in excess of natural recharge, and in Windhoek, Namibia, which is in a similar situation to that of Dendron, but the City of Windhoek chose to implement large-scale artificial recharge to replenish the aquifer and to fully utilise the aquifer's storage in conjunction with their surface water storage dams. Atlantis, near Cape Town, is another example, however, in this case water levels have not dropped tens of meters, but rather, the aquifer is used continually, and at the same time, it is continually recharged with treated waste water. The continual abstraction from the aquifer results in a permanent depressed water level which is fed from the infiltration basins nearby. This way the sustainable yield of the aquifer is increased by the rate of artificial recharge.

In aquifers that are under pressure because they are confined by an overlying impermeable horizon, it is also possible to store artificially recharge water in them. This is done in a number of places throughout the world, and on very large scales in the USA. In the USA it is usually done in saline aquifers where the recharged fresh water displaces the saline water thereby creating massive "bubbles" of fresh water within the greater saline aquifer. Instead of "filling up" the aquifer as would be the case in unconfined aquifers, which are most common in South Africa, water would be injected under pressure into the confined aquifer. Later, when water is required, it is abstracted from the same place that it was recharged.

Will the water go in?

Regarding the issue of whether water can get into the aquifer rapidly enough, this depends on the permeability of the aquifer. Where artificial recharge is done by means of borehole injection, exiting borehole's abstraction rates provide a good indication of the injection potential as they will be roughly similar. This means that all areas that have high borehole yields are potential artificial recharge areas. It does not mean that areas with low borehole yields are not artificial recharge areas. The injection borehole at Kharkams, in the Northern Cape, for example has an injection capacity of less than 1 l/s, but because the demand is also low, artificial recharge at this rate is hugely beneficial.

In unconfined sandy aquifers it is usually best to opt for infiltration basins. Because their surface area is very large (in comparison to an injection borehole), the permeability of the sand does not necessarily have to be very high, although the higher the better. This means that all areas with reasonably permeable (and highly permeable) sandy aquifers are potential artificial recharge areas. Atlantis is a good example of this; likewise, Polokwane, where treated waste water is discharged into a normally dry sandy river bed which in turn recharges the alluvial aquifer, which then recharges the hard-rock aquifer below. Deep boreholes drilled into the underlying hard-rock aquifer are used to abstract both the natural groundwater and the recharged water.

Other factors that could initiate an artificial recharge assessment are:

i) Is there surplus water at any time of the year that cannot be stored locally in dams? Are there areas where water is being lost to the sea?
ii) Is water for recharge available during or after the high groundwater abstraction period (when levels would be down)?
iii) Are there artificial recharge opportunities that present themselves because of favourable geology?
iv) Are there areas where water from dams could be transferred to aquifers so that dam water levels can be kept down to receive flood water? Prime sites for this are areas where rainfall variability and flooding is expected to increase with climate change.

Is there surplus water, and is the timing of water availability and depressed groundwater levels right?

Aquifers are usually naturally replenished during the rainfall season and therefore when surplus water is available or recharge, there is no space in the aquifer to accept it. It is possible to create the space by heavily abstracting groundwater prior to the rainfall season, however, this is only an option in areas with reliable rainfall. There are areas, however, where aquifers are not necessarily full and where there is surplus surface water. The best example is the central and eastern course of the Orange River. In these semi-arid areas aquifers can easily be over-pumped because natural recharge is low. Water from the perennial Orange River could be used to replenish these aquifers either on a regular basis, or during periods when the upstream dam releases are high – usually towards the end of the rainy season when the dams are full, or during floods.

Thus a suitable artificial recharge area can be an area where the timing of both the aquifer space and available water is right. A suitable artificial recharge area may be an area where surplus surface water flows past or nearby an aquifer located in a different climatic zone, such as the Orange River example above, or the aquifer and the source water may be in adjacent catchments, and the source water would have to be transferred to the aquifer's catchment for recharge purposes. A good example of this latter case is the agricultural area around Vanrhynsdorp in the semi-arid north western part of the Western Cape Province. The irrigation potential for this area is limited by the groundwater resources from a dolomitic aquifer. In the adjacent catchment, the underutilised Doring River could be used as a source for artificial recharge. This river draws its water from a relatively high rainfall area in the Cedarberg, is not dammed and has a reliable winter runoff.

A perennial source of municipal water is treated waste water. Increasingly, this water is being recycled in some form or another – usually for irrigation of golf courses, municipal gardens, etc. However, if the conditions are suitable, this water can be used for artificial recharge. If the intended use is for domestic supply, such as at Atlantis, then the water needs to be treated to compliance standards and recharged in a sandy aquifer where the travel time to the boreholes is sufficient to allow for acceptable die-out of harmful micro-organisms.

Suitable geological environments

Deep sandy aquifers such as those found in the Sandveld along the west coast of the Western Cape Province and in the Cedarville Flats near Matatiele in Kwa-Zulu Natal are potentially major sub-surface storage areas – purely because of the huge volume of water that can be stored in these thick, extensive sandy aquifers. Karst areas with high storage and permeability characteristics are favourable for subsurface storage, however, the potential for sink hole formation in some of these areas would limit this as groundwater levels cannot be drawn down deeply. Faults and other zones of high hydraulic conductivity can be localised targets for artificial recharge. The perfect scenario would have a sand dam built over a highly permeable fault that crosses a sandy river bed. These type of environments are not uncommon over the extensive Table Mountain Group Aquifer where faulting causes brittle fracturing with high perm abilities and the quartzitic geology results in sandy river beds.

Creating space for artificial recharge

If an aquifer is suitable for artificial recharge and there is a suitable source water but the timing of source water availability is not right, it may be possible to create space in the aquifer for artificial recharge at the "right" time. This would only be worthwhile if surface water is often lost from the area due to limited dam storage capacity. The aquifer would then be turned into "extra storage capacity" by lowering the water table far more than usual, knowing that it will be rapidly replenished when "lost" surface water is available for recharge. Like previous examples, the aquifer would effectively supply its sustainable yield plus the artificial recharge yield.

A comprehensive description of artificial recharge "success criteria" is provided in the Artificial Recharge Strategy (DWAF, 2007). The ten "success criteria" are:

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

Focus in this section has been given to the two most important criteria:

i) The source water
ii) Aquifer hydraulics, or the ability of the aquifer to receive artificially recharged water.

3. GIS assessment of potential artificial recharge areas

3.1 National level assessment of potential artificial recharge areas

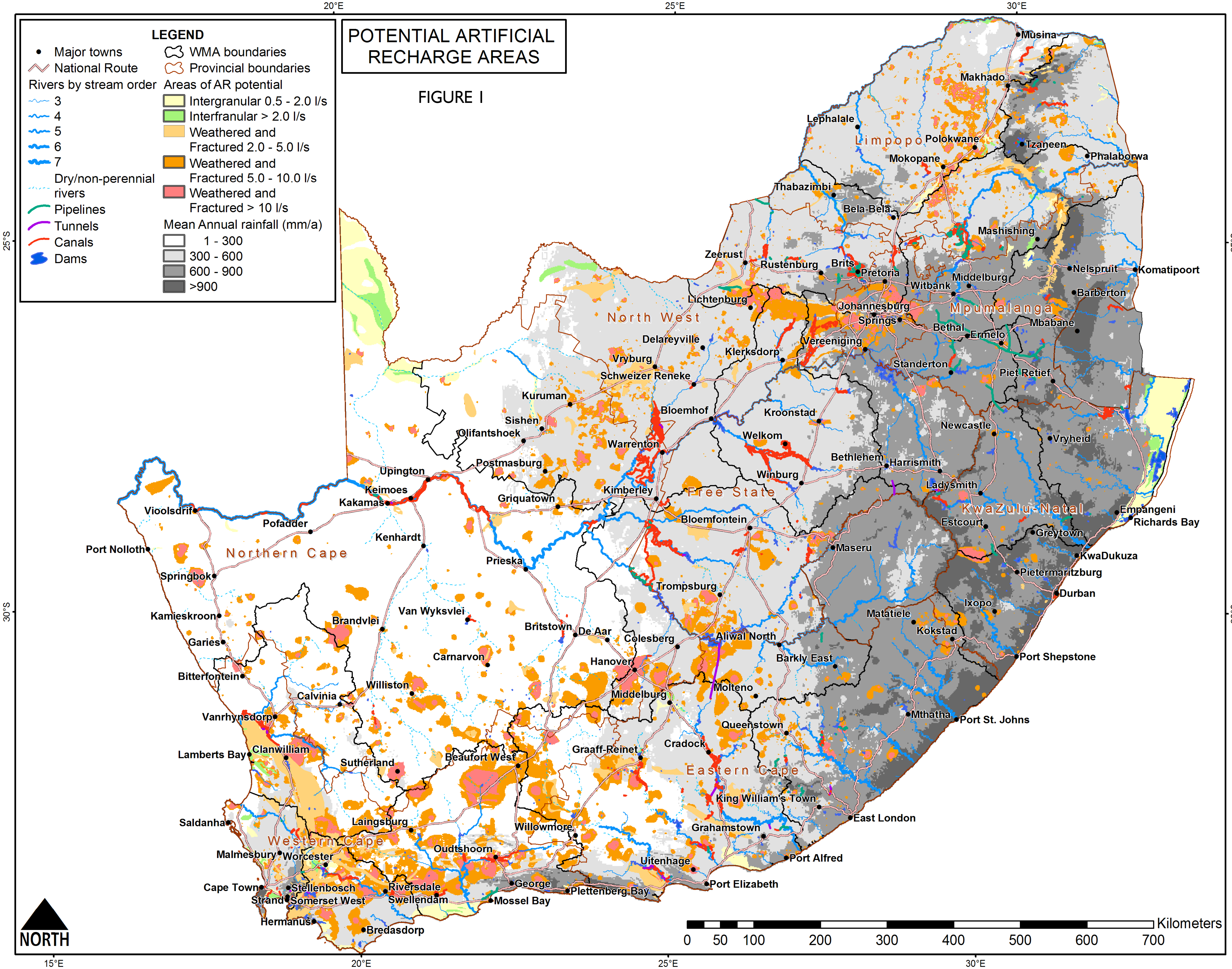
The feasibility of successful artificial recharge implementation depends on numerous factors that are relevant at a local level (see Chapter 2). In this chapter potential artificial recharge areas have been mapped on a national scale by identifying aquifers that could receive recharge water based on an indicator of aquifer permeability. This study upgrades the similar assessment that was conducted for the Artificial Recharge Strategy (DWAF, 2007). In the Artificial Recharge Strategy, potential aquifer storage volumes were also estimated and presented per sub-WMA. The results presented below provide an updated, rough indication of suitable artificial recharge areas on a regional scale based on areas of high permeability. These include the following:

- **Primary aquifers.** Primarily alluvium, coastal aquifers and localised riverbed alluvium, also referred to as Sandy Aquifers. 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.** Hard rock aquifers with yields of more that 2 l/s have been identified from the 1:500 000 hydrogeological maps. The identified areas have been combined with processed borehole yields from the National Groundwater Data Base (NGDB). Two criteria were applied to the borehole yields from the NGDB: 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 NGDB has been used to identify the areas of highest borehole yield. The data from the NGDB have been superimposed on the selected Fractured and Weathered sections from the 1:500 000 hydrogeological maps to identify the prime artificial recharge areas. Artificial recharge by means of borehole injection may be appropriate in such areas.

The areas of artificial recharge potential based on the above criteria for aquifer suitability is presented in **Figure 1**, and examples of these areas where there may be a source of surface water from dams, rivers and canals are shown in **Figure 2**. In these examples, the challenge would be to maximise the use of sub-surface storage by heavily abstracting groundwater during the dry season, thereby creating the space to recharge and store surplus surface water in the aquifer during the wet season. The key issues to consider are the availability of surface water (which may only be in flood events), and the timing and extent of aquifer abstraction and replenishment.

Appendix 1 presents the areas of artificial recharge potential for each WMA. Additional information such as major pipelines canals and tunnels have been included in these where this information was available.


POTENTIAL ARTIFICIAL RECHARGE AREAS
FIGURE I
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
Mpumalanga
North West
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
Musina
Makhado
Lephalale
Polokwane
Tzaneen
Phalaborwa
Mokopane
Thabazimbi
Bela-Bela
Mashishing
Zeerust
Rustenburg
Brits
Pretoria
Nelspruit
Komatipoort
Middelburg
Witbank
Barberton
Lichtenburg
Johannesburg
Springs
Mbabane
Bethal
Ermelo
Delareyville
Vereeniging
Klerksdorp
Standerton
Vryburg
Piet Retief
Schweizer Reneke
Kuruman
Bloemhof
Kroonstad
Sishen
Newcastle
Olifantshoek
Welkom
Vryheid
Warrenton
Bethlehem
Harrismith
Postmasburg
Upington
Winburg
Keimoes
Ladysmith
Kimberley
Kakamas
Griquatown
Empangeni
Richards Bay
Estcourt
Vioolsdrif
Bloemfontein
Pofadder
Greytown
Kenhardt
Maseru
Port Nolloth
KwaDukuza
Prieska
Pietermaritzburg
Springbok
Trompsburg
Durban
Ixopo
Van Wyksvlei
Kamieskroon
Matatiele
Brandvlei
Britstown
De Aar
Kokstad
Colesberg
Aliwal North
Garies
Carnarvon
Barkly East
Port Shepstone
Hanover
Bitterfontein
Williston
Molteno
Middelburg
Calvinia
Mthatha
Port St. Johns
Vanrhynsdorp
Queenstown
Cradock
Clanwilliam
Graaff-Reinet
Lamberts Bay
Sutherland
Beaufort West
King William's Town
East London
Saldanha
Laingsburg
Willowmore
Grahamstown
Malmesbury
Worcester
Oudtshoorn
Port Alfred
Uitenhage
Cape Town
Stellenbosch
Riversdale
George
Plettenberg Bay
Port Elizabeth
Strand
Somerset West
Swellendam
Mossel Bay
Hermanus
Bredasdorp
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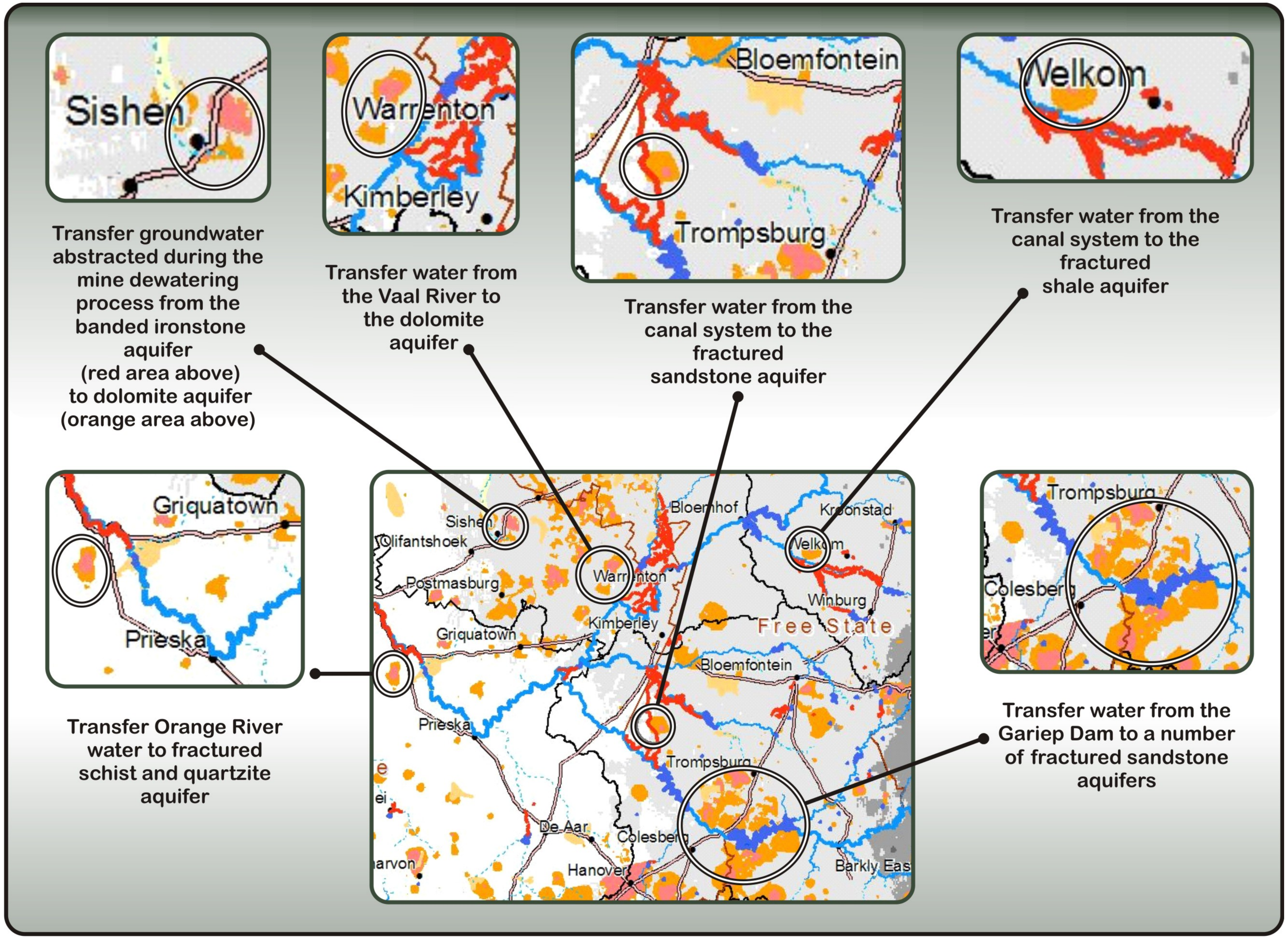


FIGURE 2 Examples of areas where aquifer conditions appear favourable for artificial recharge

3.2 WMA-scale assessment of potential artificial recharge areas: The Olifants/Doorn WMA

The approach described below includes a process of identifying aquifers that may be suitable for artificial recharge. The key factor is identifying aquifers that are sufficiently permeable to receive artificially recharged water. The approach taken is described in four steps below, and combines GIS data sets with local knowledge.

Step 1: Compile data sets

The baseline data sets are:

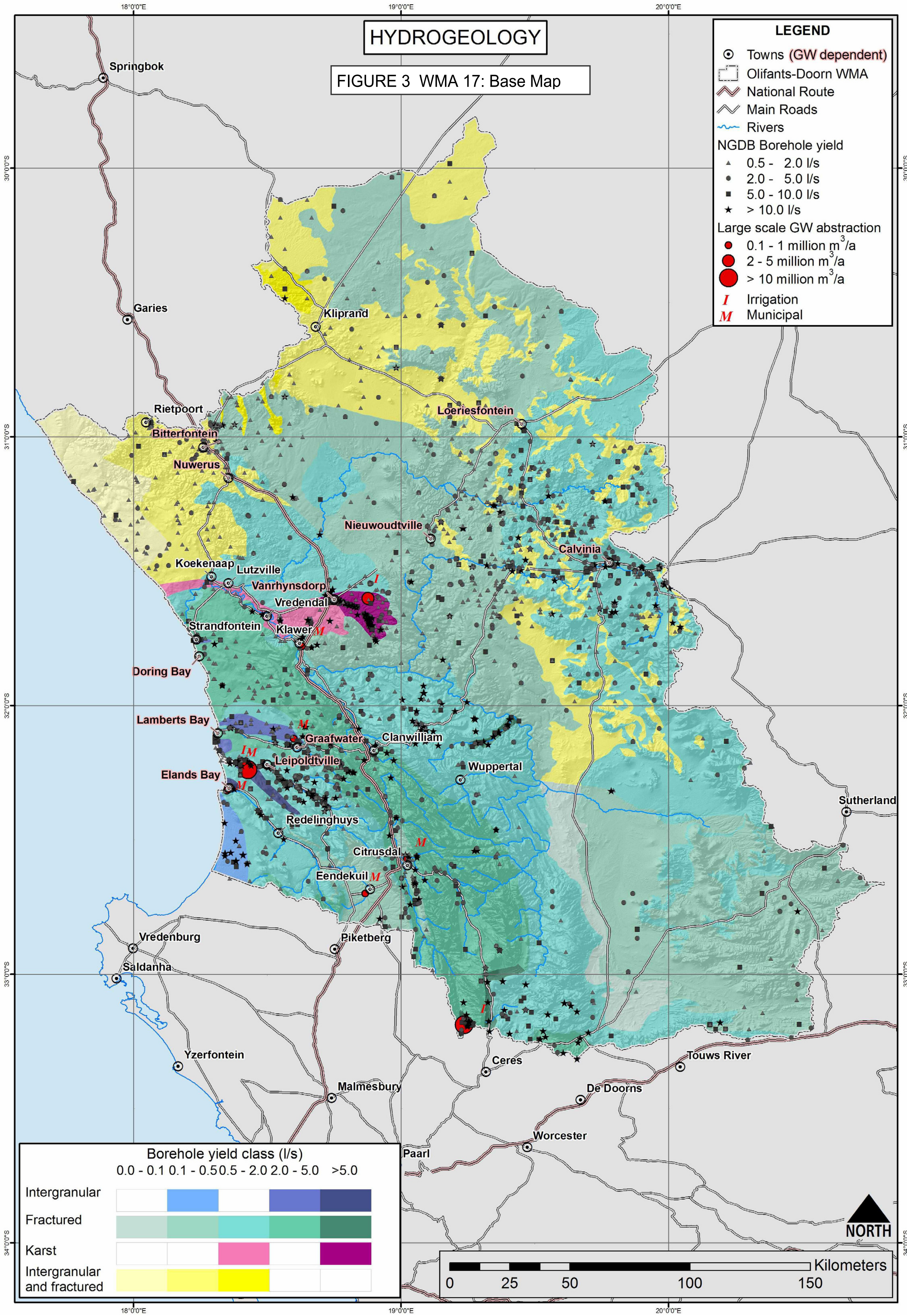
- Hydrogeological maps - 1:500 000
- Geological maps: 1:1000 000; 1:250 000; 1:50 000
- Topographical maps: 1: 50 000
- National Groundwater Data Base (NGDB)
- Bulk water supply infrastructure
- Settlements, roads, rivers
- Hillshade (derived from Shuttle Radar Topography Mission (SRTM) elevation data supplied by DWA)
- In other WMAs, data from DWA's GRIP (groundwater information) and other data sets may be of value.

Step 2: Develop the base map (Figure 3)

The key information contained in the base map is the following:

- Hydrogeological maps. 1:500 000 showing hydrogeological environments (intergranular, fractured, karst, and intergranular and fractured), and classed according to borehole yield
- NGDB boreholes showing yield, classed as follows:
  - 0.5 – 2 l/s
  - 2 – 5 l/s
  - 5 – 10 l/s
  - >10 l/s
- High groundwater use areas from the 1:500 000 Hydrogeological maps
- Towns, roads and rivers

The base map is shown in **Figure 3**.



Step 3: Identify favourable geological environments (Figures 4 & 5)

Hard rock areas, where borehole injection is usually the most appropriate artificial recharge method, typically require relatively high yielding boreholes to get the water into the aquifer, and for this reason, they have been separated out from sandy, primary aquifers where infiltration basins are usually more appropriate. The respective maps contain the following:

Hard-rock aquifers (Figure 4)

Local knowledge of the area together with borehole yield data show that there are three favourable fractured and weathered rock types:

- Table Mountain Group sandstones
- Vanrhynsdorp Group dolomitic marble rocks (karst)
- Karoo dolerites

These three rock types together with borehole yields and water quality were used to produce the next map. In order to screen out the alluvium boreholes, those with depths greater than 30 m were selected since virtually all hard-rock boreholes are greater than this depth. The next map contains the following:

- Areas from the 1:500 000 Hydrogeological maps with the following classes:
    - Fractured > 5 l/s
    - Karst 0.5 – 2 l/s
    - Karst >5 l/s
    - Intergranular and fractured 2 – 5 l/s and >5 l/s would have been selected if there were any such areas in this WMA
- Areas with outcropping TMG sandstones, Vanrhynsdorp dolomites and Karoo dolerites (excluding dykes, as they are too localised for WMA-scale representation)
- Faults from the 1:500 000 Hydrogeological maps. If major dykes were prominent in this WMA, they would have been included.
- Boreholes with depths greater than 30 m classes as follows:
    - 5 – 10 l/s
    - >10 l/s
    - Borehole water quality, if available, classed as follows:
    - 0 – 150 mS/m
    - 150 – 370 mS/m
    - 370 – 520 mS/m
    - >520 mS/m
- Towns, roads and rivers
- For similar studies conducted on other WMA's, additional coverages appropriate to the specific WMA may be identified from scrutinising the hydrogeological, geological and topographical maps. Favourable areas such as dolerite ring structures, breccia pipes and other structures may be mapped or evident from the available maps. These have been left out of this study.

The favourable hard-rock aquifers map is shown in **Figure 4**.

Sandy aquifers or Intergranular/alluvial aquifers (Figure 5)

Sandy aquifers are usually most favourable for artificial recharge because infiltration basins, which are relatively low maintenance, can be used, and because the quality of the source water does not have to be as good as that for borehole injection schemes. For information on artificial recharge methods and on source water quality refer to the Artificial Recharge Strategy (DWAF, 2007).

The Sandy Aquifer map contains the following:

- Areas from the 1:500 000 Hydrogeological maps with the following classes:
    - Intergranular 2 – 5 l/s
    - Intergranular >5 l/s
- Alluvium from the 1: 1000 000 geological map
- Rivers (primary and secondary rivers from WR2005 at 1:500 000) buffered by 200m combined with river areas from 1:50 000 river data set.
- Areas of known thick sands (from local data sets)
- Boreholes with depths less than 30 m classed as follows:
    - 0.5 - 2 l/s
    - >2 l/s
- Boreholes with depths greater than 30 m with yields greater than 5 l/s (to cover those boreholes that penetrate both alluvial and hard-rock aquifers).
- Borehole water quality classed as follows:
    - 0 – 150 mS/m
    - 150 – 370 mS/m
    - 370 – 520 mS/m
    - >520 mS/m
- Towns, roads and rivers.
- For similar studies conducted on other WMA's, additional coverages appropriate to the specific WMA may be identified from scrutinising the hydrogeological, geological and topographical maps.

The favourable sandy aquifers map is shown in **Figure 5**.

Figure 4 & 5/…

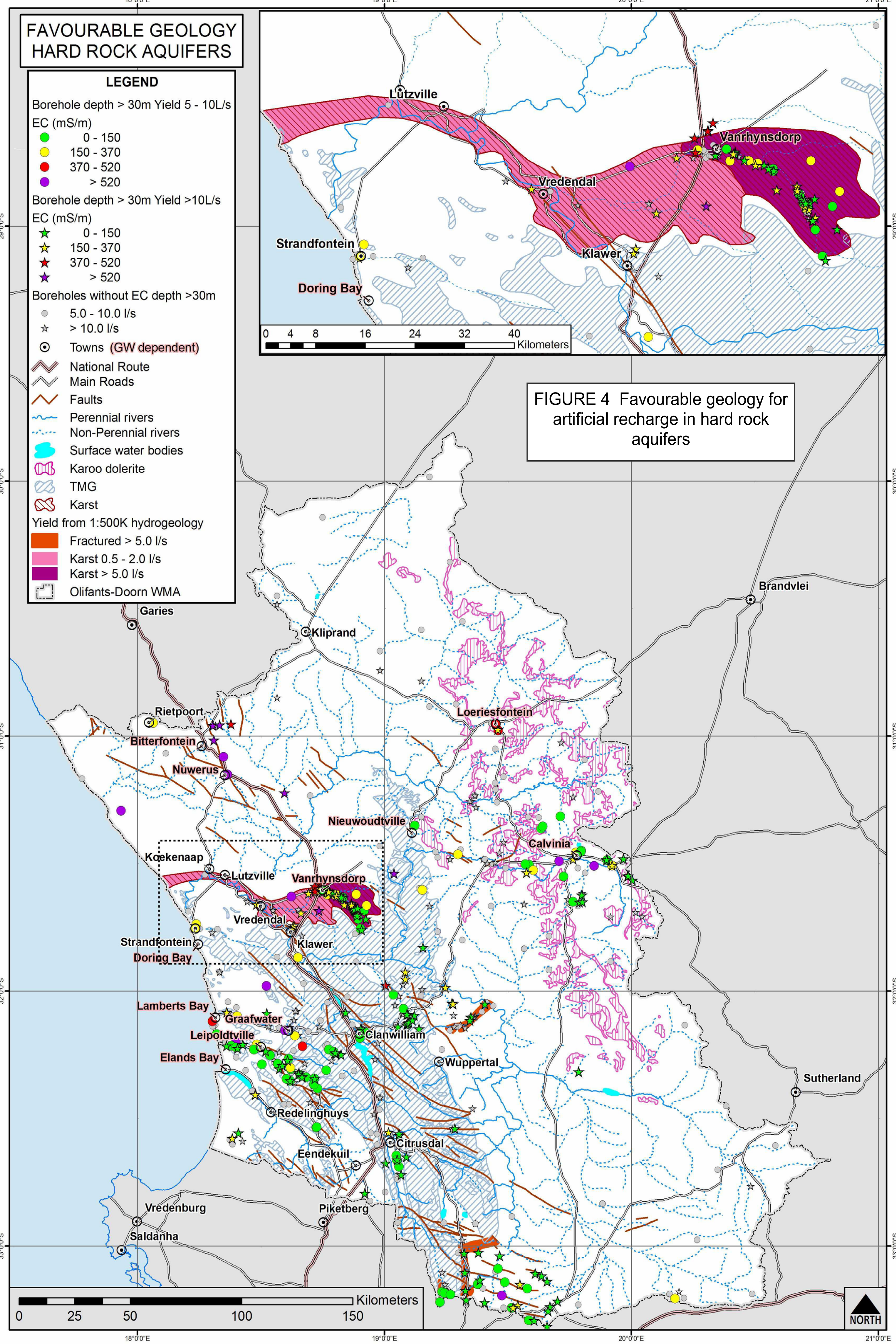


FIGURE 4 Favourable geology for artificial recharge in hard rock aquifers

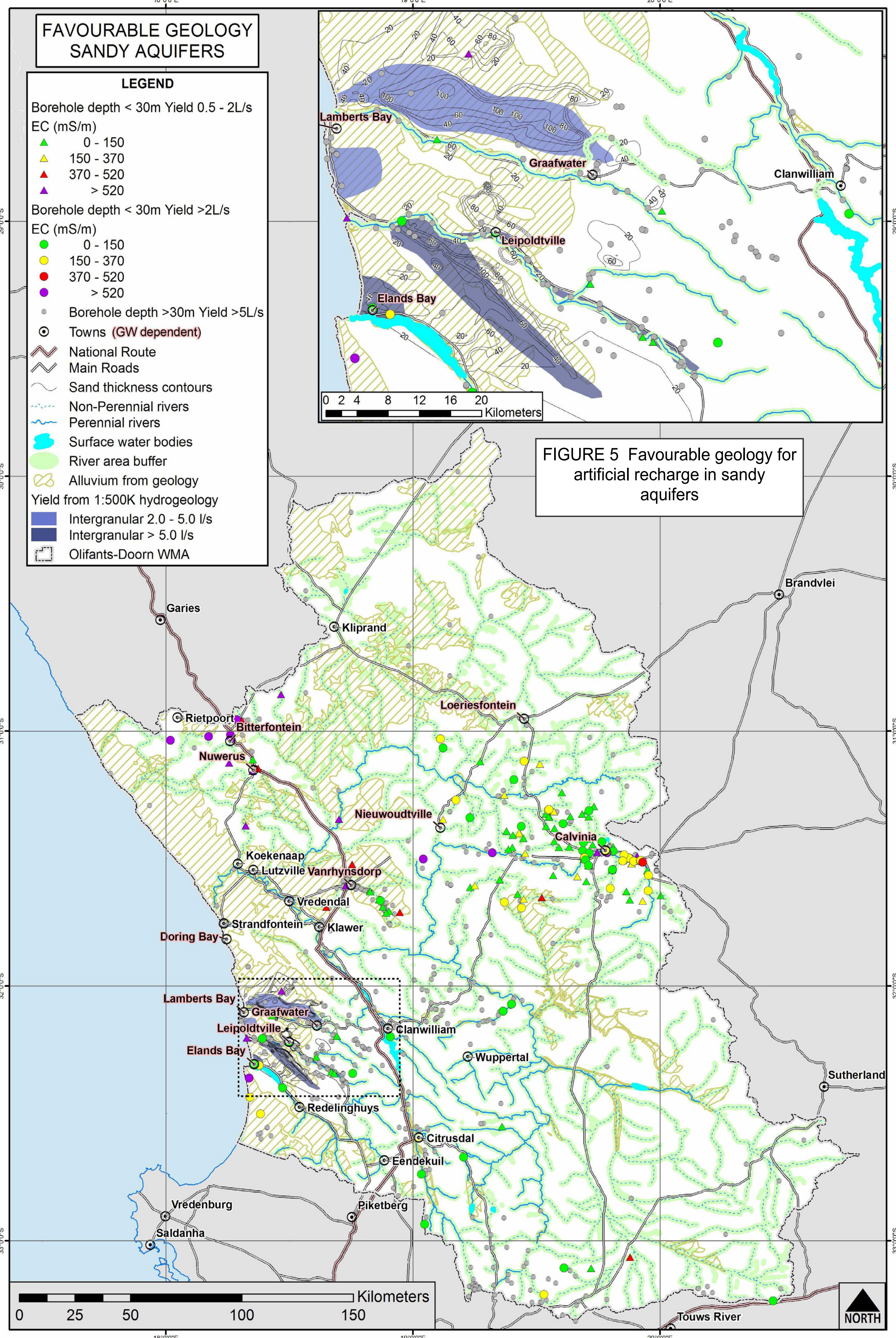


FIGURE 5 Favourable geology for artificial recharge in sandy aquifers

Step 4: Prioritising favourable areas (Figures 6 & 7)

The final map is a refinement of the GIS data sets and expert knowledge.

Hard rock aquifers (Figure 6)

The Karoo dolerites were removed because in this area, they are sills with generally low groundwater yield potential; only the higher yielding karst areas were selected; and the TMG sandstones were restricted to only those areas that are reasonably accessible. The final map consists of:

- Areas from the 1:500 000 Hydrogeological maps with the following classes:
  - Fractured > 5 l/s
  - Karst >5 l/s
- Areas with outcropping TMG sandstones that are below 1000mamsl and have a slope of less than 12%.
- Faults from the 1:500 000 Hydrogeological maps.
- Boreholes with depths greater than 30 m classes as follows:
  - 5 – 10 l/s
  - >10 l/s
- Borehole water quality classed as follows:
  - 0 – 150 mS/m
  - 150 – 370 mS/m
  - 370 – 520 mS/m
  - >520 mS/m
- Towns, roads and rivers.

The prioritised hard rock aquifers map is shown in **Figure 6**.

Sandy aquifers (Figure 7)

In order to disregard much of the shallow alluvium that is marked on the geological map, only those areas where the buffered rivers and the geologically mapped alluvium overlay each other were selected. The map contains the following:

- Areas from the 1:500 000 Hydrogeological maps with the following classes:
  - Intergranular 2 – 5 l/s
  - Intergranular >5 l/s
- Combined alluvium from the three geological input maps that overlay the rivers (primary and secondary rivers from WR2005 at 1:500 000 buffered by 200m combined with river areas from 1:50 000 river data set
- Areas of known thick sands (from local data sets)
- Faults from the 1:500 000 Hydrogeological maps
- Boreholes with depths less than 30 m classes as follows:
  - 0.5 - 2 l/s
  - >2 l/s
- Boreholes with depths greater than 30 m with yields greater than 5 l/s (to cover those boreholes that penetrate both alluvial and hard-rock aquifers).
- Borehole water quality classed as follows:
  - 0 – 150 mS/m
  - 150 – 370 mS/m
  - 370 – 520 mS/m
  - >520 mS/m
- Towns, roads and rivers.

The prioritised sandy aquifers map is shown in **Figure 7**.

Examples of artificial recharge opportunities from the final maps (Figures 6 & 7)

The prioritised hard rock aquifers map Figure 6.
The following examples show areas where large-scale borehole injection may be possible if suitable water source could be diverted to these areas. These areas have numerous boreholes with yields in excess of 10 l/s and in most cases, salinity levels less than 150 mS/m.

- The karst area east of Vanrhynsdorp
- The Table Mountain Group Aquifer (TMG) west and south east of Leipoldsville
- Around Citrusdal in the TMG Aquifer, and particularly 10 – 15 km south of the town
- In the TMG Aquifer around Clanwilliam (the borehole yields are generally lower, in the 5 – 10 l/s range)
- Faults in the TMG , and particularly where they cross rivers.

The prioritised sandy aquifers map Figure 7.
Areas where the alluvium is known to be thick:

- The E-W trending basin between Lamberts Bay and Graafwater
- The basin NE of Lamberts Bay
- The NW-SE trending basins immediately north and south of Leipoldsville
- The NW-SE trending basin east of Elands Bay (south of Leipoldsville)
- The Sandlaagte Aquifer SW of Klawer (marked with an "S" in Figure 7). This aquifer is estimated to store more than 80 Mm^3 but was rejected as a possible artificial recharge site because (primarily) of economic reasons (PGWC. 2006).
- The coastal sands which may be suitably thick in places
- Numerous riverine alluvium areas, some of which may contain thick alluvium. In most areas where there is alluvium in the TMG, it will be predominantly sandy (as opposed to clayey) due to the quartzitic nature of the TMG. In a few areas faults cross the riverine alluvium. These areas could be suitable for building sand dams or other measures to stall the river flow and to allow for rapid infiltration to the fault zones.

Figure 6/…

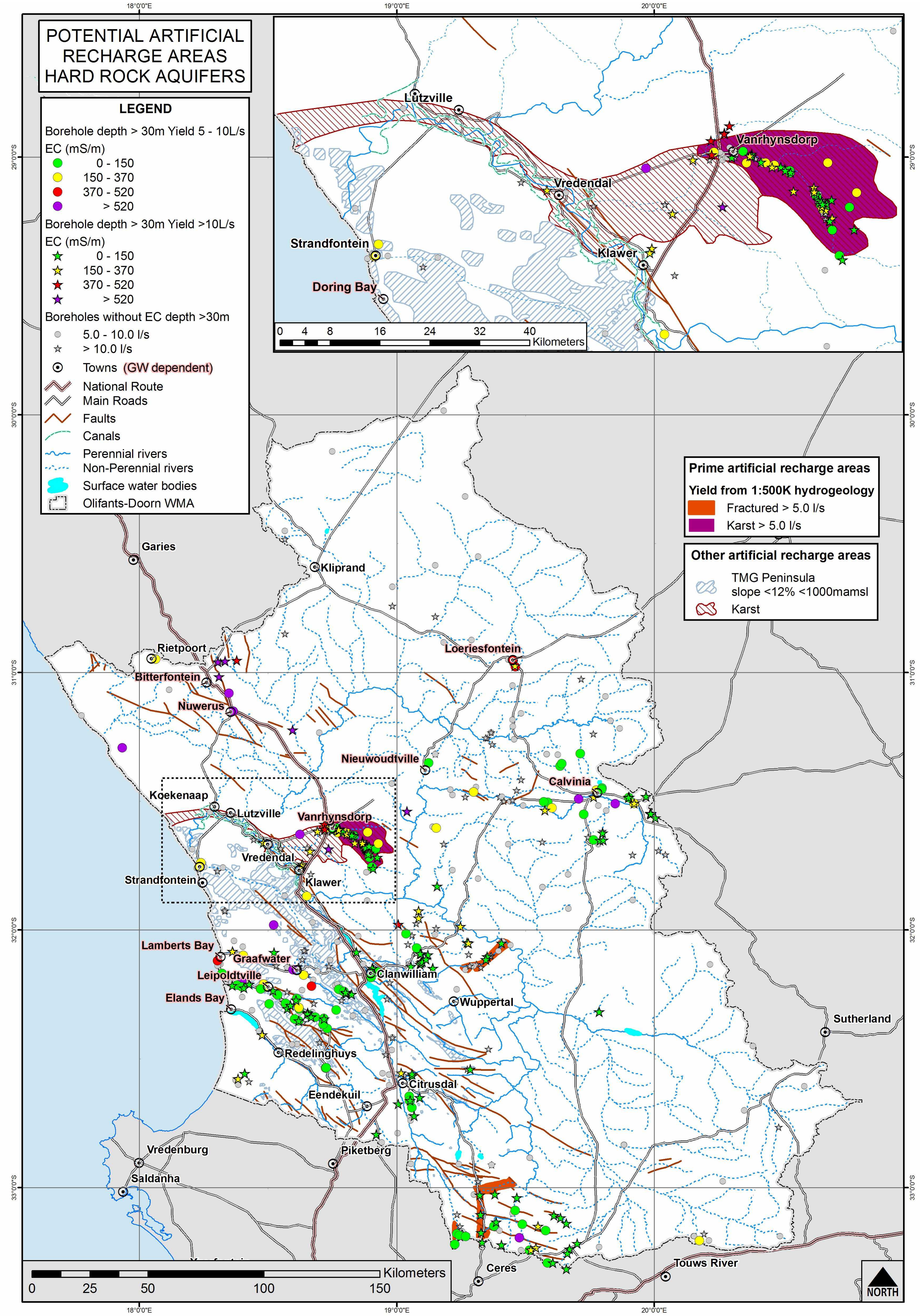


FIGURE 6 WMA 17: Prioritised areas of potential artificial recharge in hard rock aquifers

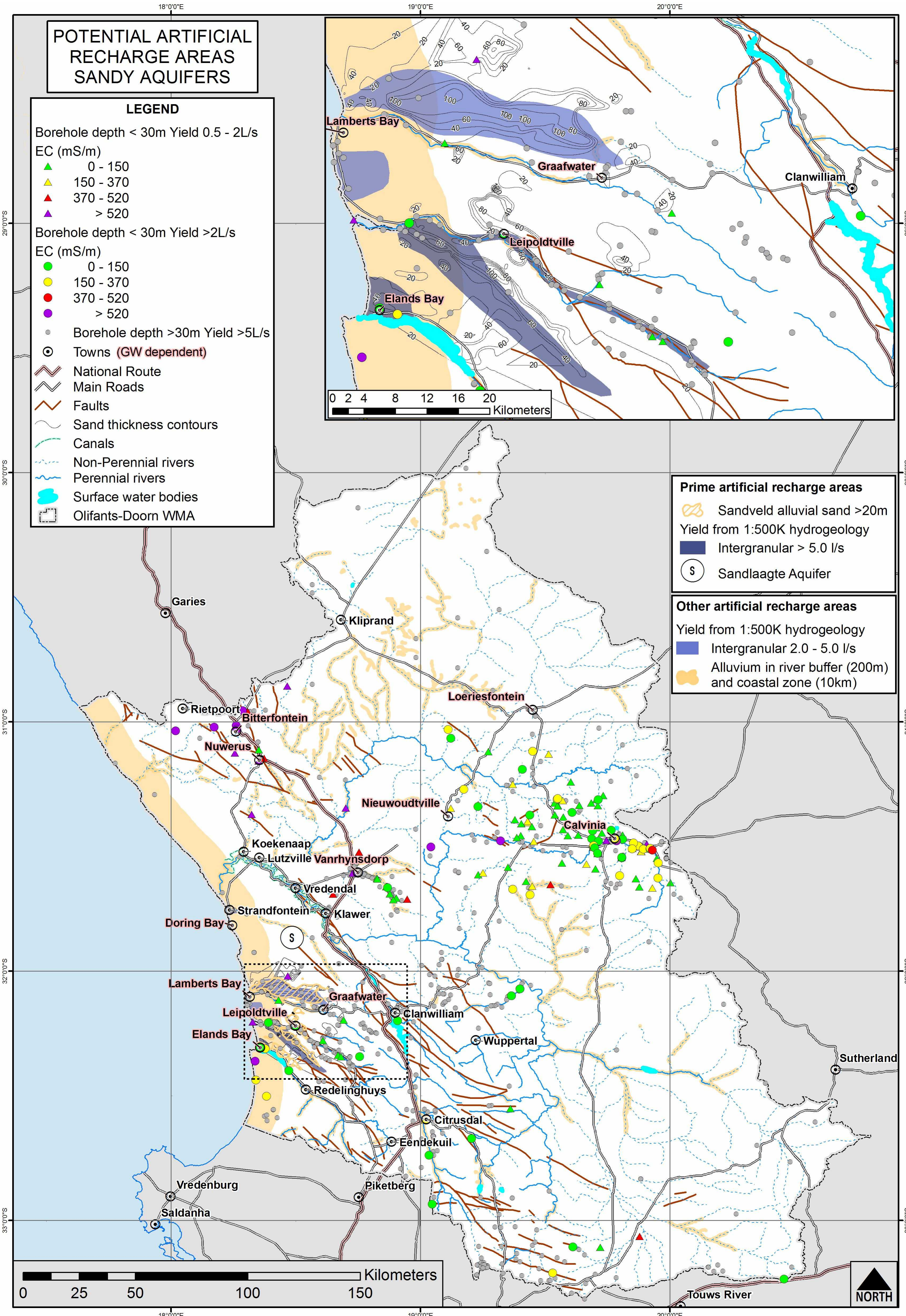


FIGURE 7 WMA 17: Prioritised areas of potential artificial recharge in sandy aquifers

4. Site specific areas for potential artificial recharge

4.1 Introduction and list of potential areas

Site-specific areas where artificial recharge should be considered were identified from the GIS-identified areas (identified in the previous section), from liaising with people in the water supply sector and from reports where artificial recharge is mentioned. These sites include areas:

i) Where groundwater resources have been heavily utilised and where space in the aquifers may be available for artificial recharge
ii) Where conjunctive use of surface and groundwater resources using artificial recharge appears sensible
iii) Where the conditions for large-scale subsurface storage appear favourable.

The list of potential areas is given in **Table 1**, and a more detailed description of a selection of these sites is provided in **Appendices 2 – 8**. By no means is this list attempting to be comprehensive, rather, it should be considered as examples of areas where artificial recharge should be considered. **Figure 8** shows the location of these sites as well as existing schemes and areas where feasibility studies have been conducted.

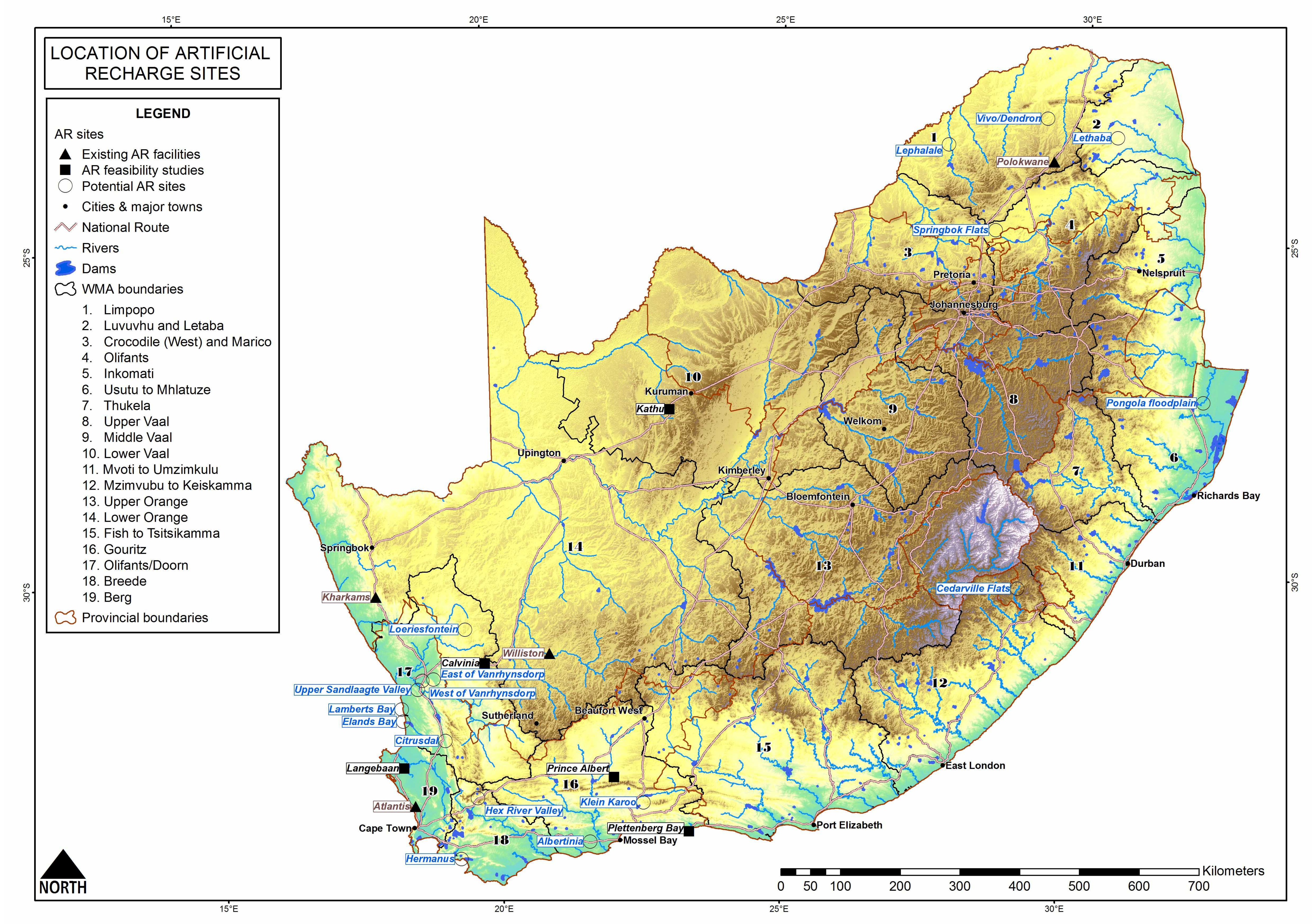


FIGURE 8 Location of existing artificial recharge schemes and identified areas for artificial recharge assessments

TABLE 1 POTENTIAL ARTIFICIAL RECHARGE SITES

Area	Location (central point)	Aquifer/ Groundwater level data	Water source/ Main beneficiary or use	Aim / Comments
WMA 1. Limpopo				
Vivo/Dendron	S: 23° 15' E: 29° 20'	Gneiss Good WL data	Water source: None Use: Agriculture	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)	S: 23° 41' E: 27° 43'	Sandstone WL data: No long-term data	Water source: Hartebeesport Dam Use: Power stations	Need for water security for power stations. Aim would be to use aquifers for local storage (ie minimise risk of supply failure by including localised storage. Groundwater and AR options are presented in Appendix 2.
WMA 2. Luvuvhu / Letaba				
Between the Klein & Groot Letaba Rivers	S: 23° 30' E: 30° 30'	Granitic WL data: Good data since 2006	Water source: Klein Letaba River Use: Rural communities	Groundwater usage is going to increase substantially due to forecasted increase in demand and poor surface water options. AR could be built into water supply planning. Some immediate tasks should include: i) Initiate a groundwater level monitoring programme; ii) Ensure injection boreholes are drilled near all new high-yielding production boreholes; iii) Ensure the developers of the groundwater scheme are aware of what' is required to implement and AR scheme.
WMA 4. Olifants				
Springbok Flats – Settlers area	S: 24° 57' E: 28° 32'	Confined sandstones WL data: Good historic data. Unsure if still maintained.	Water source: None Use: Agriculture	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 during floods) to this area for large-scale sub-surface storage.
WMA 6. Usuthu to Mhlatuze				
Pongola floodplain	S: 27° 24' E: 32° 10'	Alluvium Aquifer is underutilised and probably full when surplus water is available for recharge.	Water source: Surplus surface water (Pongolapoort Dam). Use: No local need for large-scale supplies.	This area is one of a few in RSA where a sizeable alluvial aquifer could be used to maximise water storage. Intensive commercial agriculture takes place over a relatively small part of this area. There are, however, no major groundwater users and the aquifer is likely to be full most of the time. This aquifer could possibly be used (with AR) as a large-scale storage reservoir, but this would only be necessary when there is a need within an economic radius of the area.
WMA 10. Lower Vaal				
Kathu	S: 23° 05' E: 27° 40'	Dolomite WL data: Good historic data.	Water source: Surplus water from Khumba Mine (Sishen). Use: Kathu town	Water levels in the wellfield area of the Kathu Aquifer have dropped by over 20 m in 27 years, and there is a general decrease in water levels of about 0.7m/a (Murray, 2006). This trend could be stopped or reversed by borehole injection via very high yielding (20-30 l/s)boreholes in and up-gradient of the hydraulic depression. 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.
WMA 12. Mzimvubu to Keiskamma				
Cedarville Flats	S: 30° 19' E: 29° 07'	Alluvium WL data: No long-term data	Water source: Mzimvubu River Use: Agriculture and possibly town supplies (Matatiele, Cedarville, Koktad)	This area forms one of the few deep alluvial basins in RSA. 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 that currently takes place by farmers. Ultimately the aquifer's yield could be increased significantly with AR. An immediate need is to initiate a water level and abstraction monitoring programme. A conceptual plan of this potential scheme is presented in Appendix 3.
WMA 16. Gouritz				
Klein Karoo Water Supply Scheme	S: 33° 37' E: 22° 33'	TMG fractured sandstones/quartzites Good WL data	Water source: Flash floods Use: Towns supplied by the KKWSS	Capture flood runoff and inject into high-lying boreholes where water levels have dropped by tens of metres over the years; or use the lower boreholes more and replenish with artificially recharged water. The main question is: Is flood runoff available for long enough periods to make a difference? A conceptual plan of this potential scheme is presented in Appendix 4.
Albertinia	S: 34° 12' E: 21° 35'	TMG – Nardouw Fm Good WL data	Water source: Dam Use: Albertinia town	Space has been created in the aquifer by continuous groundwater abstraction. Additional water supplies are needed and surface water sources are being considered. An option is to develop a small-scale surface water source that is utilised for town supplies in summer and for recharge in winter. This way it will be possible to use the aquifer to a greater extent in summer. This would only be

Area	Location (central point)	Aquifer/ Groundwater level data	Water source/ Main beneficiary or use	Aim / Comments
				an option if the overall costs (construction and O&M) of the AR scheme is cheaper than the large surface water scheme. A conceptual plan of this potential scheme is presented in Appendix 5.
WMA 17. Olifants / Doorn				
East of Vanrhynsdorp	S: 31° 41' E: 18° 52'	Dolomitic marble Good WL data	Water source: Flood runoff in the catchment or surplus Doring River runoff Use: Agriculture	Water levels have declined with high abstraction. 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. A conceptual plan of this potential scheme is presented in Appendix 6.
West of Vanrhynsdorp	S: 31° 42' E: 18° 40'	Dolomitic marble WL data: Unknown	Water source: Olifants River and TMG groundwater Use: Agriculture	The concept involved transferring water from the Olifants River and possibly the TMG aquifer near Klawer into a confined limestone aquifer. The plan suggests transferring about 120 Mm^3 over the six winter months via 154 injection/abstraction boreholes spaced 500 m apart into the aquifer. Water compatibility concerns (between the recharged water and the aquifer water) prevented further investigation of this option. References PGWC. 2006. Clanwilliam Dam Raising Study, Specialist Screening Workshop, 23 November 2004.
Upper Sandlaagte Valley	S: 31° 50' E: 18° 35'	Deep sands in a paleo-channel WL data: Unknown	Water source: Olifants River and TMG groundwater Use: Agriculture	A similar scheme as that of the limestone aquifer west of Vanrhynsdorp was considered. The source waters are the same, but the estimated storage volume is about 80 Mm^3 and the artificial recharge target 20 Mm^3/a. The operation and maintenance costs were considered too high and this scheme was not investigated further. References: PGWC. 2006. Clanwilliam Dam Raising Study, Specialist Screening Workshop, 23 November 2004.
Calvinia	S: 31° 28' E: 19° 20'	Breccia pipes	Water source: Karee Dam (municipal dam)/ Farm dams Use: Municipal/agriculture	A breccia pipe is a cylindrical plug of highly fractured rocks. They range up to a few 100 m in diameter and open spaces in fractures and cavities make them good storage reservoirs. A feasibility study was conducted on one of the numerous breccia pipes in the Calvinia area and it had potential to store 80 000m^3. This particular one is highly mineralised which made the stored water unfit for human consumption (although if blended correctly with surface water it would be potable. There are numerous other breccia pipes in the western Karoo Basin.
Calvinia "saaidamme"	S: 31° 43' E: 20° 19'	Deep alluvial soils	Diverted flood waters fro the Visrivier, Sakrivier and the Kromrivier	Saaidamme or "planting dams" are used by the farmers to infiltrate water in the alluvial sands of the Vis, Sak and Krom river valleys. The flood-waters come from a distant mountainous catchment and are diverted into a series of large, flat basins (between 1 ha and 100 ha in size). The basins are ringed by a low earth wall forming a shallow dam or infiltration basin. The water is allowed to stand in the basins up to 1 m deep for between 1 and 3 days to saturate the alluvial soils and then is released. The stored water is used by deep rooted crops like lucerne that is planted directly in the basin. Saaidamme have been operating in this area for over 100 years. An example of saaidamme is shown in the satellite image in Figure 9. Source of information: Umhlaba. 2008.
Citrusdal	S: 32° 37' E: 19° 02'	TMG fractured sandstones/quartzites WL data: unknown	Water source: Olifants River\Use: Municipal/ agriculture	The aim of this scheme would be to abstract heavily from the TMG aquifer during summer and recharge the aquifer with surface water during winter. There are numerous places where such a scheme could be developed, one of which is at the Boschkloof wellfield near Citrusdal. An attractive option is to recharge and abstract from a confined TMG aquifer (Peninsula Formation) via deep boreholes as this would not affect the water table, and thus have minimal environmental impacts.
Loeriesfontein	S: 30° 57' E: 19° 26'	Alluvium WL data: No long-term data	Water source: Runoff Use: Municipal and agriculture	Surface water runoff from floods is captured in small earth dams constructed in the normally dry riverbed. The main water supply boreholes have been drilled below these dams and recharge is enhanced by infiltration of water from the dams into the alluvium of the riverbed. This existing practice is widely used across South Africa as an effective strategy for maximising recharge. An example of earth dams with downstream boreholes is shown in the satellite image in Figure 10.
Lamberts Bay	S: 32° 07' E: 18° 17'	Sandy aquifer WL data: Good in two of the three potential AR areas	Water source: The most viable option is to use water from the Olifants River. Use: Municipal and agriculture	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 TMG aquifer. All these options would be costly. The benefit of artificial recharge would be 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 for the area. A conceptual plan of this potential scheme is presented in Appendix 7.
Elands Bay	S: 32° 18' E: 18° 18'	Dune sands WL data: Good	Water source: The most viable option is to use water from the Olifants River. Use: Municipal and agriculture	The Elands Bay option is exactly the same as the Lamberts Bay option, but the potential artificial recharge volumes would be much less as the thickness of the targeted aquifer is less than those of the Lamberts Bay aquifers. A conceptual plan of this potential scheme is presented in Appendix 8.

Area	Location (central point)	Aquifer/ Groundwater level data	Water source/ Main beneficiary or use	Aim / Comments
WMA 18. Breede				
Hermanus	S: 34° 25' E: 19° 15'	Alluvial sand troughs inland from the rocky shoreline. There are many existing well point users and water levels drop significantly during summer months. WL data: No data (residents report declining yields from wellpoints)	Water source: Storm water, domestic rain water harvesting Use: mainly garden irrigation	The plan would require diverting rain water from hard surfaces to infiltration basins and trenches wherever and whenever possible. This would increase recharge during the wet winter and tit 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 diverted to infiltration basins where possible. 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.
Hex River Valley and various sites in the Breede River Valley	Hex River Valley: S: 33° 30' E: 19° 35'	Alluvium WL data: No long-term data	Water source: Surplus runoff Use: Agriculture and to maintain the Reserve	Divert surplus runoff from tributaries into infiltration basins or trenches parallel and up-slope of the main rivers. The aim would be to recharge the alluvium as far up-slope as possible. This would allow for slow movement to the deep alluvium, thereby extending the usual winter recharge period, or allow for slow discharge from the alluvium into the river to maintain river flow for longer periods. The concern is whether the aquifers are full (even in the up-slope areas) during winter when surface water is available and thus unable to receive additional artificially recharged water. A monitoring programme is necessary to establish this.

AR: Artificial recharge
WL: Borehole water level

5. References

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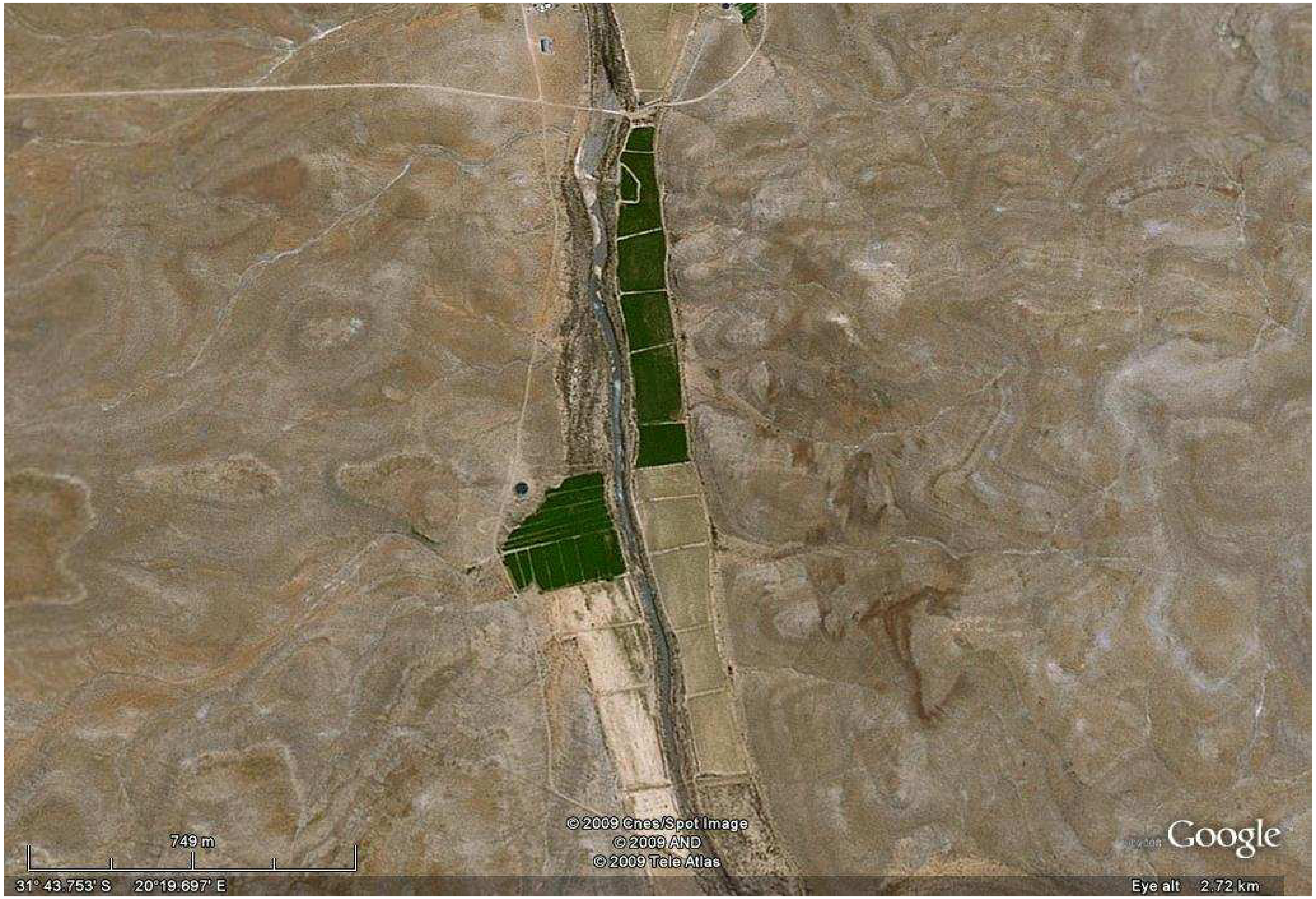

FIGURE 9 Saaidamme along the Fish River 26km southeast of Calvinia.

Saaidamme or "planting dams" are used by the farmers to infiltrate water in the alluvial sands. Flood-waters are diverted into a series of large, flat basins (between 1 ha and 100 ha in size) which are ringed by low earth walls forming shallow dams or infiltration basins. The water is allowed to stand in the basins up to 1 m deep for between 1 and 3 days to saturate the alluvial soils and then is released. The stored water is used by deep rooted crops like lucerne that is planted directly in the basin.

FIGURE 10 Loeriesfontein boreholes located below earth dam walls.
Surface water runoff from floods is captured in small earth dams constructed in normally dry riverbeds. Water from these dams slowly leaks into the riverbed alluvium below the dams thereby enhancing recharge. Boreholes are drilled below the dams to intercept this water.