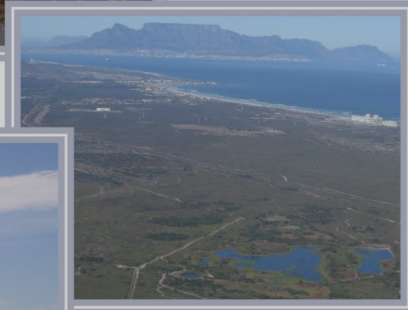
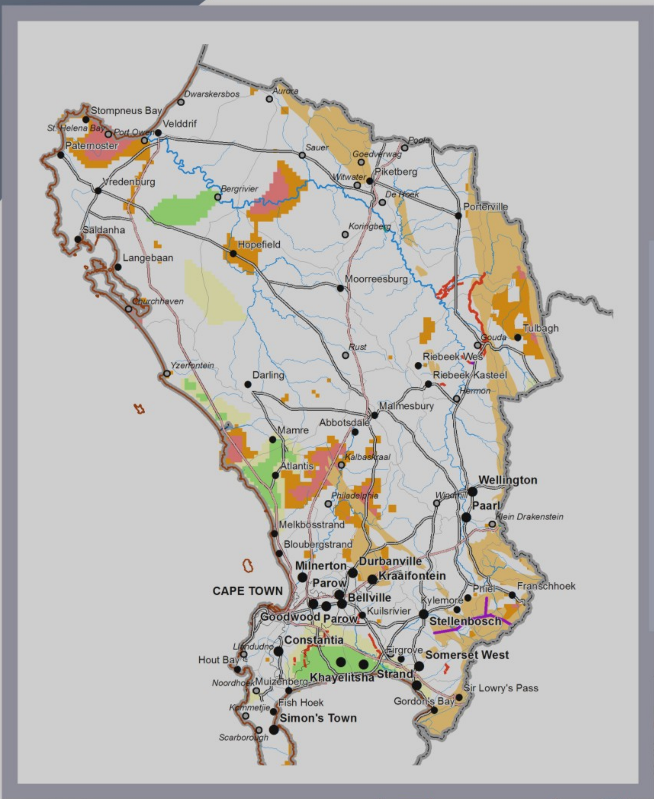
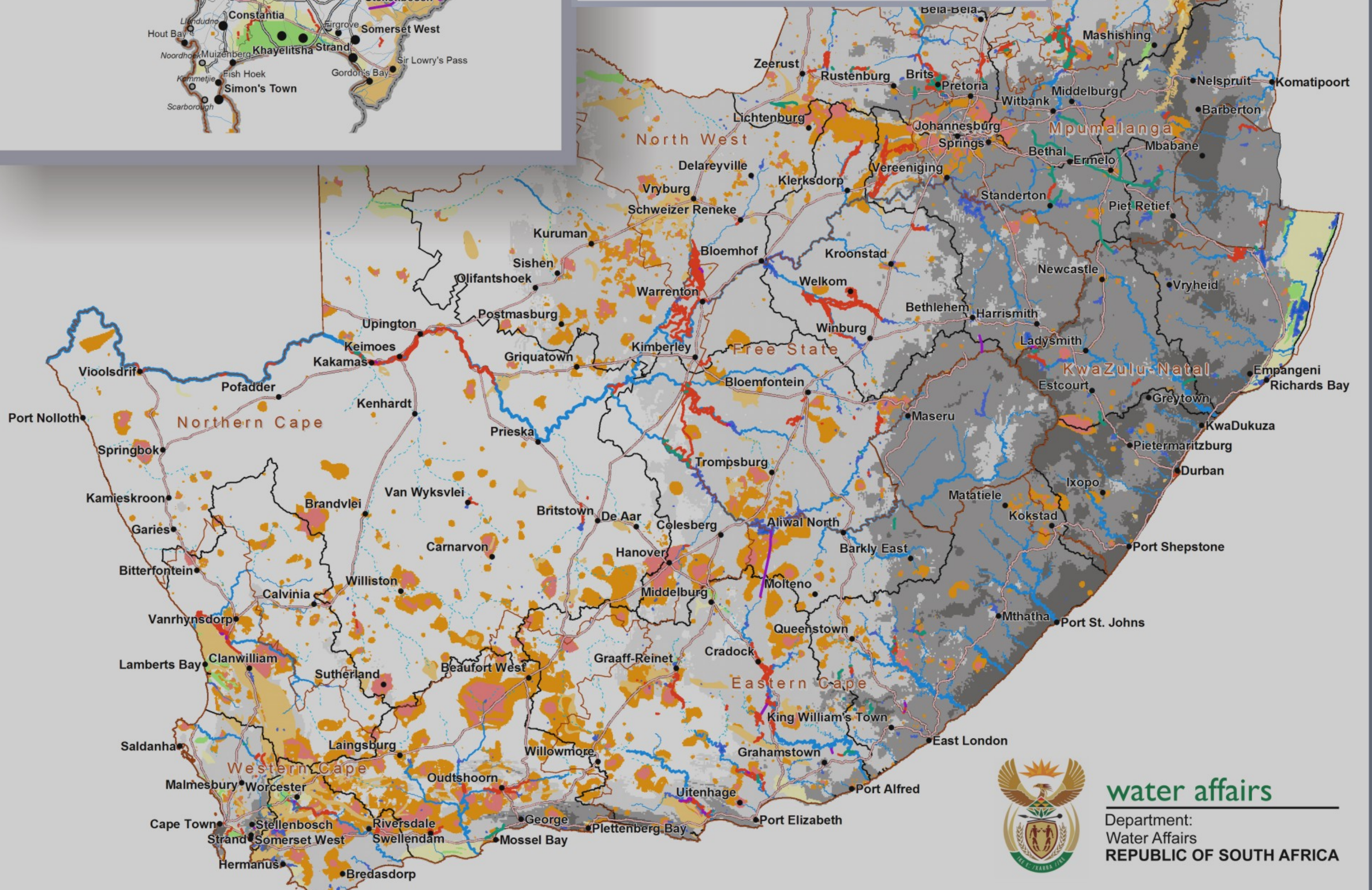
Potential Artificial Recharge Areas in South Africa

September 2009







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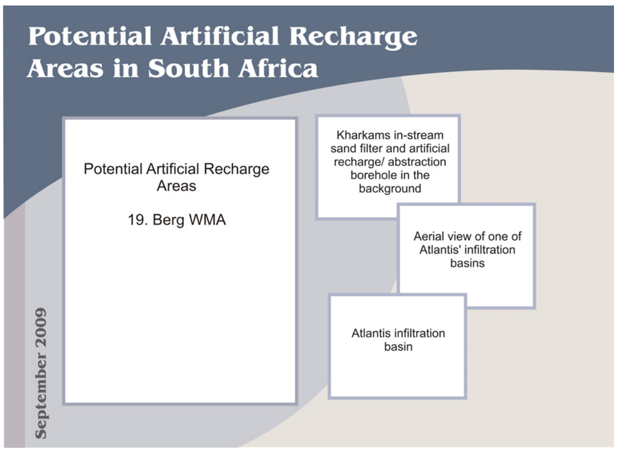

Potential Artificial Recharge Areas in South Africa
Potential Artificial Recharge Areas
19. Berg WMA
Kharkams in-stream sand filter and artificial recharge/ abstraction borehole in the background
Aerial view of one of Atlantis' infiltration basins
Atlantis infiltration basin
September 2009

Appendices

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:

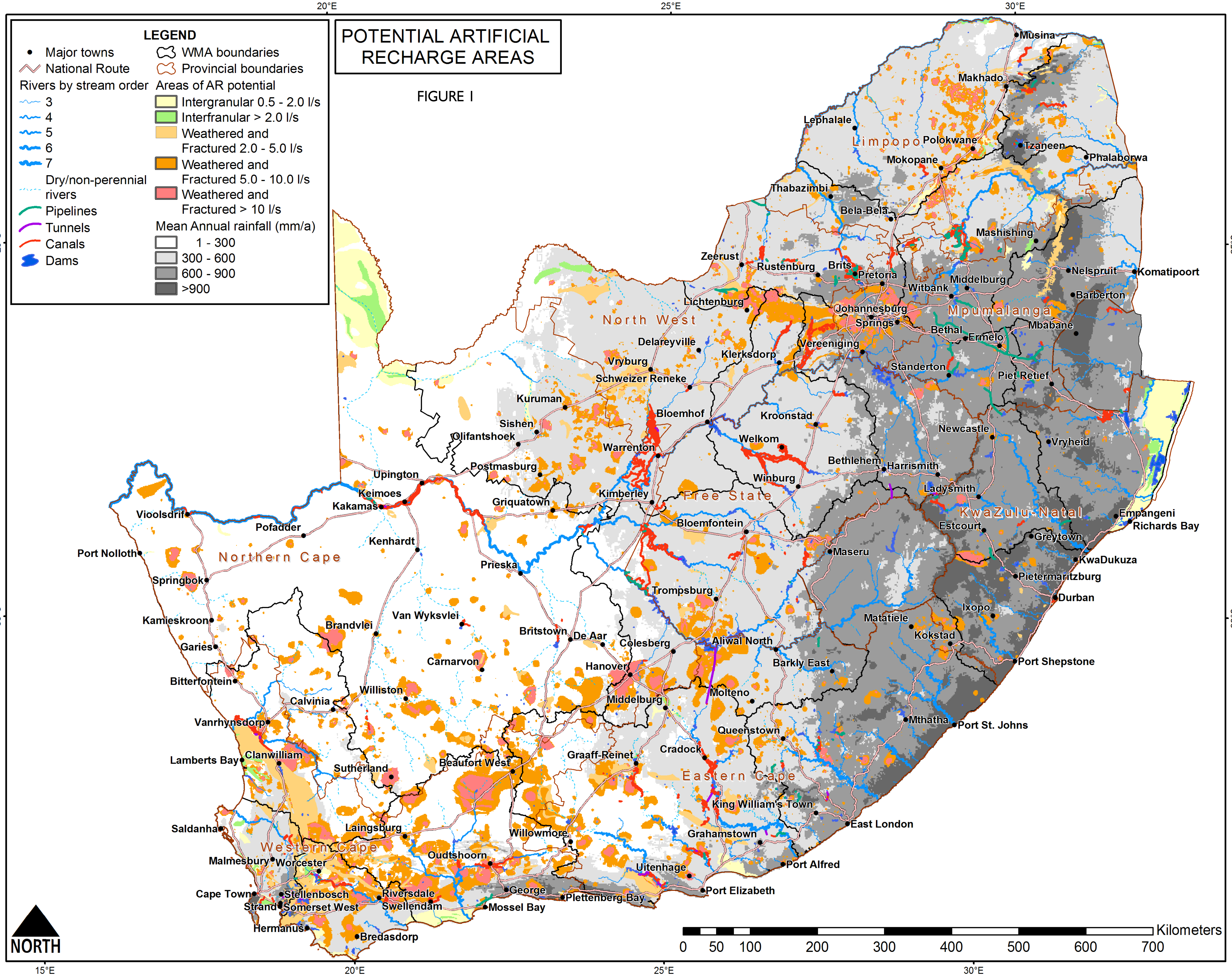
- **Primary aquifers.** Primarily alluvium, coastal aquifers and localised riverbed alluvium, also referred to as Sandy Aquifers. The zones identified as intergranular with borehole yields more than 0.5 l/s on the 1:500 000 hydrogeological maps have been used for this purpose. artificial recharge by 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.

Figure 1/…


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
North West
Mpumalanga
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
NORTH
0 50 100 200 300 400 500 600 700 Kilometers

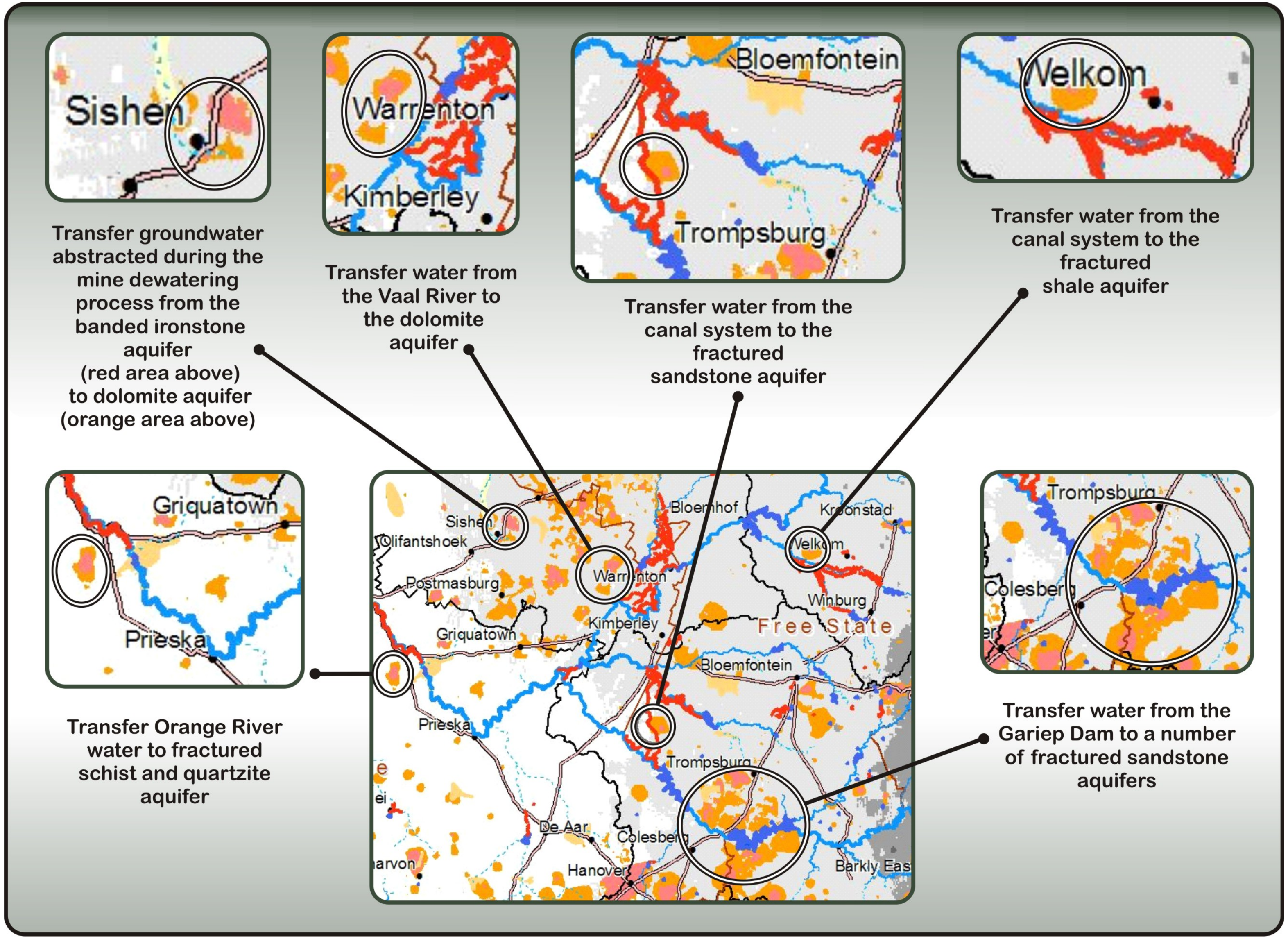


FIGURE 2
Examples of areas where aquifer conditions appear favourable for artificial recharge

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**.

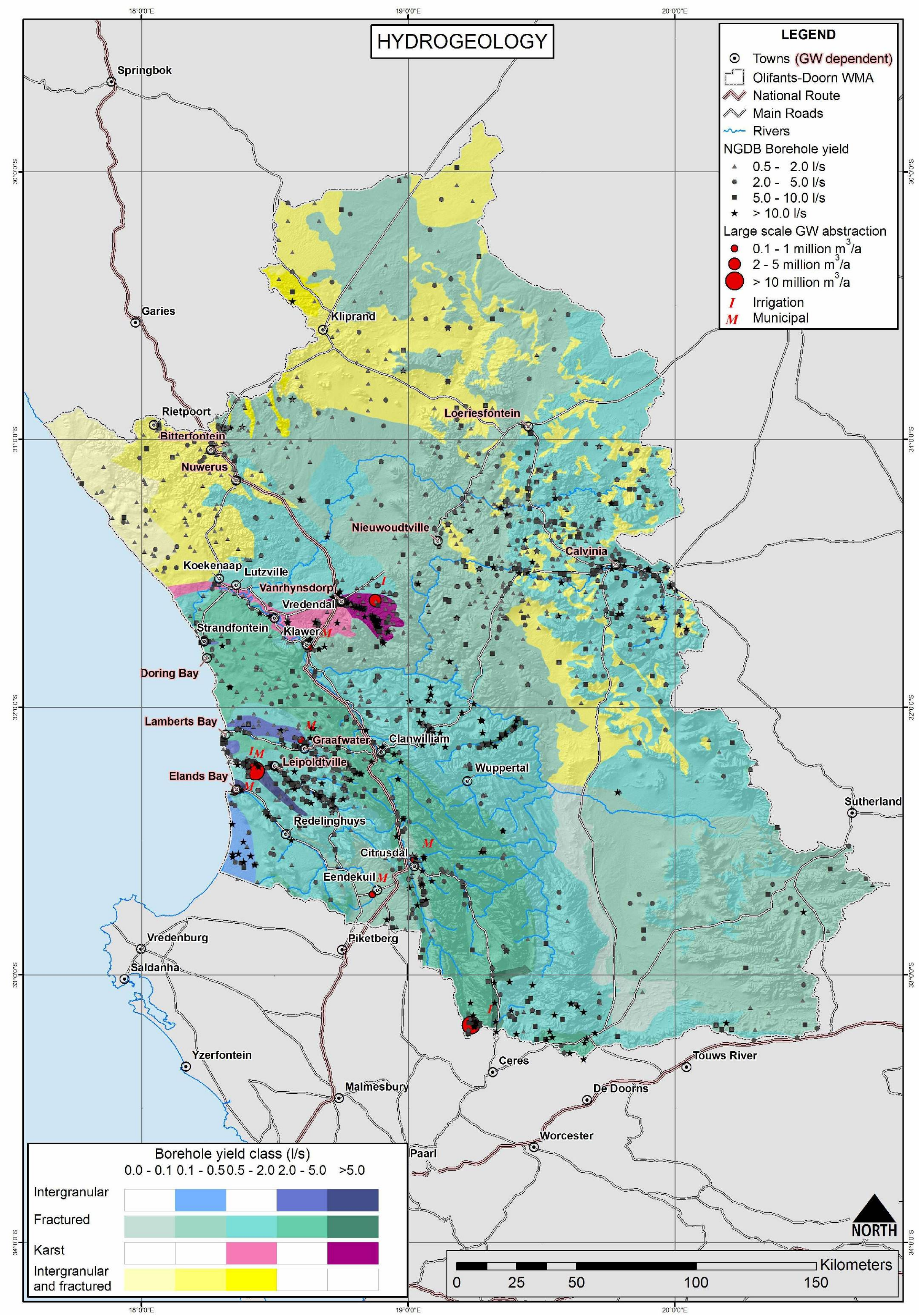


FIGURE 3 WMA 17: Base Map

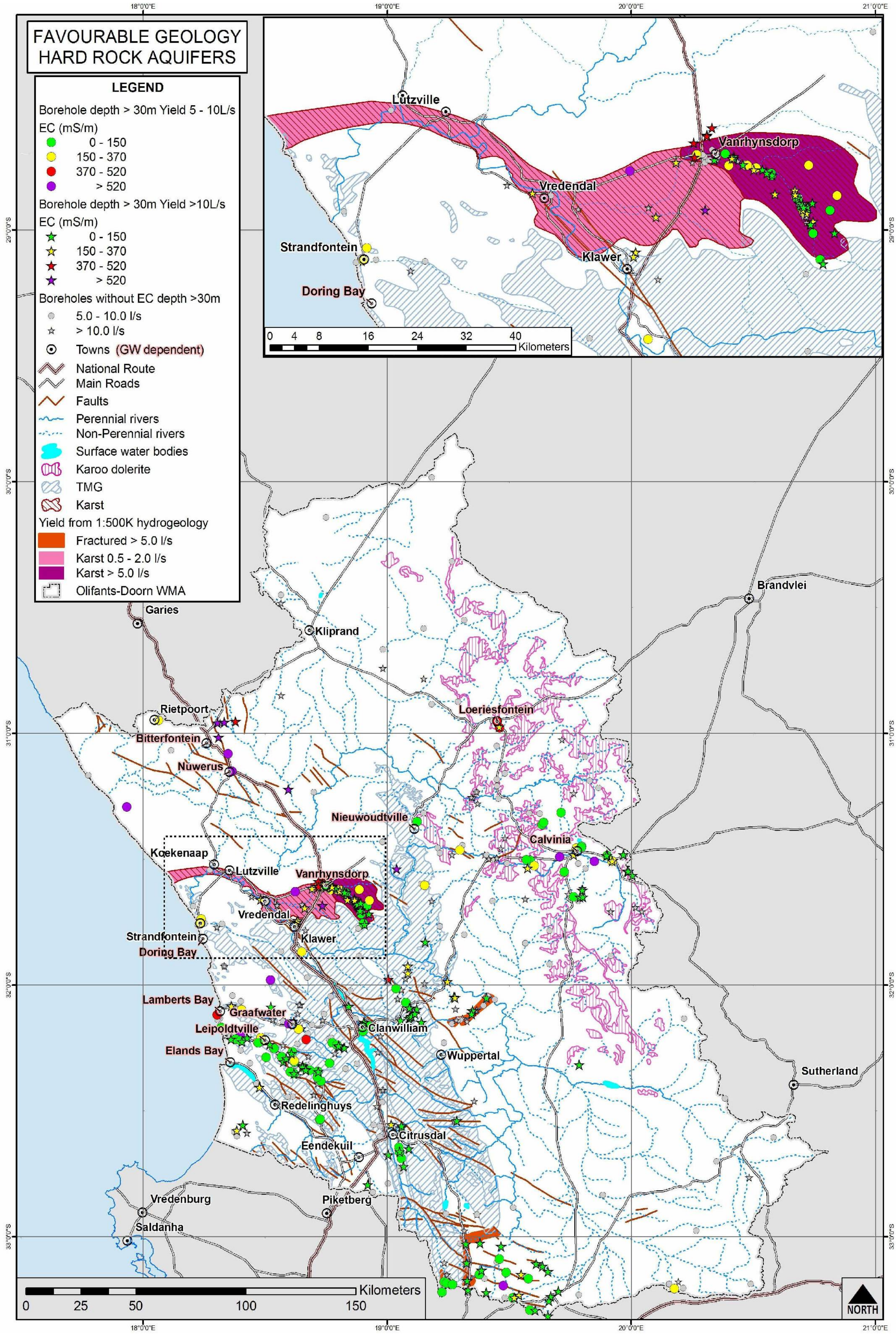


FIGURE 4 Favourable geology for artificial recharge in hard rock aquifers

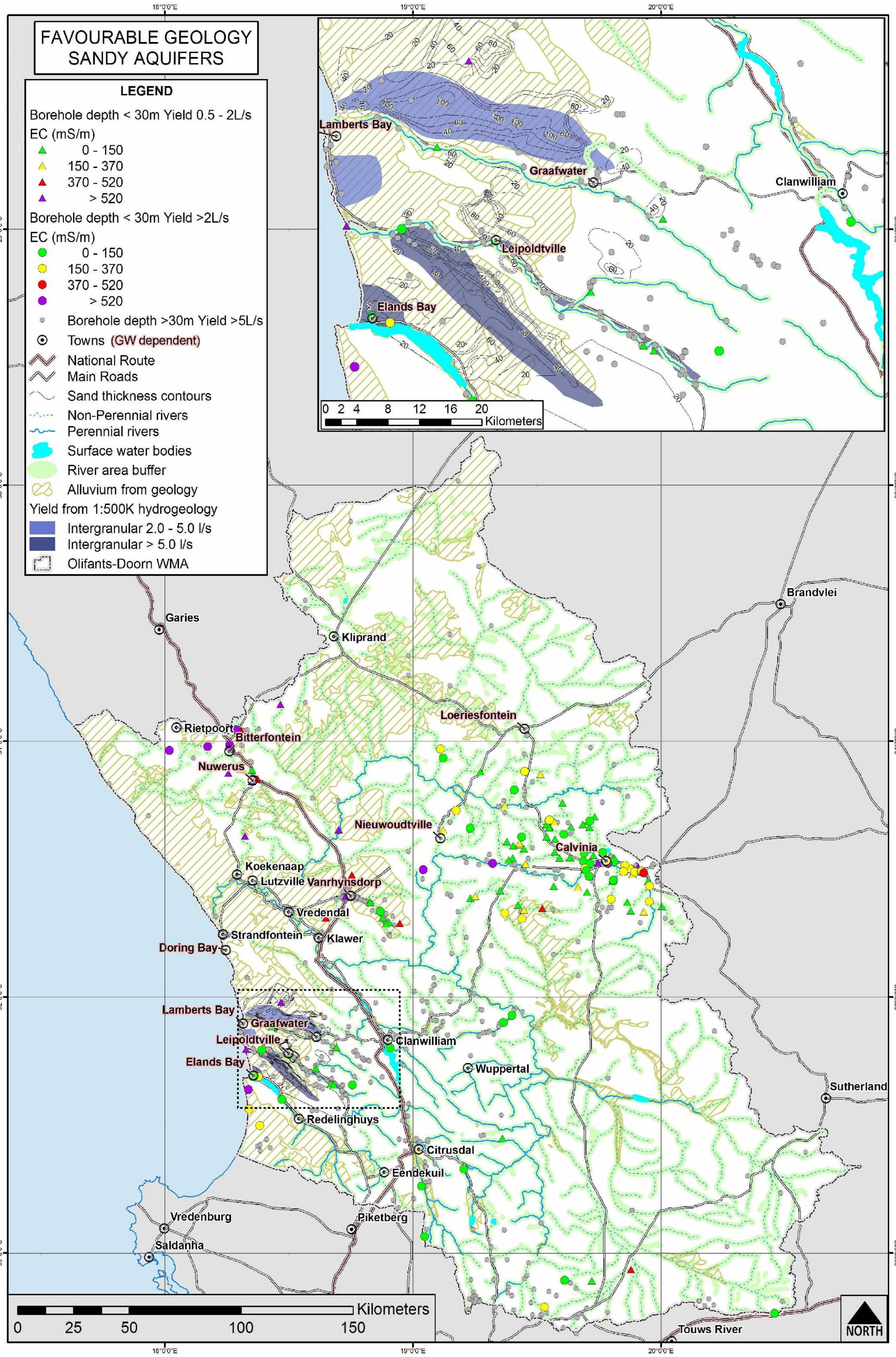


FIGURE 5 Favourable geology for artificial recharge in sandy aquifers

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/…

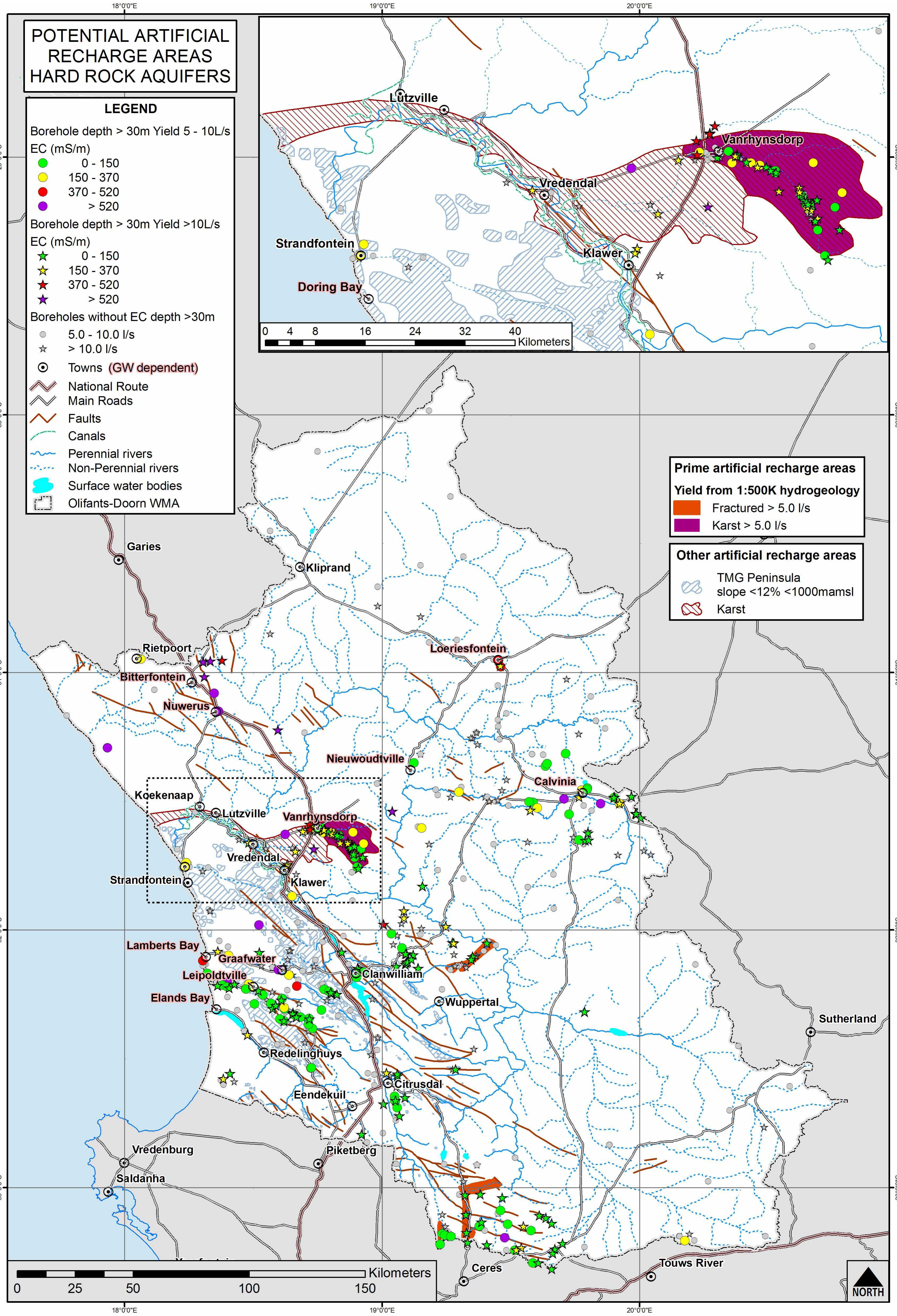


FIGURE 6 WMA 17: Prioritised areas of potential artificial recharge in hard rock aquifers

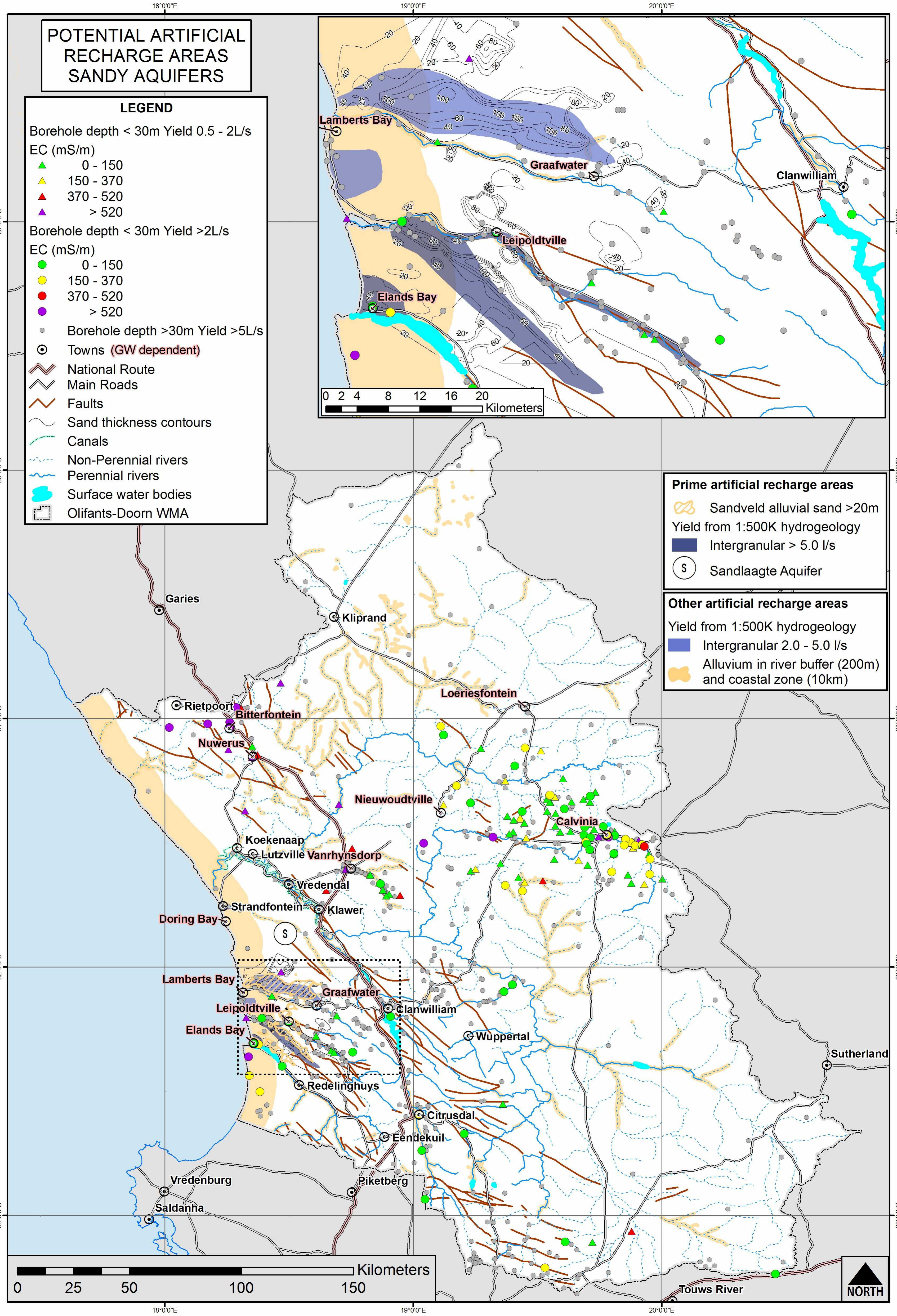


FIGURE 7 WMA 17: Prioritised areas of potential artificial recharge in sandy aquifers

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.

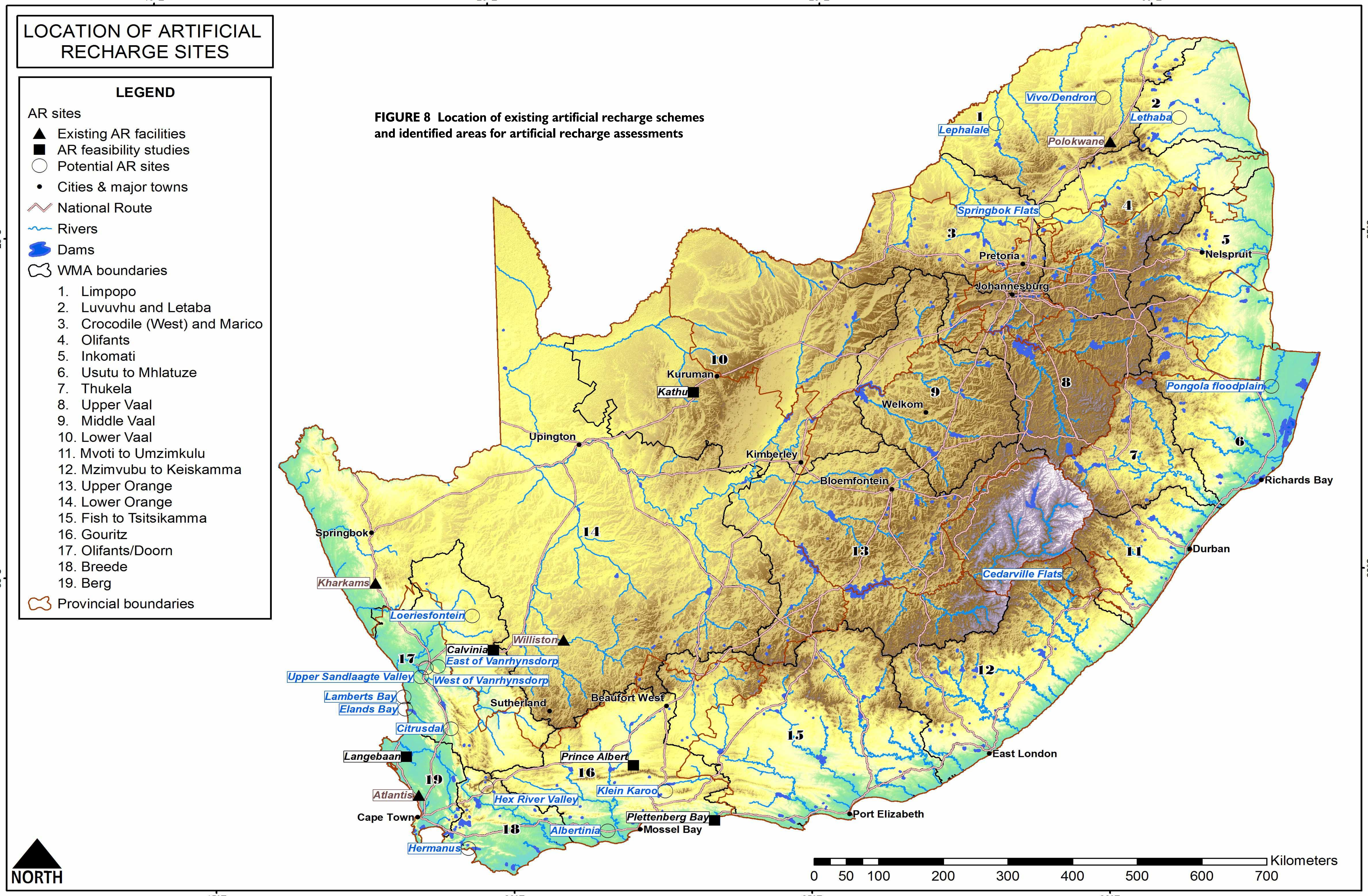


FIGURE 8 Location of existing artificial recharge schemes and identified areas for artificial recharge assessments

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	Water source: Surplus water from	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

Area	Location (central point)	Aquifer/ Groundwater level data	Water source/ Main beneficiary or use	Aim / Comments
		data.	Khumba Mine (Sishen). Use: Kathu town	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 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	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.

Area	Location (central point)	Aquifer/ Groundwater level data	Water source/ Main beneficiary or use	Aim / Comments
			Use: Agriculture	
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.

Area	Location (central point)	Aquifer/ Groundwater level data	Water source/ Main beneficiary or use	Aim / Comments
				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.
WMA 18. Breede				
Hermanus	S: 34° 25' E: 19° 15'	Alluvial sand troughs inland from the rocky shoreline. There are many existing well point	Water source: Storm water, domestic rain water harvesting Use: mainly garden	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

Area	Location (central point)	Aquifer/ Groundwater level data	Water source/ Main beneficiary or use	Aim / Comments
		users and water levels drop significantly during summer months. WL data: No data (residents report declining yields from wellpoints)	irrigation	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

PGWC. 2006. Provincial Government Western Cape: Department of Agriculture: Western Cape. 2005. Main Report. Draft Final. Prepared by Arcus Gibb (Pty) Ltd as part of Contract No. 259-2000/2001. Western Cape Olifants/Doring River Irrigation Study. PGWC Report No. 259/2004/02.

Murray, R. 2006. Kathu Aquifer Artificial Recharge Pre-feasibility Study. Confidential Report to Sishen Iron Ore Company (Pty) Ltd.

Umhlaba. 2008. Indigenous Water Harvesting and Conservation Practices: Historical Context, Cases and Implications. WRC Project No: K/5/1777/4. Umhlaba Consulting Group (Pty) Ltd.

Figure 9/…

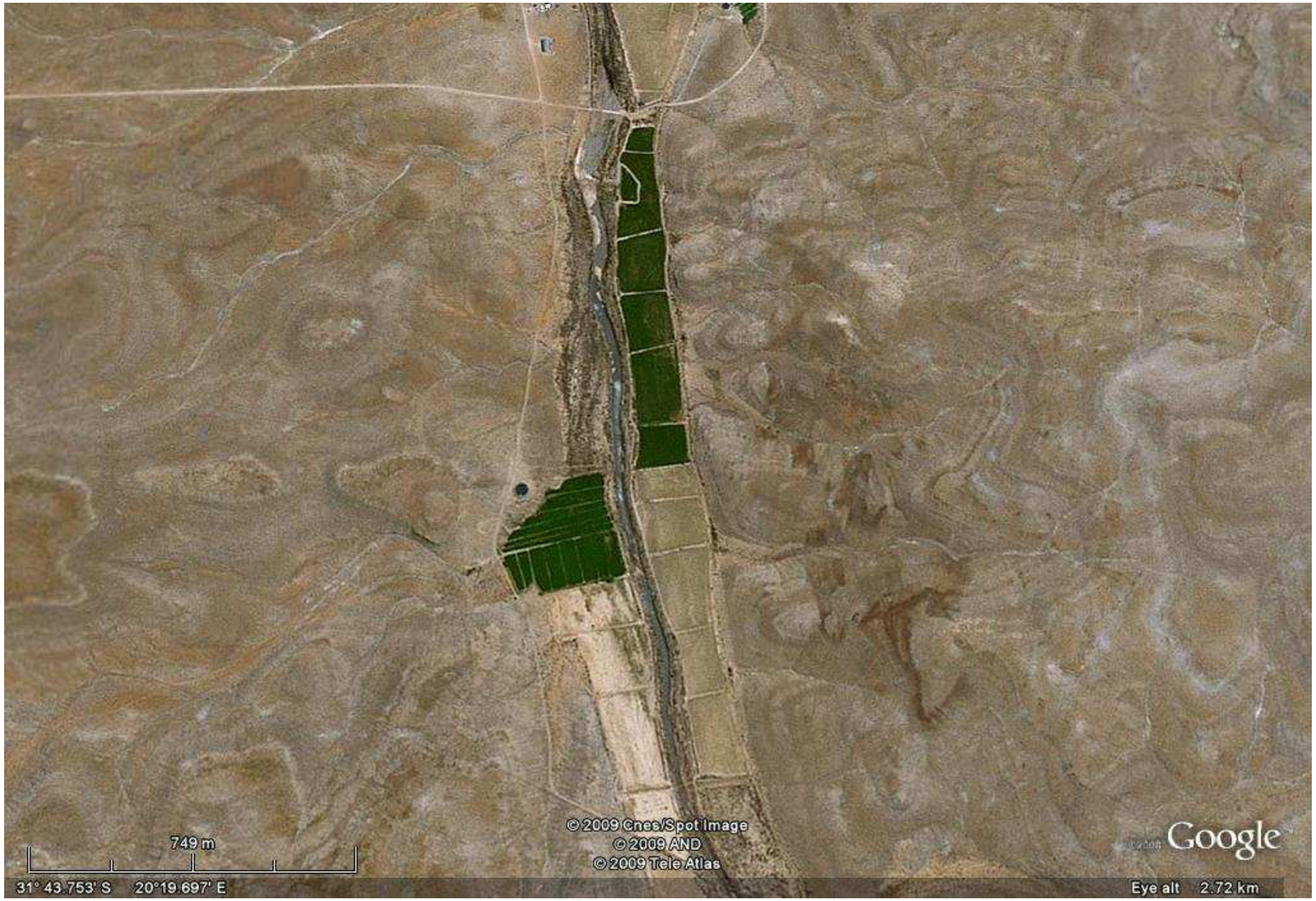


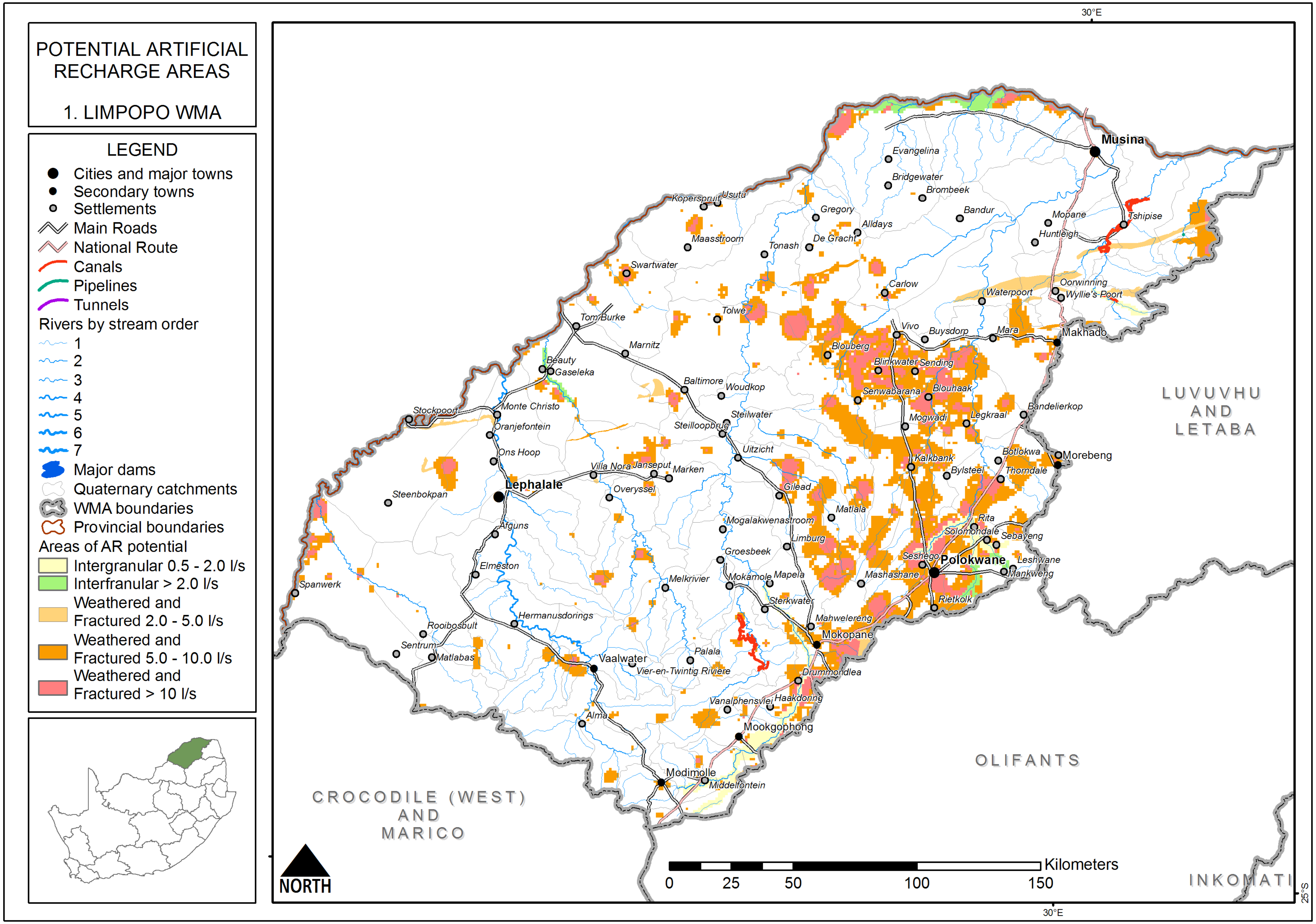
FIGURE 9 Saaidamme along the Fish River 26km southeast of Calvinia.

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.

Appendix 1: WMA maps of potential artificial recharge areas



POTENTIAL ARTIFICIAL RECHARGE AREAS
1. LIMPOPO WMA
LEGEND
Cities and major towns
Secondary towns
Settlements
Main Roads
National Route
Canals
Pipelines
Tunnels
Rivers by stream order
1
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5
6
7
Major dams
Quaternary catchments
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
Musina
Lephalale
Polokwane
Makhado
Mokopane
Modimolle
Mookgophong
Morebeng
Vaalwater
LUVUVHU AND LETABA
OLIFANTS
CROCODILE (WEST) AND MARICO
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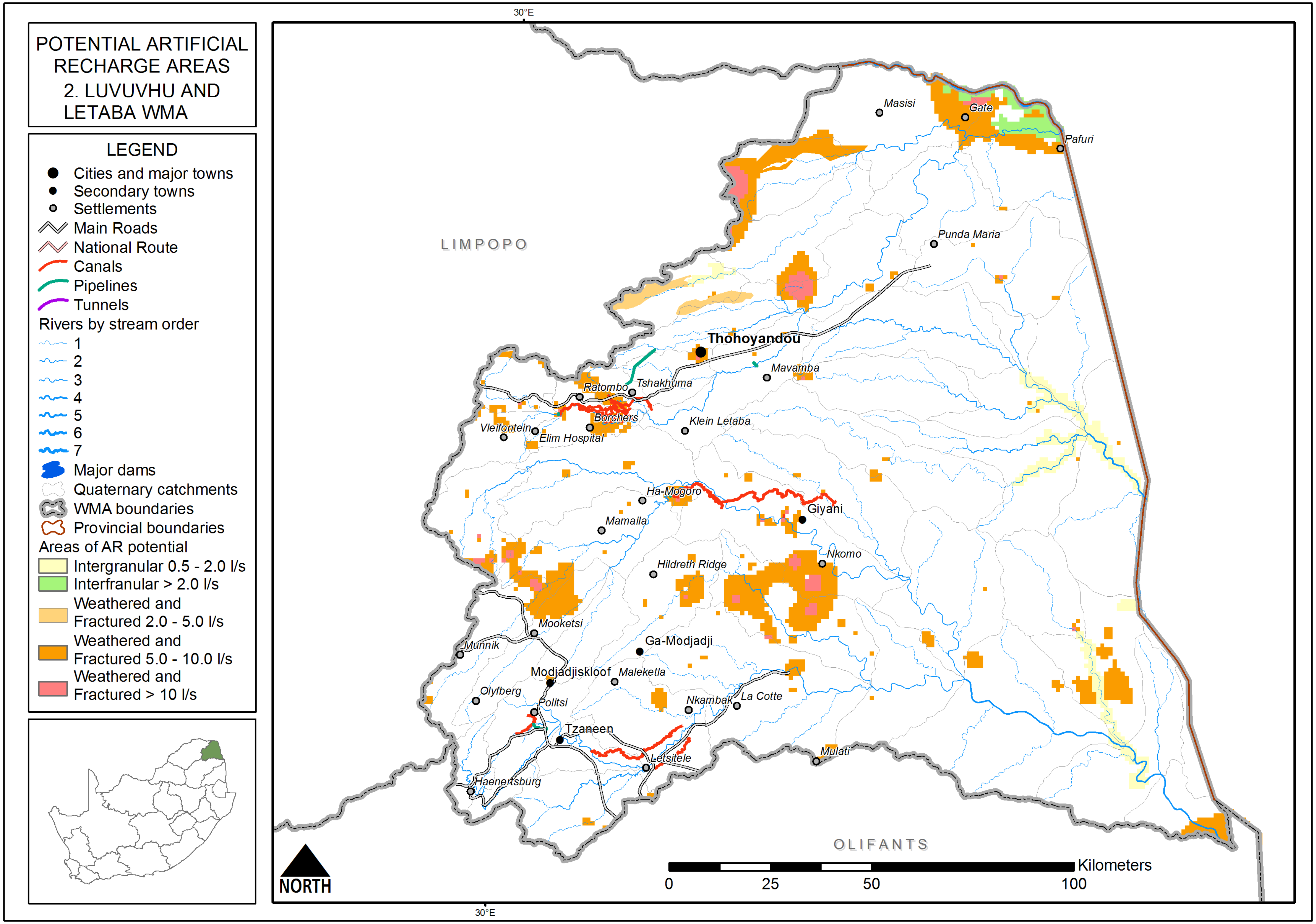

POTENTIAL ARTIFICIAL RECHARGE AREAS
2. LUVUVHU AND LETABA WMA
LEGEND
Cities and major towns
Secondary towns
Settlements
Main Roads
National Route
Canals
Pipelines
Tunnels
Rivers by stream order
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Major dams
Quaternary catchments
WMA boundaries
Provincial 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
30°E
LIMPOPO
OLIFANTS
Masisi
Gate
Pafuri
Punda Maria
Thohoyandou
Mavamba
Ratombo
Tshakhuma
Borchers
Klein Letaba
Vleifontein
Elim Hospital
Ha-Mogoro
Giyani
Mamaila
Nkomo
Hildreth Ridge
Mooketsi
Munnik
Ga-Modjadji
Modjadjiskloof
Maleketla
Olyfberg
Politsi
Nkambak
La Cotte
Tzaneen
Letsitele
Mulati
Haenertsburg
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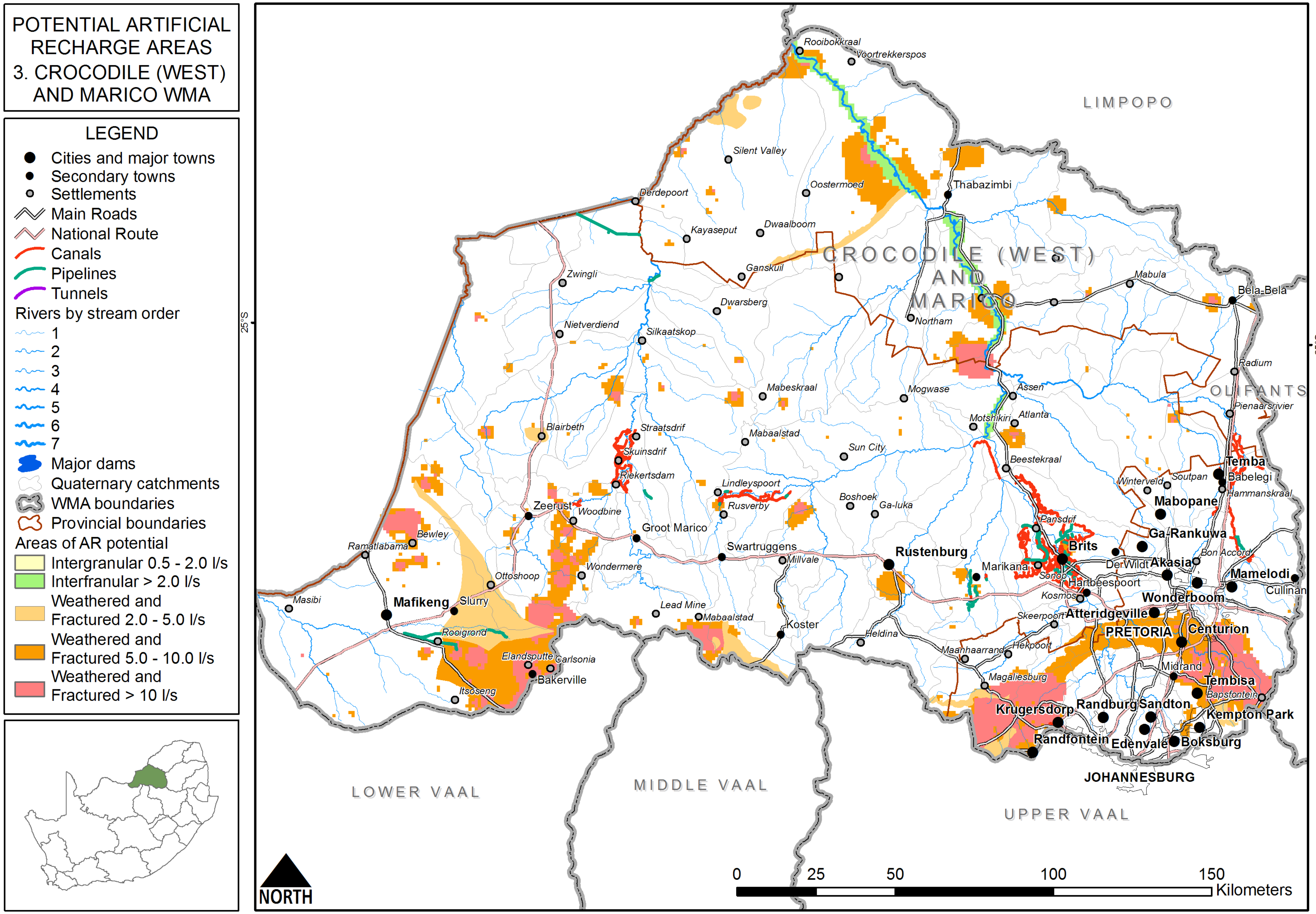
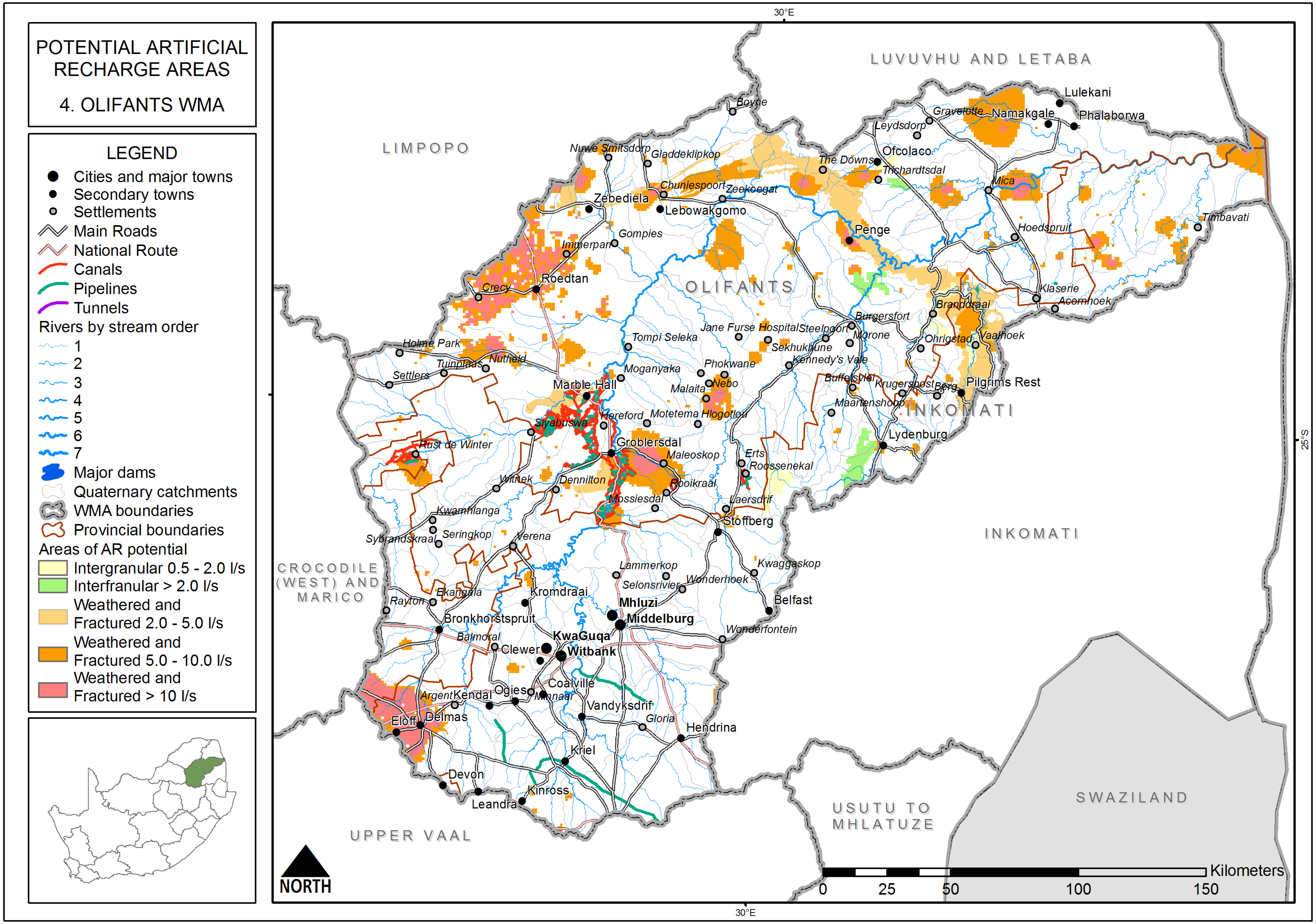
POTENTIAL ARTIFICIAL RECHARGE AREAS 3. CROCODILE (WEST) AND MARICO WMA




POTENTIAL ARTIFICIAL RECHARGE AREAS
4. OLIFANTS WMA
LEGEND
Cities and major towns
Secondary towns
Settlements
Main Roads
National Route
Canals
Pipelines
Tunnels
Rivers by stream order
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Major dams
Quaternary catchments
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
30°E
25°S
LUVUVHU AND LETABA
LIMPOPO
OLIFANTS
INKOMATI
CROCODILE (WEST) AND MARICO
UPPER VAAL
USUTU TO MHLATUZE
SWAZILAND
Lulekani
Phalaborwa
Namakgale
Gravelotte
Leydsdorp
Ofcolaco
The Downs
Trichardtsdal
Mica
Hoedspruit
Timbavati
Klaserie
Acornhoek
Penge
Boyne
Nuwe Smitsdorp
Gladdeklipkop
Chuniespoort
Zeekoegat
Zebediela
Lebowakgomo
Gompies
Immerpan
Roedtan
Crecy
Holme Park
Nutfield
Tuinplaas
Settlers
Tompi Seleka
Jane Furse
Hospital
Steelpoort
Burgersfort
Brandboom
Morone
Ohrigstad
Vaalhoek
Sekhukhune
Kennedy's Vale
Phokwane
Moganyaka
Malaita
Nebo
Marble Hall
Buffelshoek
Krugerspost
Berg
Pilgrims Rest
Maartenshoop
Lydenburg
Hereford
Motetema
Hlogotlou
Siyabuswa
Rust de Winter
Groblersdal
Maleoskop
Erts
Roossenekal
Witnek
Dennilton
Rooikraal
Mossiesdal
Laersdrif
Stoffberg
Kwamhlanga
Seringkop
Sybrandskraal
Verena
Lammerkop
Selonsrivier
Wonderhoek
Kwaggaskop
Belfast
Ekangala
Rayton
Kromdraai
Mhluzi
Middelburg
Bronkhorstspruit
Wonderfontein
Balmoral
Clewer
KwaGuqa
Witbank
Coalville
Argent
Kendal
Ogies
Minnaar
Vandyksdrif
Gloria
Hendrina
Eloff
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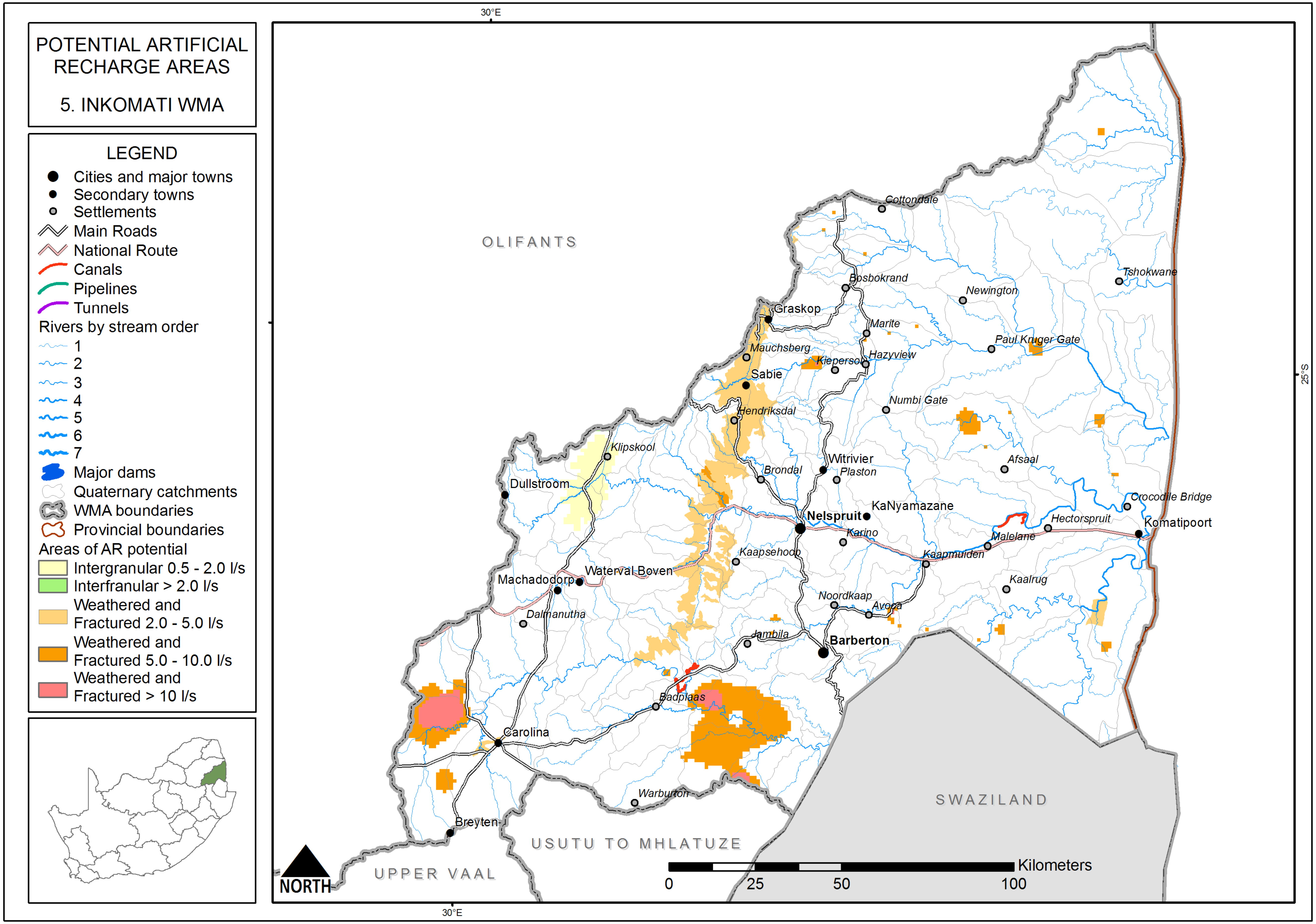
POTENTIAL ARTIFICIAL RECHARGE AREAS
5. INKOMATI WMA
LEGEND
Cities and major towns
Secondary towns
Settlements
Main Roads
National Route
Canals
Pipelines
Tunnels
Rivers by stream order
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Interfranular > 2.0 l/s
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Weathered and Fractured > 10 l/s
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25°S
OLIFANTS
USUTU TO MHLATUZE
UPPER VAAL
SWAZILAND
NORTH
Kilometers
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Tshokwane
Bosbokrand
Newington
Graskop
Marite
Paul Kruger Gate
Mauchsberg
Hazyview
Kiepersol
Sabie
Numbi Gate
Hendriksdal
Klipskool
Witrivier
Afsaal
Brondal
Plaston
Dullstroom
KaNyamazane
Crocodile Bridge
Nelspruit
Hectorspruit
Komatipoort
Karino
Malelane
Kaapsehoop
Kaapmuiden
Waterval-Boven
Machadodorp
Kaalrug
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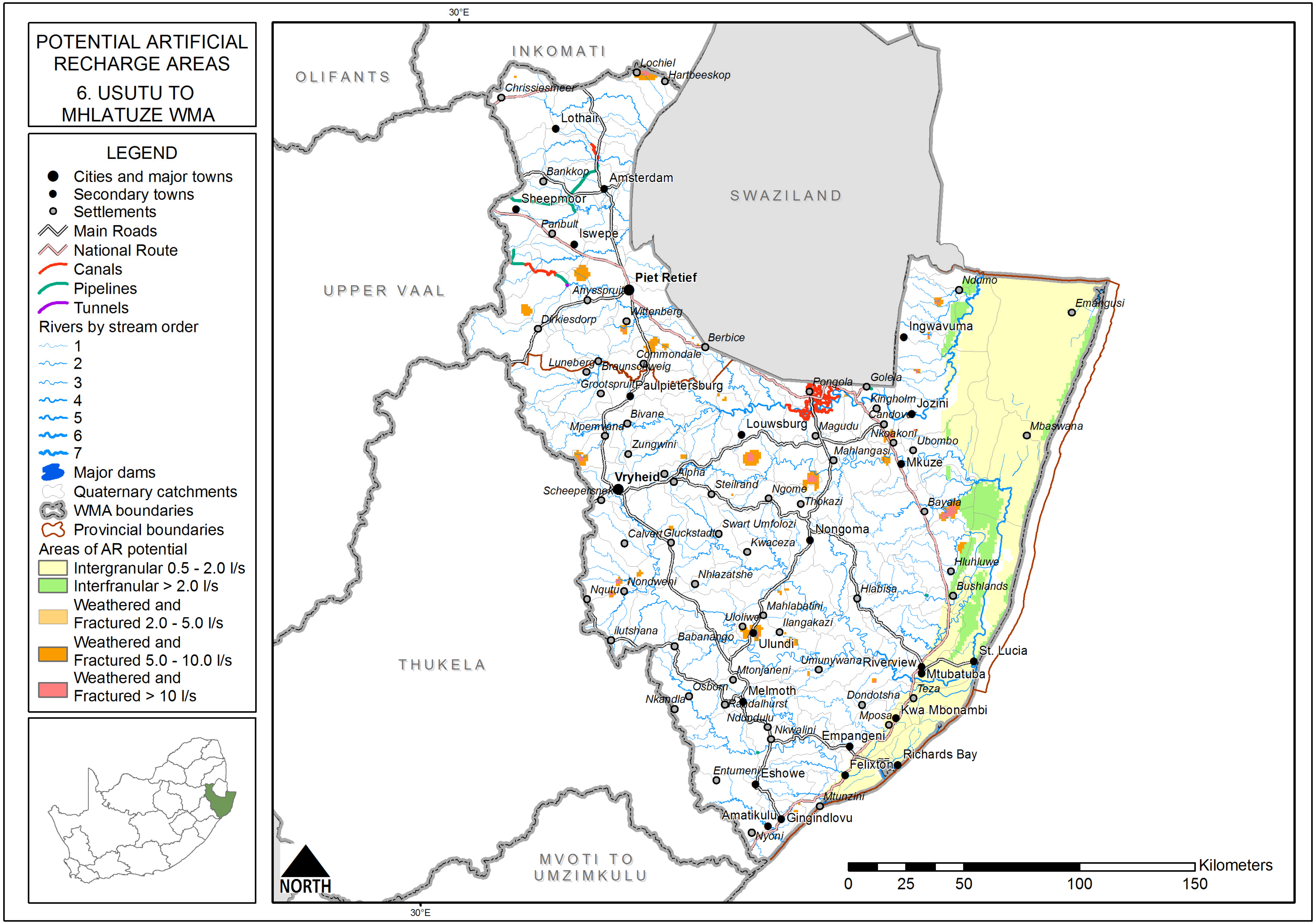
Avoca
Dalmanutha
Jambila
Barberton
Badplaas
Carolina
Warburton
Breyten


POTENTIAL ARTIFICIAL RECHARGE AREAS
6. USUTU TO MHLATUZE WMA
LEGEND
Cities and major towns
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Settlements
Main Roads
National Route
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Interfranular > 2.0 l/s
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Weathered and Fractured 5.0 - 10.0 l/s
Weathered and Fractured > 10 l/s
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INKOMATI
OLIFANTS
UPPER VAAL
SWAZILAND
THUKELA
MVOTI TO UMZIMKULU
Lochiel
Hartbeeskop
Chrissiesmeer
Lothair
Bankkop
Amsterdam
Sheepmoor
Panbult
Iswepe
Piet Retief
Anysspruit
Wittenberg
Dirkiesdorp
Berbice
Commondale
Luneberg
Braunschweig
Grootspruit
Paulpietersburg
Pongola
Golela
Ndumo
Emangusi
Ingwavuma
Kingholm
Jozini
Candover
Bivane
Mpemvana
Louwsburg
Magudu
Nkonkoni
Ubombo
Mbaswana
Zungwini
Mahlangasi
Mkuze
Vryheid
Alpha
Steilrand
Ngome
Scheepersnek
Thokazi
Bayala
Swart Umfolozi
Calvert
Gluckstadt
Nongoma
Kwaceza
Nhlazatshe
Hluhluwe
Nondweni
Nqutu
Hlabisa
Bushlands
Mahlabatini
Ulolilwe
Ilangakazi
ilutshana
Babanango
Ulundi
St. Lucia
Umunywana
Riverview
Mtonjaneni
Mtubatuba
Osborn
Melmoth
Teza
Nkandla
Ramdalhurst
Dondotsha
Nundulu
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Nkwalini
Empangeni
Richards Bay
Felixton
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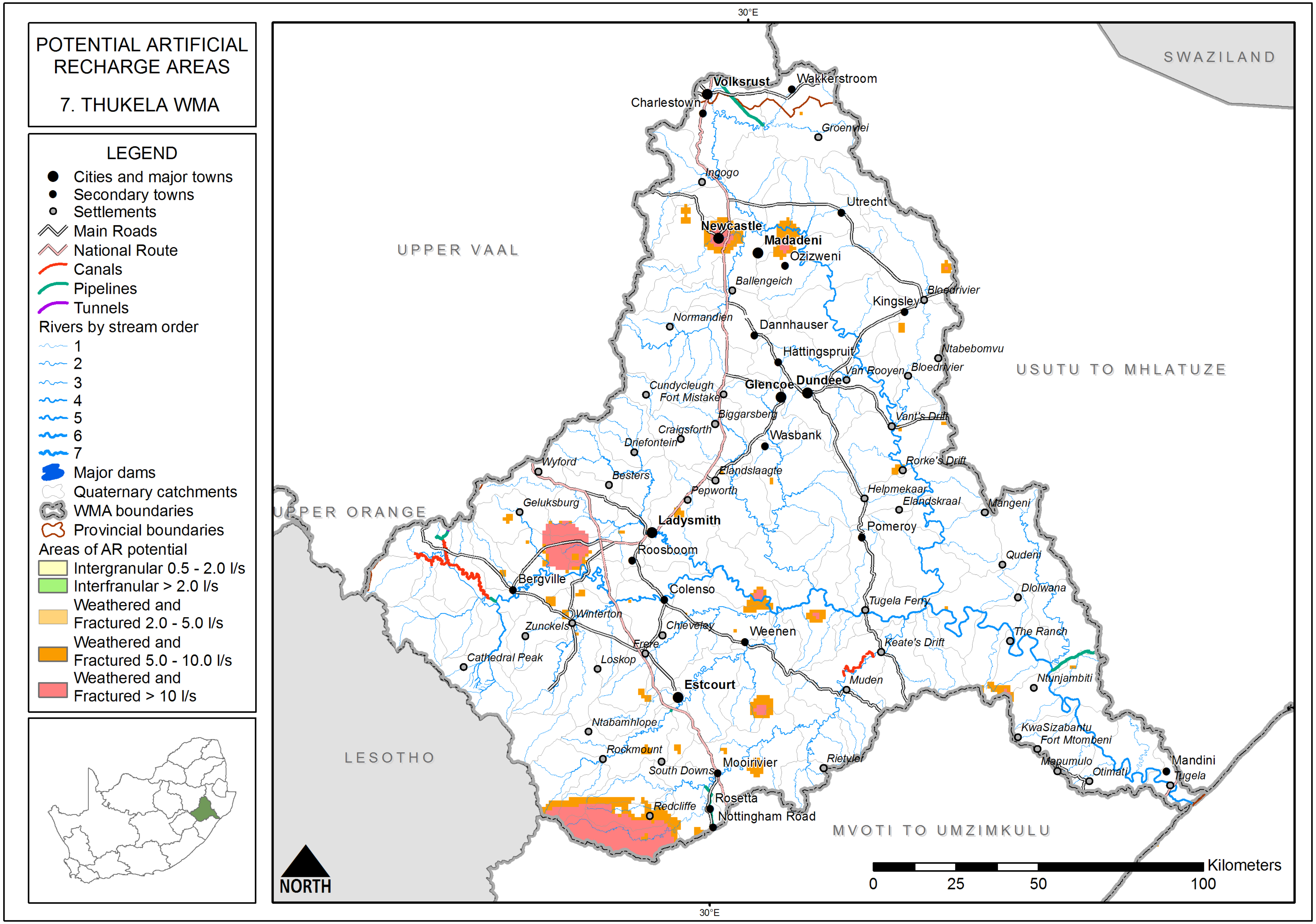
POTENTIAL ARTIFICIAL RECHARGE AREAS
7. THUKELA WMA
LEGEND
Cities and major towns
Secondary towns
Settlements
Main Roads
National Route
Canals
Pipelines
Tunnels
Rivers by stream order
1
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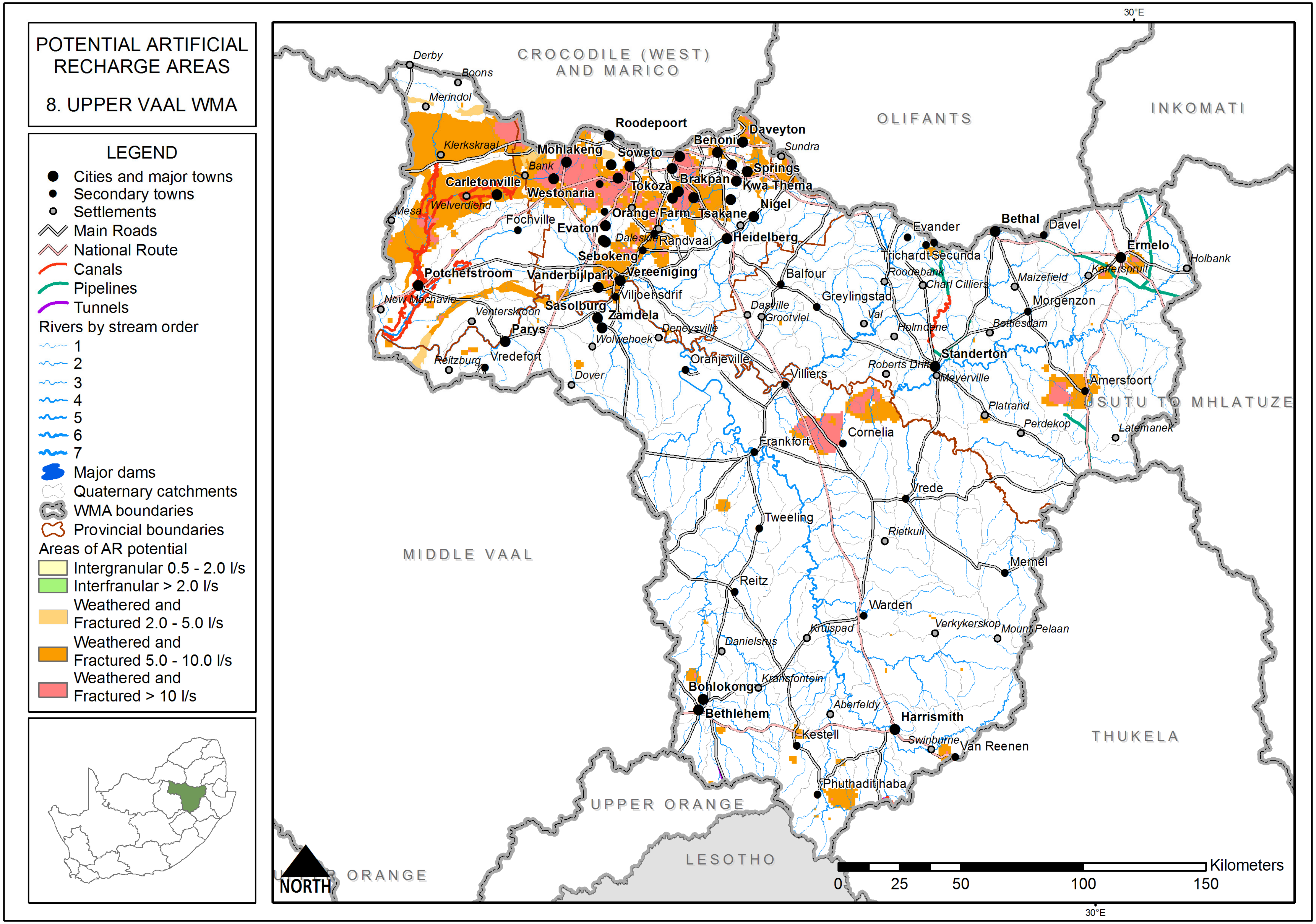
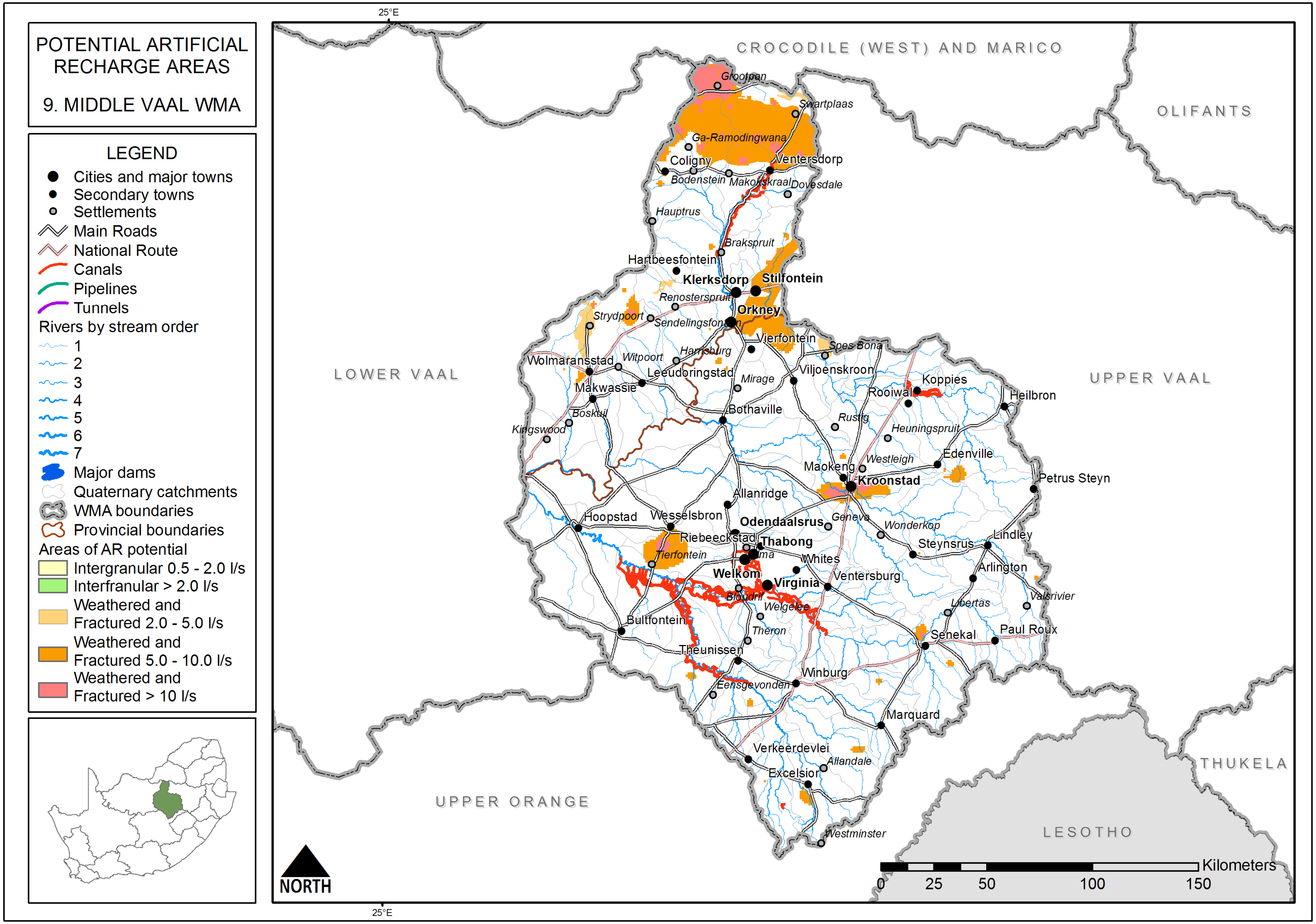
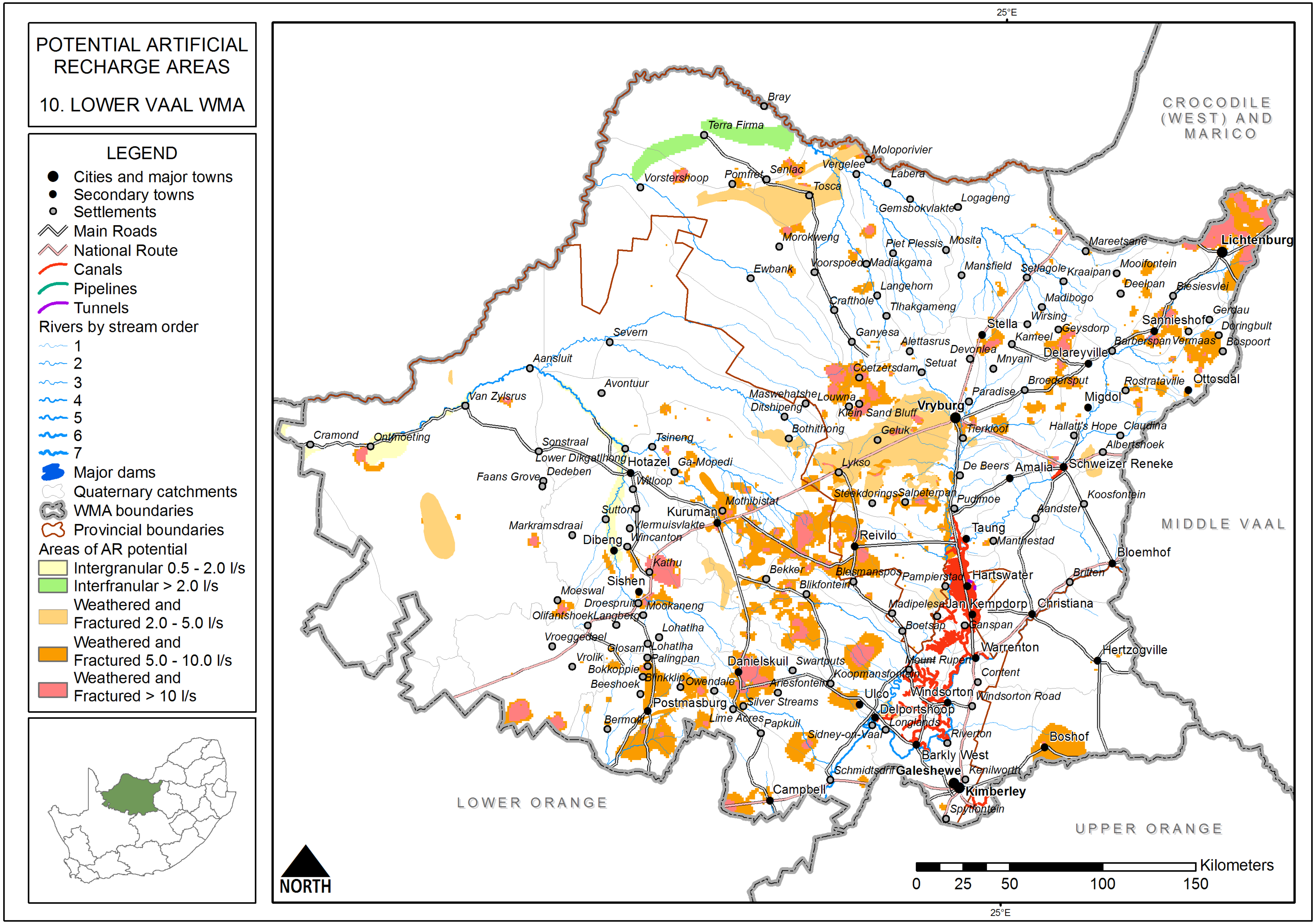
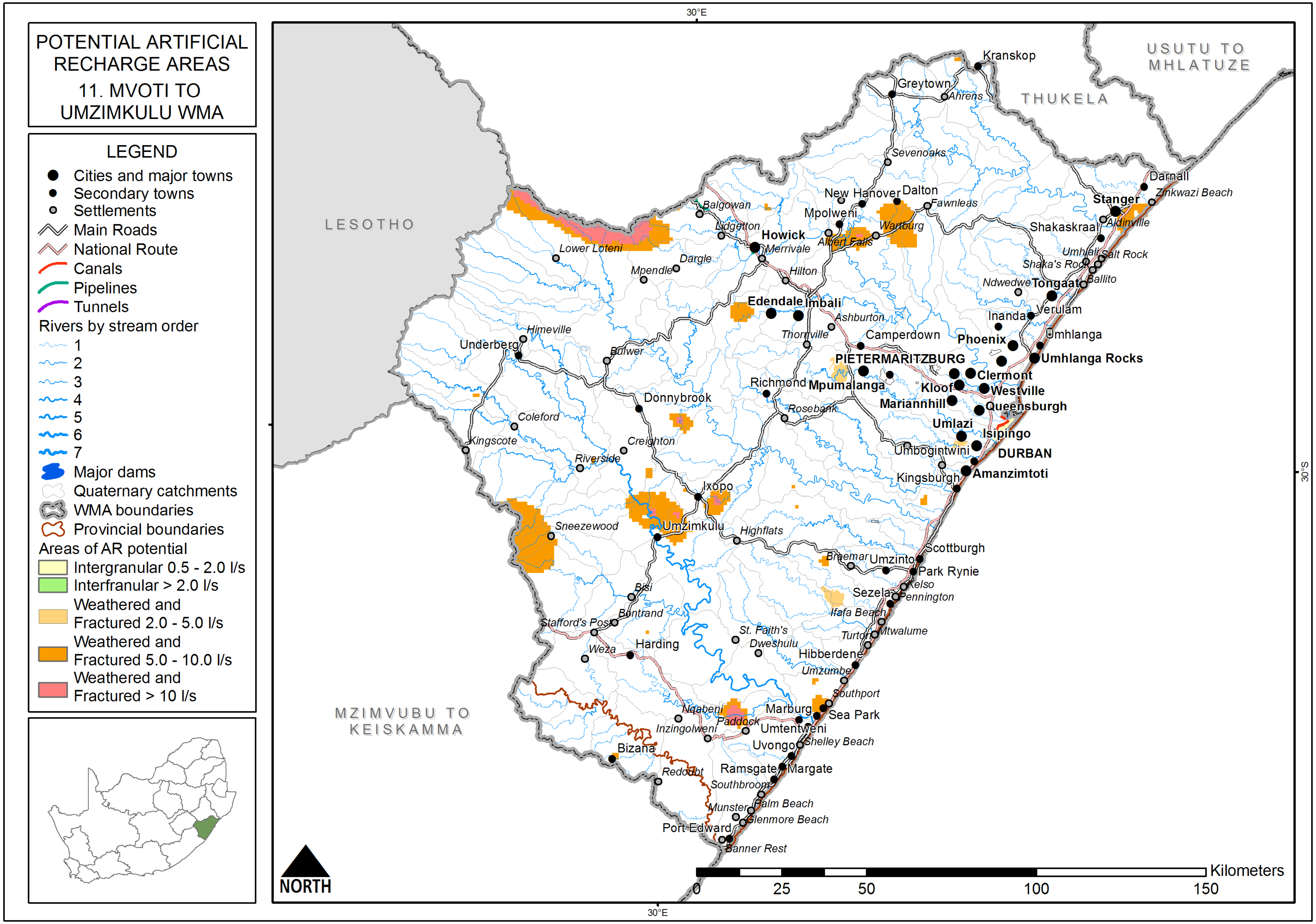
4
5
6
7
Major dams
Quaternary catchments
WMA boundaries
Provincial boundaries
Areas of AR potential
Intergranular 0.5 - 2.0 l/s
Interfranular > 2.0 l/s
Weathered and Fractured 2.0 - 5.0 l/s
Weathered and Fractured 5.0 - 10.0 l/s
Weathered and Fractured > 10 l/s
30°E
SWAZILAND
UPPER VAAL
USUTU TO MHLATUZE
UPPER ORANGE
LESOTHO
MVOTI TO UMZIMKULU
Volksrust
Wakkerstroom
Charlestown
Groenvlei
Ingogo
Utrecht
Newcastle
Madadeni
Ozizweni
Ballengeich
Bloedrivier
Kingsley
Normandien
Dannhauser
Hattingspruit
Ntabebomvu
Van Rooyen
Bloedrivier
Cundycleugh
Fort Mistake
Glencoe
Dundee
Biggarsberg
Vant's Drift
Craigsforth
Driefontein
Wasbank
Rorke's Drift
Wyford
Besters
Elandslaagte
Helpmekaar
Pepworth
Elandskraal
Mangeni
Geluksburg
Ladysmith
Pomeroy
Roosboom
Qudeni
Bergville
Colenso
Dlolwana
Tugela Ferry
Winterton
Zunckels
Chieveley
Weenen
The Ranch
Keate's Drift
Frere
Cathedral Peak
Loskop
Muden
Ntunjambiti
Estcourt
Ntabamhlope
KwaSizabantu
Fort Mtombeni
Rockmount
Mooirivier
Rietvlei
Mapumulo
Mandini
South Downs
Otimati
Tugela
Rosetta
Redcliffe
Nottingham Road
NORTH
0
25
50
100
Kilometers


POTENTIAL ARTIFICIAL RECHARGE AREAS
8. UPPER VAAL WMA
LEGEND
Cities and major towns
Secondary towns
Settlements
Main Roads
National Route
Canals
Pipelines
Tunnels
Rivers by stream order
1
2
3
4
5
6
7
Major dams
Quaternary catchments
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
CROCODILE (WEST) AND MARICO
OLIFANTS
INKOMATI
USUTU TO MHLATUZE
MIDDLE VAAL
THUKELA
UPPER ORANGE
LESOTHO
Derby
Boons
Merindol
Klerkskraal
Roodepoort
Daveyton
Benoni
Sundra
Mohlakeng
Soweto
Springs
Bank
Carletonville
Brakpan
Kwa Thema
Tokoza
Westonaria
Nigel
Mesa
Welverdiend
Orange Farm
Tsakane
Fochville
Evaton
Heidelberg
Dalesíde
Randvaal
Sebokeng
Evander
Bethal
Davel
Ermelo
Holbank
Kaffirspruit
Trichardt
Secunda
Roodebank
Charl Cilliers
Maizefield
Morgenzon
Potchefstroom
Vanderbijlpark
Vereeniging
Balfour
Viljoensdrif
Greylingstad
New Machavie
Sasolburg
Dasville
Grootvlei
Venterskroon
Zamdela
Val
Bettiesdam
Parys
Deneysville
Holmdene
Standerton
Wolwehoek
Reitzburg
Vredefort
Oranjeville
Roberts Drift
Meyerville
Dover
Villiers
Amersfoort
Platrand
Perdekop
Latemanek
Cornelia
Frankfort
Vrede
Tweeling
Rietkuil
Memel
Reitz
Warden
Verkykerskop
Mount Pelaan
Kruispad
Danielsrus
Kransfontein
Bohlokong
Aberfeldy
Bethlehem
Harrismith
Kestell
Swinburne
Van Reenen
Phuthaditjhaba
NORTH
0
25
50
100
150
Kilometers
30°E


POTENTIAL ARTIFICIAL RECHARGE AREAS
9. MIDDLE VAAL WMA
LEGEND
Cities and major towns
Secondary towns
Settlements
Main Roads
National Route
Canals
Pipelines
Tunnels
Rivers by stream order
1
2
3
4
5
6
7
Major dams
Quaternary catchments
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
25°E
CROCODILE (WEST) AND MARICO
OLIFANTS
LOWER VAAL
UPPER VAAL
UPPER ORANGE
LESOTHO
THUKELA
Grootpan
Swartplaas
Ga-Ramodingwana
Coligny
Ventersdorp
Bodenstein
Makokskraal
Dovesdale
Hauptrus
Brakspruit
Hartbeesfontein
Klerksdorp
Stilfontein
Renostersprui
Orkney
Strydpoort
Sendelingsfon
Vierfontein
Spes Bona
Wolmaransstad
Witpoort
Hamburg
Leeudoringstad
Viljoenskroon
Mirage
Koppies
Makwassie
Rooiwal
Heilbron
Boskuil
Bothaville
Rustig
Kingswood
Heuningspruit
Edenville
Westleigh
Maokeng
Kroonstad
Petrus Steyn
Allanridge
Hoopstad
Wesselsbron
Odendaalsrus
Geneva
Wonderkop
Riebeeckstad
Thabong
Steynsrus
Lindley
Tierfontein
Whites
Arlington
Welkom
Virginia
Ventersburg
Bloudrif
Welgelee
Libertas
Valsrivier
Bultfontein
Theron
Senekal
Paul Roux
Theunissen
Winburg
Eensgevonden
Marquard
Verkeerdevlei
Allandale
Excelsior
Westminster
NORTH
0
25
50
100
150
Kilometers

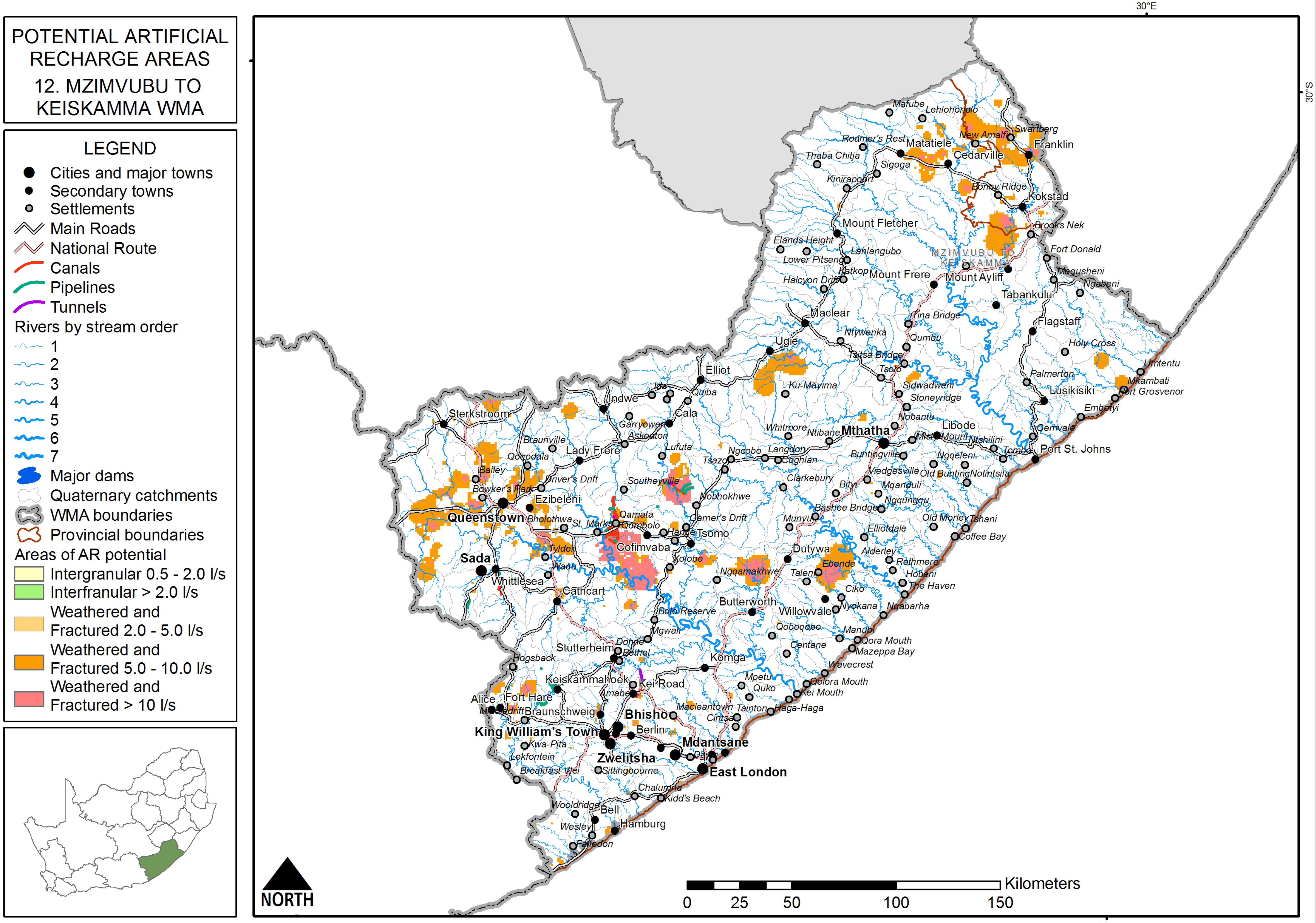


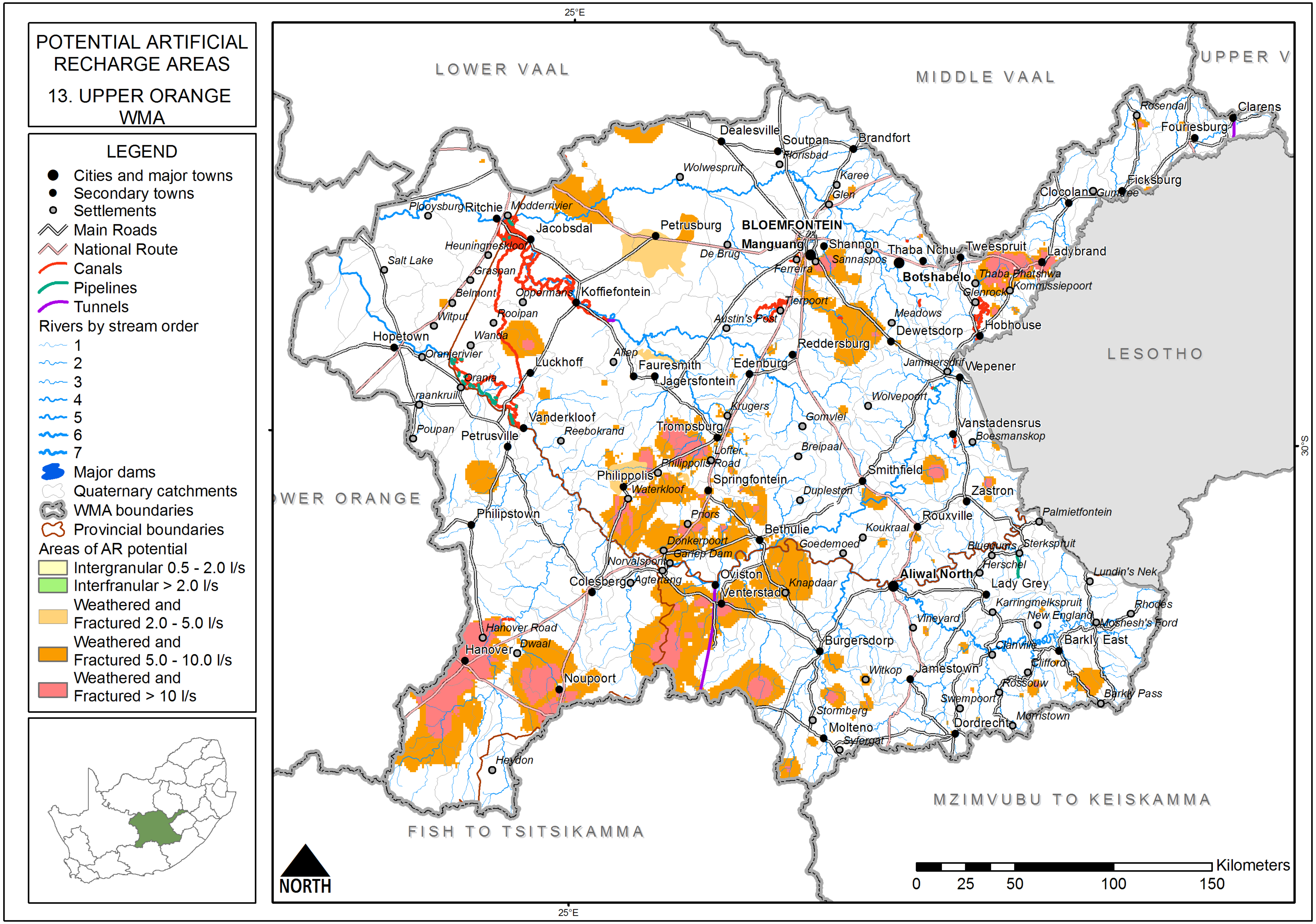
POTENTIAL ARTIFICIAL RECHARGE AREAS
10. LOWER VAAL WMA
LEGEND
Cities and major towns
Secondary towns
Settlements
Main Roads
National Route
Canals
Pipelines
Tunnels
Rivers by stream order
1
2
3
4
5
6
7
Major dams
Quaternary catchments
WMA boundaries
Provincial boundaries
Areas of AR potential
Intergranular 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
NORTH
Kilometers
0
25
50
100
150
25°E
CROCODILE (WEST) AND MARICO
MIDDLE VAAL
UPPER ORANGE
LOWER ORANGE
Bray
Terra Firma
Moloporivier
Vergelee
Senlac
Pomfret
Vorstershoop
Tosca
Labera
Gemsbokvlakte
Logageng
Morokweng
Piet Plessis
Mosita
Mareetsane
Lichtenburg
Ewbank
Voorspoed
Madiakgama
Mansfield
Setlagole
Kraaipan
Mooifontein
Deelpan
Biesiesvlei
Langehorn
Crafthole
Tlhakgameng
Madibogo
Wirsing
Stella
Sannieshof
Gerdau
Doringbult
Bospoort
Ganyesa
Alettasrus
Kameel
Geysdorp
Barberspan
Vermaas
Devonlea
Mnyani
Delareyville
Coetzersdam
Setuat
Severn
Aansluit
Avontuur
Van Zylsrus
Broedersput
Rostrataville
Ottosdal
Paradise
Maswehatshe
Louwna
Ditshipeng
Klein Sand Bluff
Vryburg
Migdol
Tierkloof
Hallatt's Hope
Claudina
Bothithong
Geluk
Albertshoek
Cramond
Ontmoeting
Sonstraal
Tsineng
Lower Dikgatlhong
Hotazel
Ga-Mopedi
Lykso
De Beers
Amalia
Schweizer Reneke
Faans Grove
Dedeben
Witloop
Steekdorings
Salpeterpan
Pudimoe
Koosfontein
Mothibistat
Sutton
Kuruman
Aandster
Markramsdraai
Vlermuisvlakte
Wincanton
Taung
Manthestad
Dibeng
Reivilo
Kathu
Bloemhof
Bekker
Blesmanspos
Pampierstad
Hartswater
Britten
Sishen
Blikfontein
Moeswal
Droespruit
Mookaneng
Madipelesa
Jan Kempdorp
Christiana
Olifantshoek
Langberg
Boetsap
Ganspan
Lohatlha
Vroeggedeel
Glosam
Warrenton
Hertzogville
Vrolik
Palingpan
Danielskuil
Swartputs
Mount Rupert
Bokkoppie
Koopmansfontein
Content
Beeshoek
Brinkklip
Owendale
Ariesfontein
Windsorton
Windsorton Road
Postmasburg
Ulco
Silver Streams
Delportshoop
Bermolli
Lime Acres
Papkuil
Longlands
Sidney-on-Vaal
Riverton
Boshof
Barkly West
Schmidtsdrif
Galeshewe
Kenilworth
Campbell
Kimberley
Spytfontein

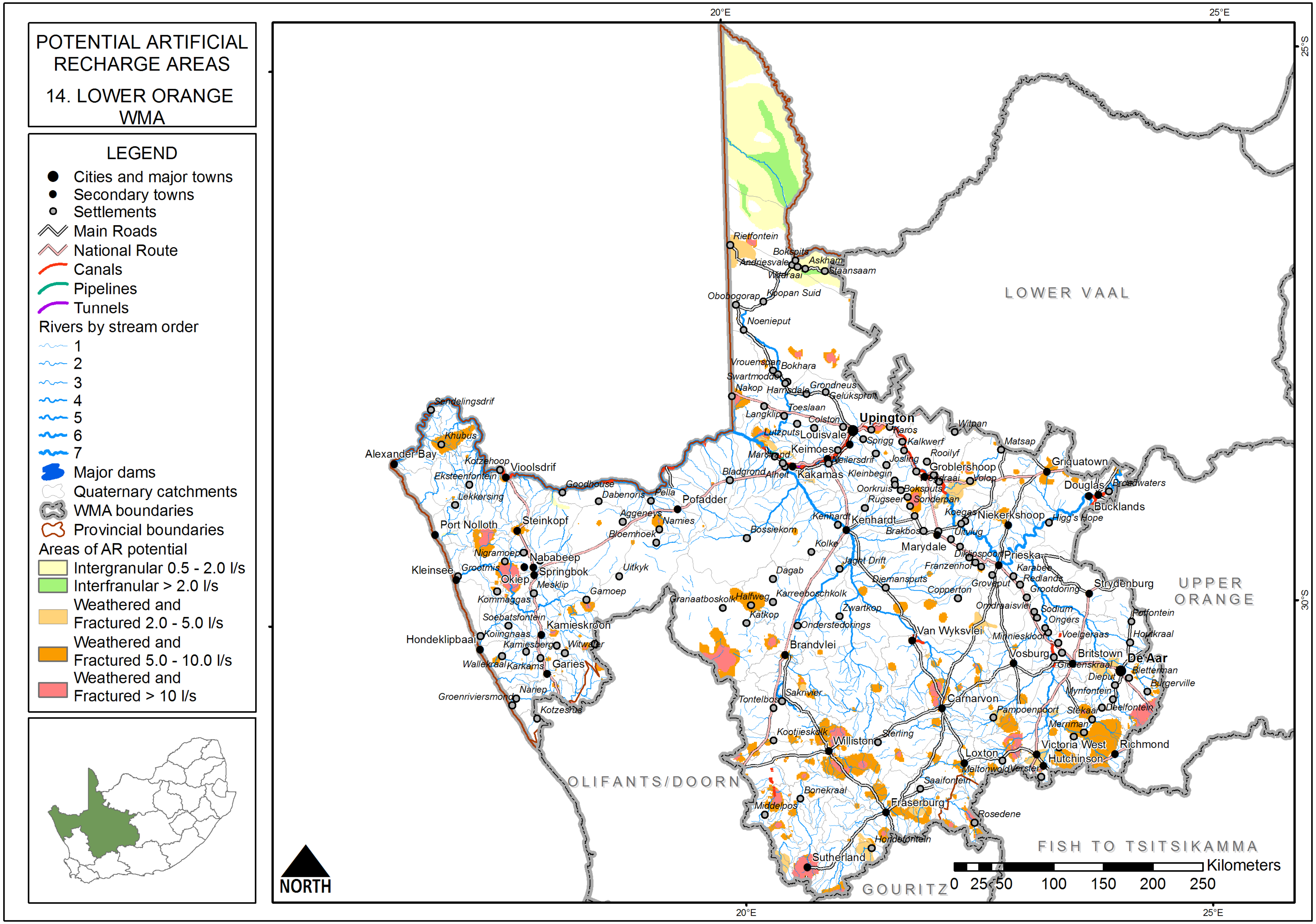


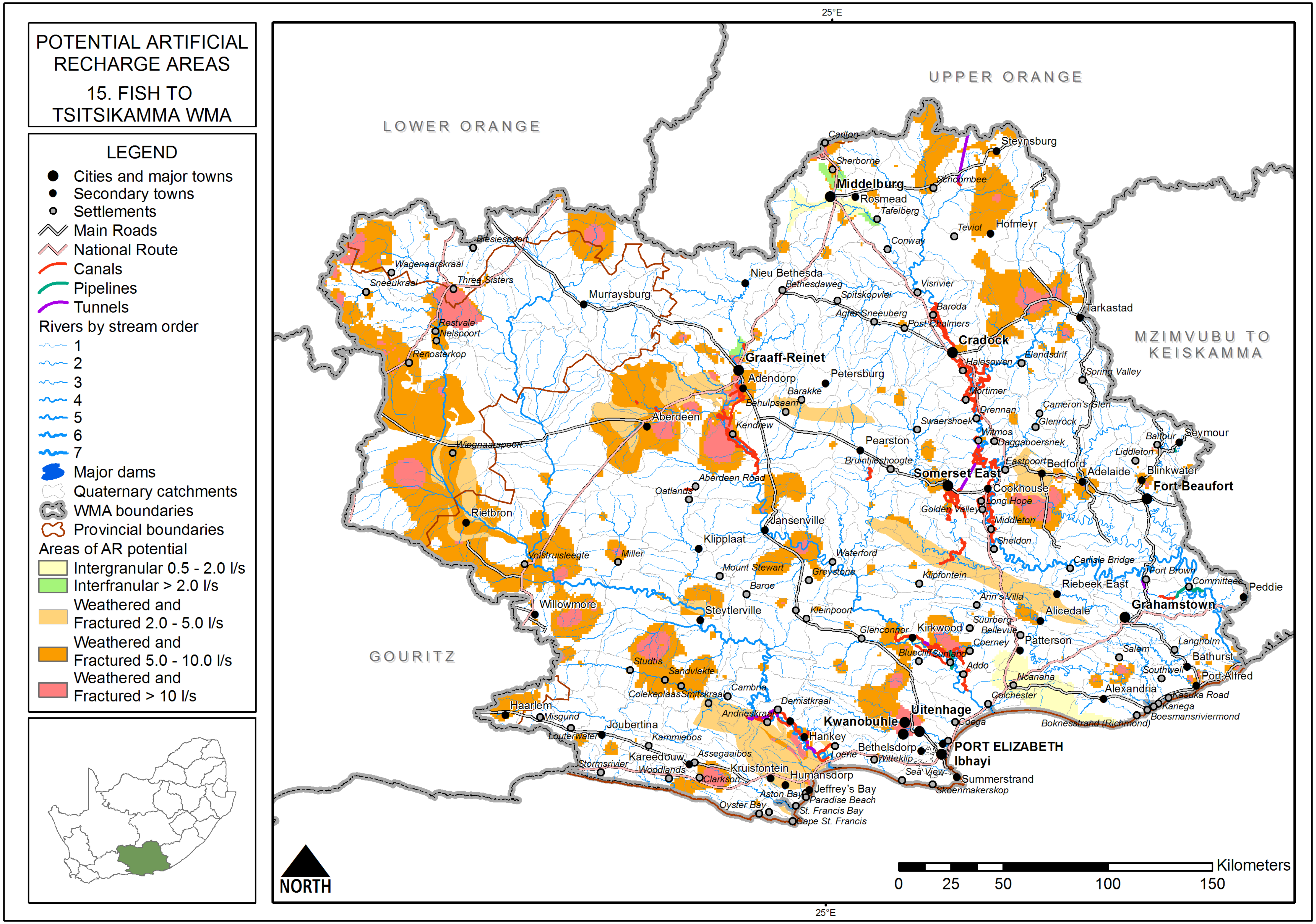
POTENTIAL ARTIFICIAL RECHARGE AREAS
11. MVOTI TO UMZIMKULU WMA
LEGEND
Cities and major towns
Secondary towns
Settlements
Main Roads
National Route
Canals
Pipelines
Tunnels
Rivers by stream order
1
2
3
4
5
6
7
Major dams
Quaternary catchments
WMA boundaries
Provincial boundaries
Areas of AR potential
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
LESOTHO
THUKELA
USUTU TO MHLATUZE
MZIMVUBU TO KEISKAMMA
PIETERMARITZBURG
DURBAN
Kranskop
Greytown
Ahrens
Sevenoaks
New Hanover
Dalton
Fawnleas
Mpolweni
Wartburg
Howick
Merrivale
Albert Falls
Balgowan
Lidgetton
Lower Loteni
Dargle
Mpendle
Hilton
Edendale
Imbali
Ashburton
Thornville
Camperdown
Himeville
Underberg
Bulwer
Richmond
Mpumalanga
Donnybrook
Rosebank
Coleford
Kingscote
Creighton
Riverside
Ixopo
Sneezewood
Umzimkulu
Highflats
Stanger
Darnall
Zinkwazi Beach
Aldinville
Shakaskraal
Umhlali
Salt Rock
Shaka's Rock
Ballito
Ndwedwe
Tongaat
Inanda
Verulam
Phoenix
Umhlanga
Umhlanga Rocks
Clermont
Kloof
Westville
Mariannhill
Queensburgh
Umlazi
Isipingo
Umbogintwini
Amanzimtoti
Kingsburgh
Scottburgh
Braemar
Umzinto
Park Rynie
Kelso
Sezela
Pennington
Ifafa Beach
Turton
Mtwalume
Bisi
Pontrand
Stafford's Post
Weza
Harding
St. Faith's
Dweshulu
Hibberdene
Umzumbe
Southport
Marburg
Sea Park
Ngabeni
Paddock
Inzingolweni
Umtentweni
Uvongo
Shelley Beach
Bizana
Redoubt
Ramsgate
Margate
Southbroom
Palm Beach
Munster
Glenmore Beach
Port Edward
Banner Rest
30°E
30°S
NORTH
Kilometers
0
25
50
100
150

POTENTIAL ARTIFICIAL RECHARGE AREAS
12. MZIMVUBU TO KEISKAMMA WMA

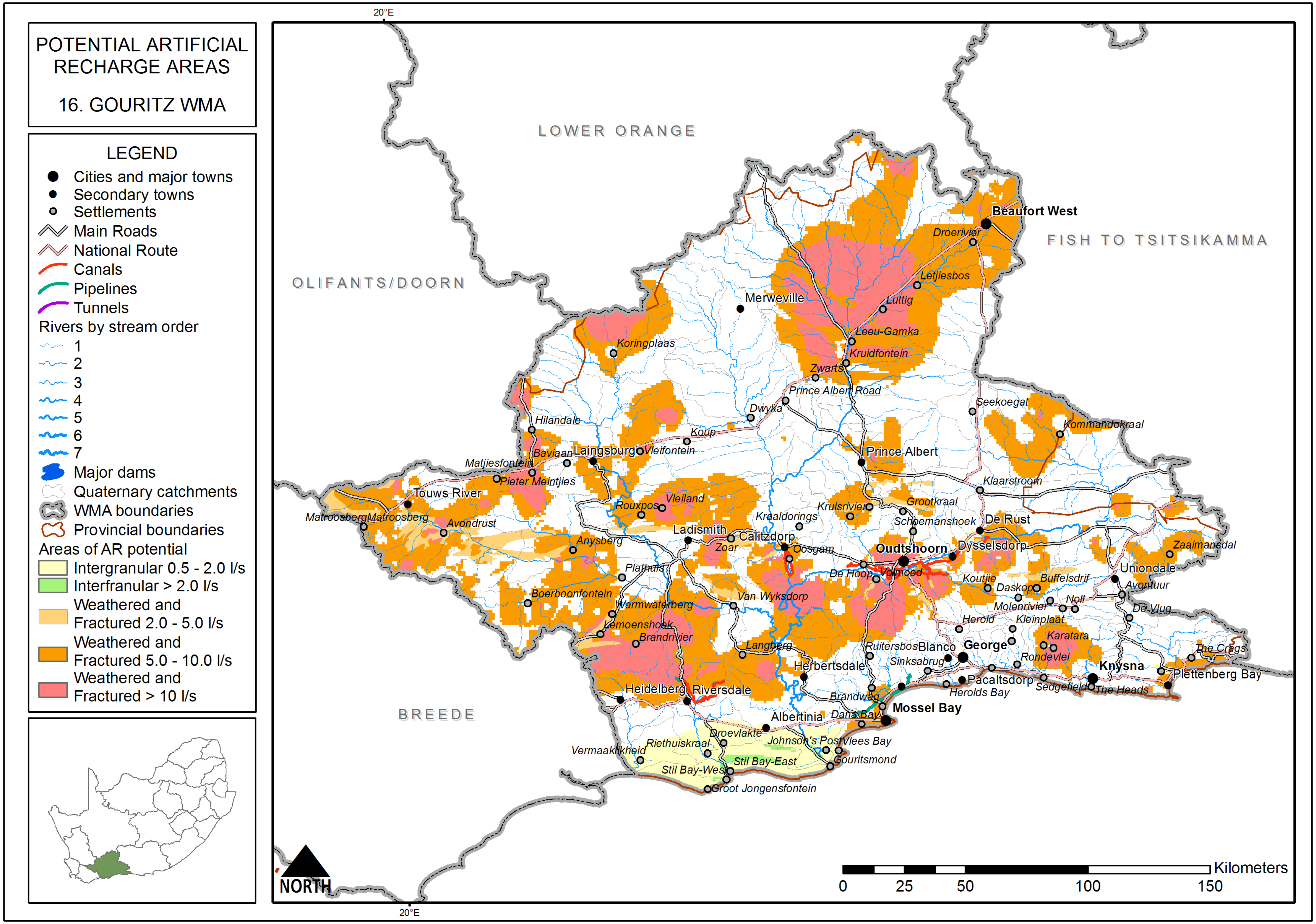



POTENTIAL ARTIFICIAL RECHARGE AREAS
13. UPPER ORANGE WMA
LEGEND
Cities and major towns
Secondary towns
Settlements
Main Roads
National Route
Canals
Pipelines
Tunnels
Rivers by stream order
1
2
3
4
5
6
7
Major dams
Quaternary catchments
WMA boundaries
Provincial boundaries
Areas of AR potential
Intergranular 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
25°E
30°S
LOWER VAAL
MIDDLE VAAL
UPPER V
LESOTHO
WER ORANGE
FISH TO TSITSIKAMMA
MZIMVUBU TO KEISKAMMA
BLOEMFONTEIN
Manguang
Botshabelo
Thaba Nchu
Aliwal North
Dealesville
Soutpan
Brandfort
Petrusburg
Jacobsdal
Ritchie
Koffiefontein
Hopetown
Luckhoff
Fauresmith
Jagersfontein
Edenburg
Reddersburg
Dewetsdorp
Wepener
Trompsburg
Philippolis
Springfontein
Smithfield
Zastron
Rouxville
Bethulie
Colesberg
Oviston
Venterstad
Burgersdorp
Jamestown
Lady Grey
Barkly East
Molteno
Dordrecht
Hanover
Noupoort
Petrusville
Vanderkloof
Philipstown
Ladybrand
Clocolan
Ficksburg
Fouriesburg
Clarens
Hobhouse
Tweespruit
Vanstadensrus
NORTH
0
25
50
100
150
Kilometers


POTENTIAL ARTIFICIAL RECHARGE AREAS
14. LOWER ORANGE WMA
LEGEND
Cities and major towns
Secondary towns
Settlements
Main Roads
National Route
Canals
Pipelines
Tunnels
Rivers by stream order
1
2
3
4
5
6
7
Major dams
Quaternary catchments
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
NORTH
20°E
25°E
25°S
30°S
LOWER VAAL
UPPER ORANGE
OLIFANTS/DOORN
FISH TO TSITSIKAMMA
GOURITZ
0 25 50 100 150 200 250
Kilometers
Upington
Alexander Bay
Vioolsdrif
Port Nolloth
Steinkopf
Nababeep
Springbok
Okiep
Kleinsee
Hondeklipbaai
Kamieskroon
Garies
Pofadder
Keimoes
Kakamas
Louisvale
Groblershoop
Griquatown
Douglas
Bucklands
Kenhardt
Niekerkshoop
Marydale
Prieska
Strydenburg
Van Wyksvlei
Brandvlei
Vosburg
Britstown
De Aar
Carnarvon
Williston
Loxton
Victoria West
Hutchinson
Richmond
Fraserburg
Sutherland



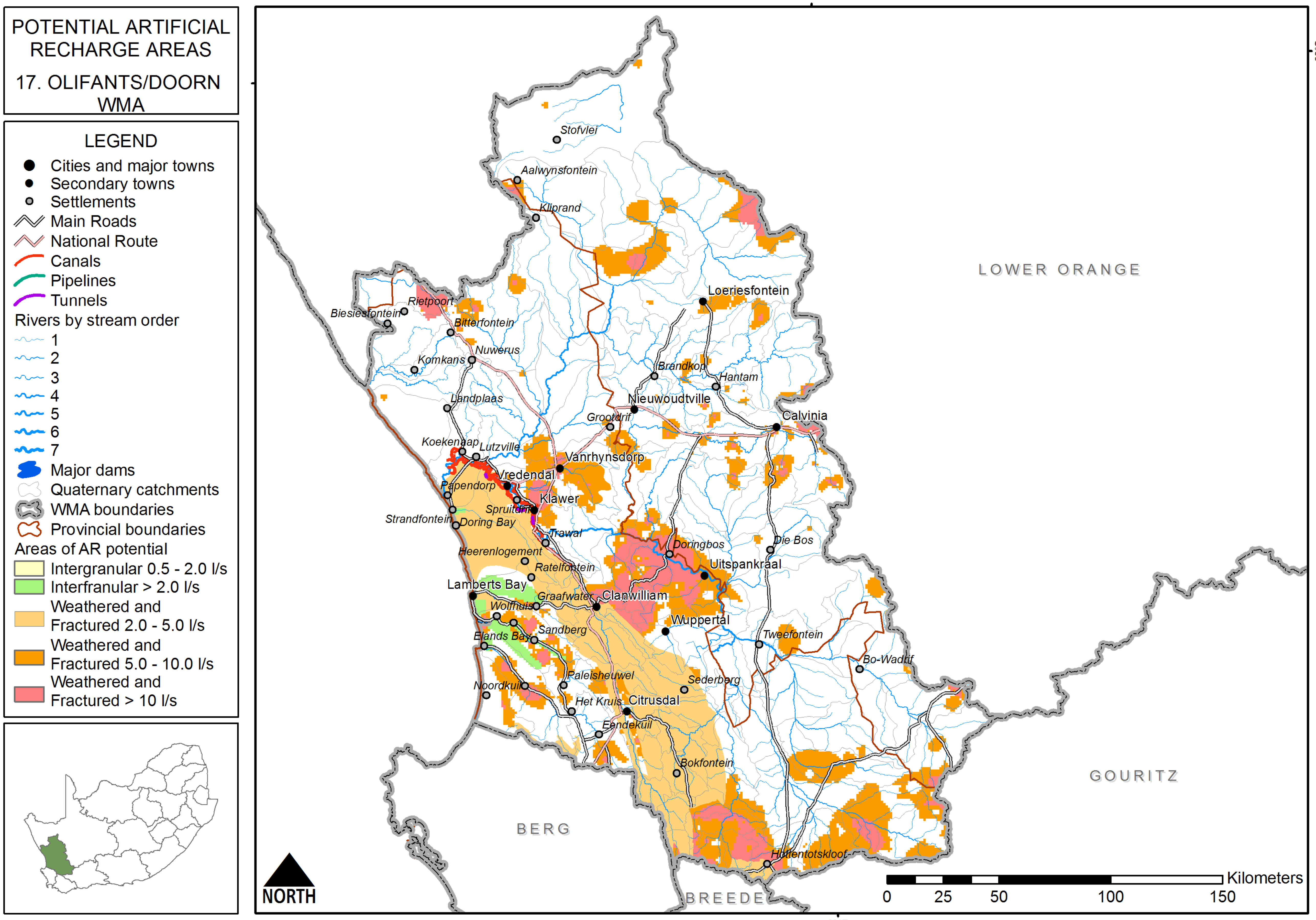
POTENTIAL ARTIFICIAL RECHARGE AREAS
15. FISH TO TSITSIKAMMA WMA
LEGEND
Cities and major towns
Secondary towns
Settlements
Main Roads
National Route
Canals
Pipelines
Tunnels
Rivers by stream order
1
2
3
4
5
6
7
Major dams
Quaternary catchments
WMA boundaries
Provincial boundaries
Areas of AR potential
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
25°E
LOWER ORANGE
UPPER ORANGE
MZIMVUBU TO KEISKAMMA
GOURITZ
Middelburg
Steynsburg
Hofmeyr
Tarkastad
Nieu Bethesda
Murraysburg
Graaff-Reinet
Adendorp
Petersburg
Cradock
Aberdeen
Pearston
Somerset East
Cookhouse
Bedford
Adelaide
Fort Beaufort
Seymour
Blinkwater
Rietbron
Jansenville
Klipplaat
Willowmore
Steytlerville
Riebeek-East
Grahamstown
Peddie
Alicedale
Kirkwood
Patterson
Alexandria
Bathurst
Port Alfred
Uitenhage
Kwanobuhle
PORT ELIZABETH
Ibhayi
Summerstrand
Bethelsdorp
Hankey
Humansdorp
Jeffrey's Bay
Kruisfontein
Kareedouw
Joubertina
Haarlem
NORTH
0 25 50 100 150
Kilometers

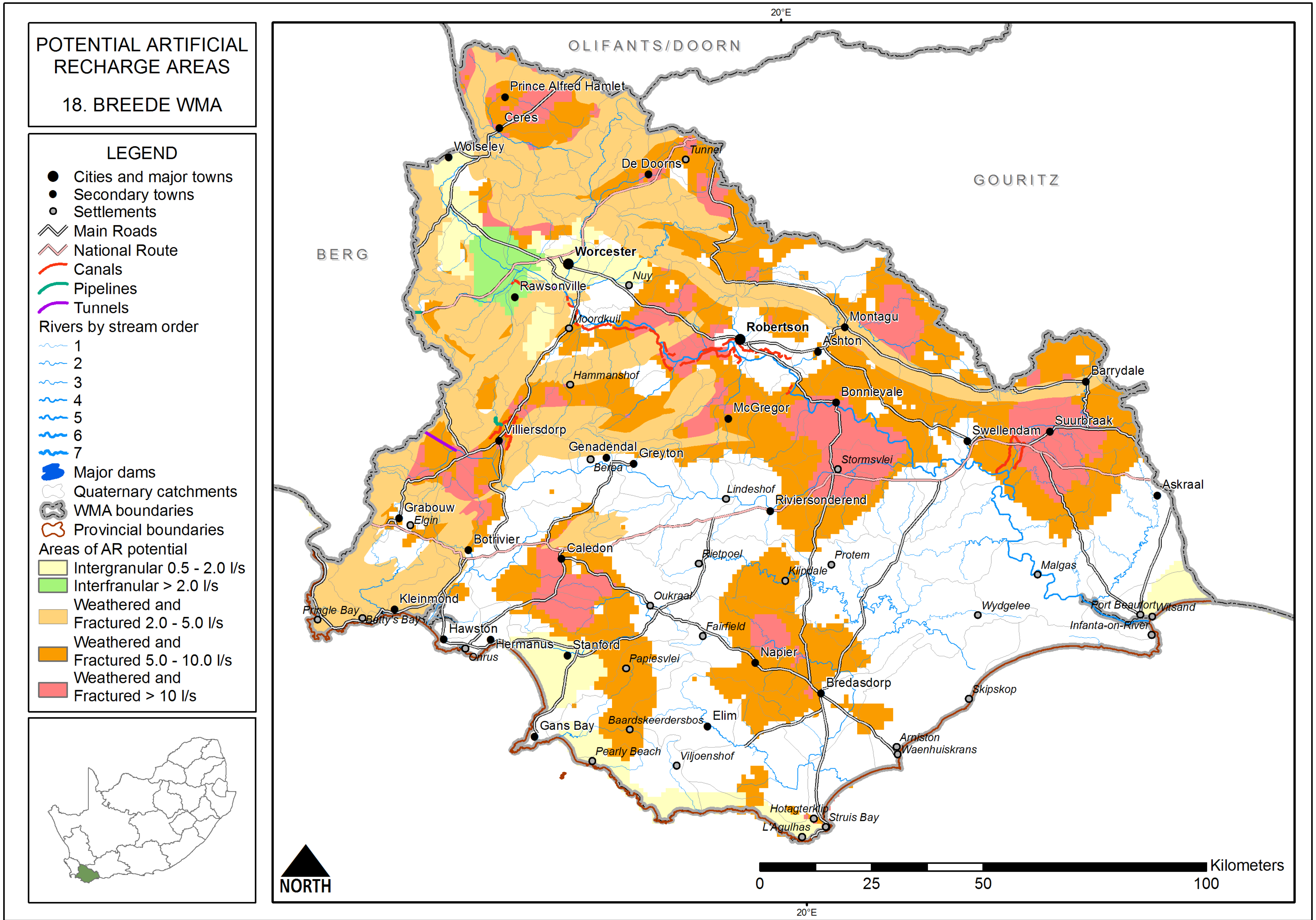


POTENTIAL ARTIFICIAL RECHARGE AREAS
16. GOURITZ WMA
LEGEND
Cities and major towns
Secondary towns
Settlements
Main Roads
National Route
Canals
Pipelines
Tunnels
Rivers by stream order
1
2
3
4
5
6
7
Major dams
Quaternary catchments
WMA boundaries
Provincial boundaries
Areas of AR potential
Intergranular 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
LOWER ORANGE
FISH TO TSITSIKAMMA
OLIFANTS/DOORN
BREEDE
20°E
Beaufort West
Merweville
Laingsburg
Prince Albert
Oudtshoorn
George
Mossel Bay
Knysna
Plettenberg Bay
Ladismith
Calitzdorp
De Rust
Heidelberg
Riversdale
Albertinia
Touws River
Kilometers
0
25
50
100
150
NORTH

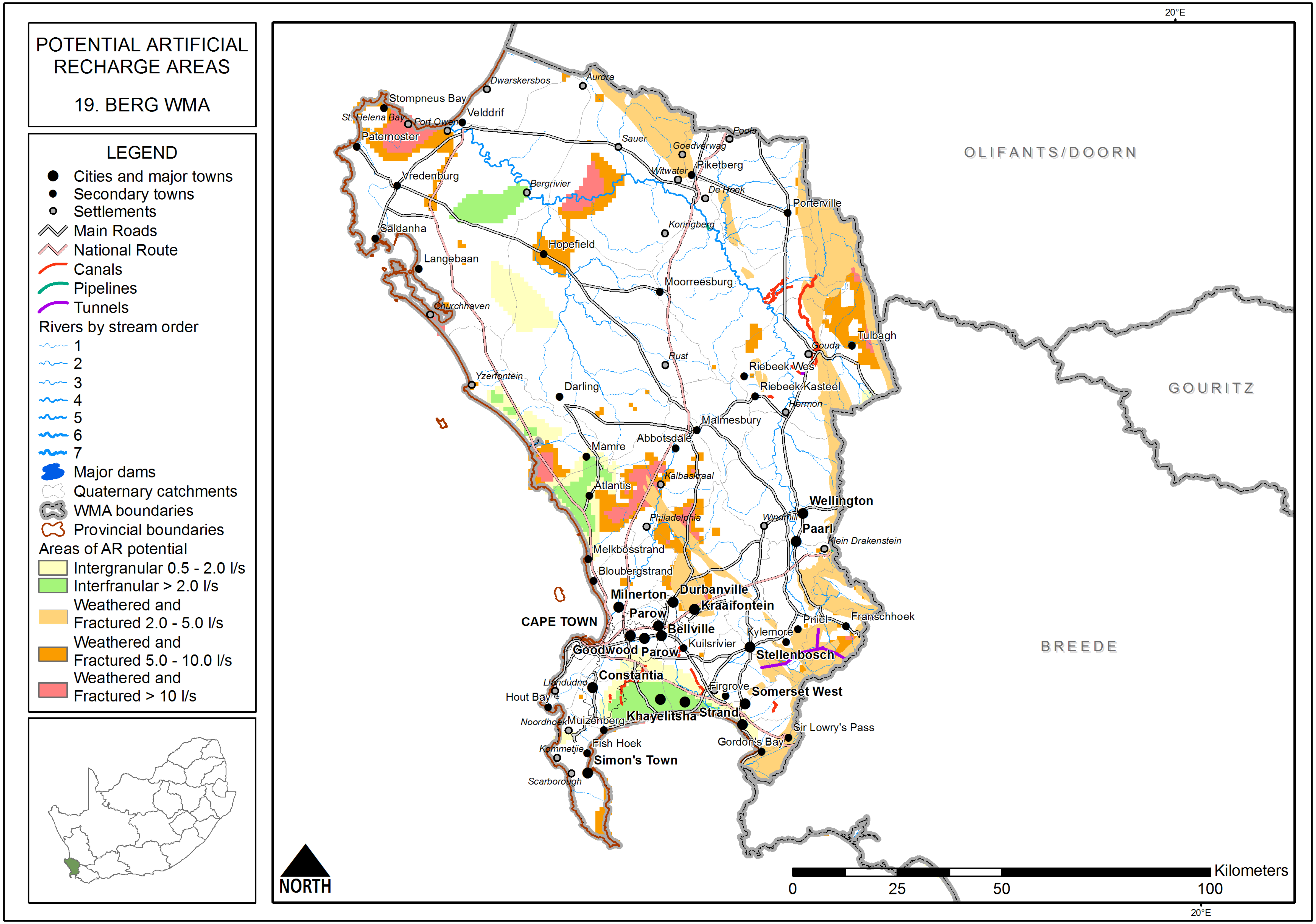
POTENTIAL ARTIFICIAL RECHARGE AREAS

17. OLIFANTS/DOORN WMA





POTENTIAL ARTIFICIAL RECHARGE AREAS
18. BREEDE WMA
LEGEND
Cities and major towns
Secondary towns
Settlements
Main Roads
National Route
Canals
Pipelines
Tunnels
Rivers by stream order
1
2
3
4
5
6
7
Major dams
Quaternary catchments
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
OLIFANTS/DOORN
GOURITZ
BERG
20°E
Prince Alfred Hamlet
Ceres
Wolseley
De Doorns
Tunnel
Worcester
Nuy
Rawsonville
Moordkuil
Robertson
Montagu
Ashton
Barrydale
Bonnievale
McGregor
Hammanshof
Villiersdorp
Swellendam
Suurbraak
Genadendal
Greyton
Berea
Stormsvlei
Askraal
Lindeshof
Riviersonderend
Grabouw
Elgin
Botrivier
Caledon
Rietpoel
Protem
Klipdale
Malgas
Pringle Bay
Betty's Bay
Kleinmond
Oukraal
Wydgelee
Port Beaufort
Witsand
Infanta-on-River
Hawston
Hermanus
Onrus
Stanford
Fairfield
Papiesvlei
Napier
Bredasdorp
Skipskop
Gans Bay
Baardskeerdersbos
Elim
Arniston
Waenhuiskrans
Pearly Beach
Viljoenshof
Hotagterklip
Struis Bay
L'Agulhas
NORTH
Kilometers
0
25
50
100


POTENTIAL ARTIFICIAL RECHARGE AREAS
19. BERG WMA
LEGEND
Cities and major towns
Secondary towns
Settlements
Main Roads
National Route
Canals
Pipelines
Tunnels
Rivers by stream order
1
2
3
4
5
6
7
Major dams
Quaternary catchments
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
OLIFANTS/DOORN
GOURITZ
BREEDE
CAPE TOWN
20°E
NORTH
0
25
50
100
Kilometers

Appendix 2: Lephalale artificial recharge options

1. INTRODUCTION

The water requirements in the Lephalale area will increase significantly with the planned new coal-fired power stations, and artificial recharge has been considered as one of the options in augmenting the water supply to the area (**Figure A2.1**). Unlike the case studies that follow this one where conceptual ideas for artificially recharging specific aquifers are described, this example presents a list of options that can be considered in the early planning stages.

2. ARTIFICIAL RECHARGE OPTIONS

The groundwater and artificial recharge water supply/ augmentation options are listed below:

1. Maximise deep/ hard-rock aquifer
2. Maximise shallow/ alluvial aquifer
3. Artificially recharge the shallow aquifer with stormwater
4. Artificially recharge the shallow aquifer with treated waste water
5. Artificially recharge the shallow aquifer with untreated dam water
6. Artificially recharge the deep aquifer with treated dam water
7. Artificially recharge the deep aquifer with stormwater
8. Artificially recharge the deep aquifer with water from the shallow aquifer by creating easy flow paths between the two using "linking" boreholes

2.1. Maximise deep/ hard-rock aquifer

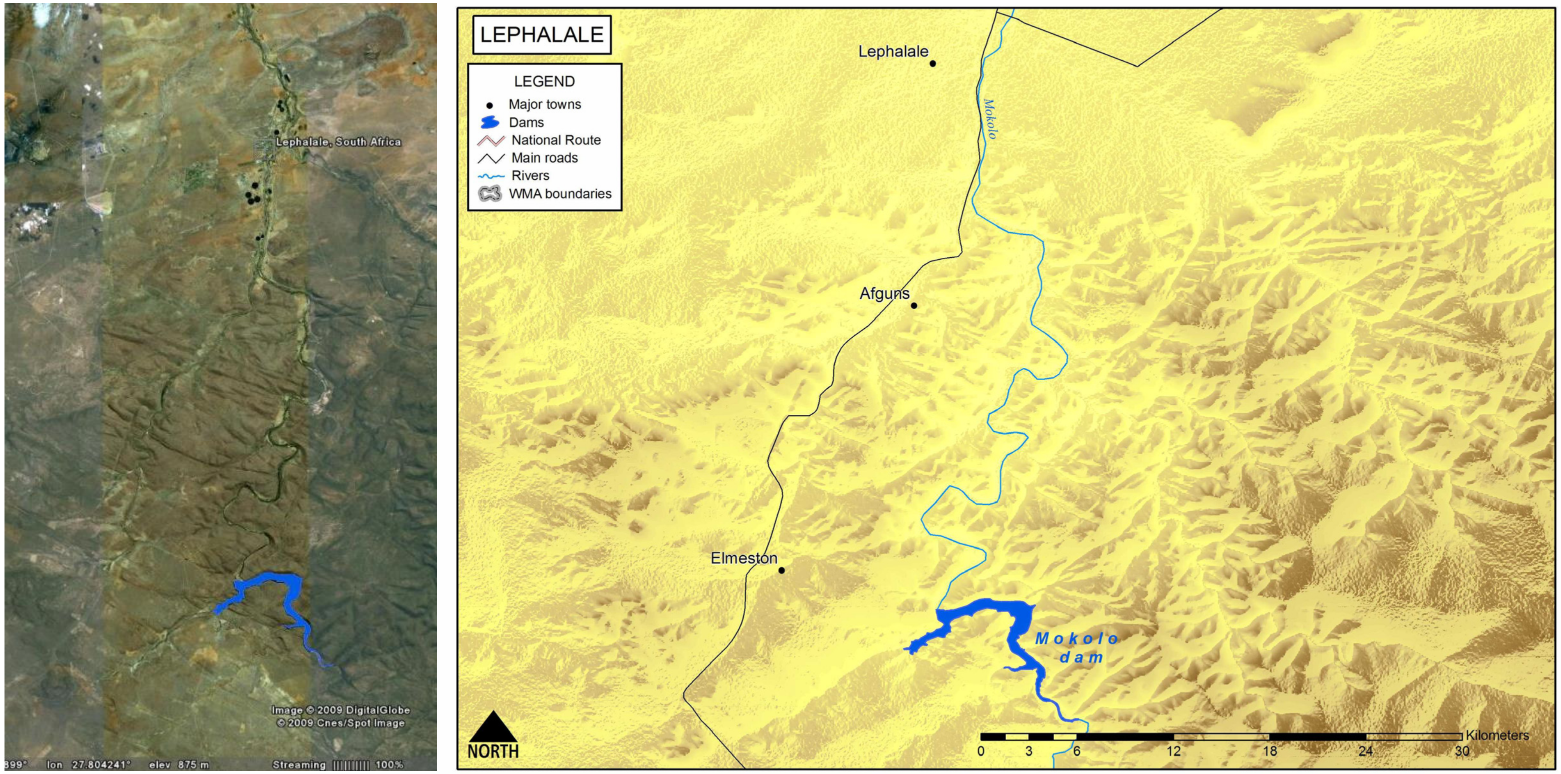
Aim: Maximise groundwater abstraction from the hard-rock aquifer

Tasks:

1. Identify, drill and test pump the remaining geological structures within an acceptable economic radius of:
    a. The town
    b. The pipeline from the dam that supplies the town (if this option is considered, first establish if it is possible to feed into the existing pipeline – ie establish engineering requirements)
2. Delineate the groundwater units/ wellfields and quantify them under conditions of simultaneous usage (ie take interference into account). This probably requires pumping from the wellfields for a considerable period and monitoring adjacent areas. The aim would be to establish their sustainable yields based on simultaneous pumping.
3. Establish their "mining" yield. If the deep aquifers are needed to bridge a period of suppy until surface water becomes available, then the aim would be to establish how long the deep aquifer can supply the required rate on a continuous basis before the storage has been drained.
4. Linked to point 2 bove: Establish whether water is induced from the alluvium if nearby deep, hard-rock boreholes are pumed heavily. Do this by large-scale abstraction from the deep boreholes and assess the drawdown curves and monitor isotopes and water quality. A nearby shallow borehole would also be best for monitoring purposes.

Figure A2.1/…

Figure A2.1 Google Earth and hill-shade images of the Lephalale area showing the Mokolo Dam upstream of the town



2.2. Maximise shallow/ alluvial aquifer

Aim: Maximise groundwater abstraction from the alluvium

Tasks:

1. Establish the volume in storage by delineating the alluvial aquifer, establishing thickness, water levels and S-values:
    a. consult the WSM report
    b. drill a few shallow boreholes to test the thickness of the alluvium, to verify WSM results (assuming they have thicknesses) & to get S-values (ie drill nearby monitoring boreholes)
    c. possibly do geophysics to dertermine thickness in selected areas
2. Establish borehole yields in the alluvium – ie test pump a few shallow holes (& monitor both pumped and nearby observation boreholes)
3. Establish throughflow (either using Darcy or a simple numeric model)
4. Determine whether a collector well system (horizontal "well/s" across the river bed) or numerous shallow boreholes parallel to the river are most cost and water supply efficient.

2.3. Artificially recharge the shallow aquifer with stormwater

Aim: Recharge the alluvium with stormwater that is collected in the stormwater dam

Key assumption: The alluvium is sufficiently transmissive to yield significant quantities of water (ie establish the borehole/collector well yield from the alluvium first)

Tasks:

1. Quantify the stormwater. Obtain an estimate of the volume of water available for recharge and only consider this option if the volume is significant. Establish whether storm runoff is already allocated or used by others.
2. Assess the quality of the stormwater if the abstraction boreholes are close to the stormwater discharge point. If so, this water will have to settle in the dam before being used for recharge. Key factors are turbidity, oils, heavy metals, etc – the determinands that are found in urban storm runoff. Note that the first storm runoff for the season should go to waste (discharged elsewhere if possible) – to flush all the reminants from the dry season.
3. Enhance canal infiltration by ripping the base and sidewalls of the canal where it crosses the alluvium.
4. Enhance infiltration in the second stormwater dam (the dam shortly before the discharge point) by ripping the base and sidewalls of the dam – ie convert to recharge basin
5. Drill a few shallow monitoring boreholes to establish effectiveness of these interventions
6. Check the discharge point – eg ensure the stormwater is not being taken by farmers.
7. Determine whether a collector well system or numerous shallow abstraction boreholes parallel to the river should be drilled below the stormwater discharge point.
8. Drill a few shallow monitoring boreholes.

2.4. Artificially recharge the shallow aquifer with treated waste water

Aim: Recharge the alluvium with treated waste water

Key assumption: The alluvium is sufficiently transmissive to yield significant quantities of water (ie establish the borehole/collector well yield from the alluvium first).

Tasks:

1. Quantify the waste water. Obtain an estimate of the volume of water available for recharge. Establish what portion is already allocated.
2. Assess the quality of the waste water.
3. Establish where waste water is discharged into the river
4. Establish all sites where (deep) alluvial boreholes could be drilled adjacent to the river (consider land ownership, access, etc).
5. Alternatively, establish a site for a collector well.

2.5. Artificially recharge the shallow aquifer with untreated dam water

Aim: Recharge the alluvium with surplus untreated dam water:

a. At a point close to town (ie where a take-off point can be installed in the existing pipeline that is not far from town)
b. From normal dam releases

Key assumption: The dam managers are willing to release surplus water in a manner that will enhance recharge (this will require selling the concept to them).

Tasks:

1. Establish current dam release practices (when and for how long)
2. Quantify releases - ie water available for recharge, and establish existing allocated water (ie compulsory releases)
3. Establish pipeline capacity to see whether surplus water can be transferred close to town for recharge; quantify this water source
4. Identify preferred discharge point
5. Cost pipeline diversion
6. If this is not an option, establish if dam managers would be ameanable to large-scale releases in pulses rather than a continous “trickle”. The aim would be to try and get a pulse of dam water to recharge the alluvium close to town (ie close to where you’d place your wellfield).
7. Study the DWA “pulse” report
8. Compare the water savings if water is left in the dam (evaporation losses) and trickle releases (evapotranspiration losses and abstraction from upstream farmers) to if it is transferred to the alluvium (evapotranspiration losses and abstraction from all farmers)

2.6. Artificially recharge the deep aquifer with treated dam water

Aim: Borehole injection (ASR) with municipal drinking water

Tasks:

1. Establish if there is ever surplus water availabile and surplus capacity in the water treatment works (WTW)
2. Assess water compatibility (municipal water and deep groundwater)
3. Conduct injection tests

2.7. Artificially recharge the deep aquifer with stormwater

Aim: ASR using storm water

Tasks:

1. Establish quantity and quality of stormwater (see Option 3 points 1 & 2)
2. Determine stormwater treatment requirements
3. Assess water compatibility (stormwater and deep groundwater)
4. Conduct injection tests

2.8. Artificially recharge deep aquifer with shallow aquifer by creating easy flow paths between the two with "linking" boreholes

Aim: Create conduits for alluvial aquifer to recharge hard-rock aquifer.

Note:

1. This is only an option if water in the alluvium is not drawn into the deep aquifer by large-scale abstraction from deep boreholes (see Option 1, point 4). If so, it is not necessary.
2. Under current (ie natural conditions), deep water will probably flow into the alluvium. For this to work, the water level in the deep aquifer must be continuously pumped.
3. Consider long-term environmental implications of this option as this will cause a permanent connection between the shallow and deep aquifer. I do not recommend this option for this reason.

Tasks:

1. Drill a deep borehole on a hard-rock structure where the alluvium is thick and perforate the casing opposite both the alluvium and the deep aquifer.
2. Assess whether the shallow aquifer will feed the deep aquifer:
    a. Analyse chemistry and isotopes of shallow water (prior to puncturing the deep aquifer)
    b. Analyse chemistry and isotopes of deep aquifer from another, nearby deep borehole that only intercepts the deep aquifer.
    c. Test pump the nearby deep borehole and monitor chemistry and isotopes
    d. Assess drawdown curve for leakage (in the test pumping of the nearby deep borehole)
3. Test pump the "linking" borehole and establish yield.
4. Repeat in other areas where structures cross the alluvium.

3. RECOMMENDATIONS

The recommended process to determine which options to pursue is as follows:

1. Establsh which of the above options are realistic.
2. If any of the artificial recharge options are considered to be realistic, initiate an artificial recharge pre-feasibility study as described in the Artificial Recharge Strategy (DWAF, 2007).

REFERENCE

VSA Report (Undated). Hydrogeology assessment and aquifer recharge potential at Lephalale Local Municipality (Ver 1.1, undated).

Appendix 3: The Cedarville flats: Potential for large-scale sub-surface storage

1. INTRODUCTION

The Cedarville Flats is a 36 000 ha expanse of flat land near Matatiele in the Eastern Cape Province (**Figure A3.1**). It consists of a deep alluvial basin with the Mzimvubu River running through it (see Figure A2-1). Boreholes with depths of up to about 100 m penetrate the alluvium and draw water from gravel layers near the base of the clays and sands that have filled the basin. Their yields are commonly between 10 - 20 l/s. The water is used for irrigation by a number of commercial farmers. Unfortunately there is no monitoring taking place, so the effect of abstraction on the water table is not known except that farmers say heavy abstraction affects boreholes' yields.

There are two key factors about this area that make it a significant potential artificial recharge area:

1. The only major undeveloped river in South Africa, the Mzimvubu, runs through this area. It could supply huge volumes of water for recharge.
2. Although the storage capacity of the aquifer is not known, it must be very large. Crude calculations of it's storage capacity put it at about 400 Mm^3 (assuming a conservative thickness of 10 m, a storage coefficient of 10% and an area of 36 000 Ha).

The summer rainfall, although variable, is reliable, and thus the source water for recharge is dependable. The aim of artificial recharge would be to substantially increase groundwater usage. The subsurface storage would be used as a reservoir that could be "mined" to some extent on an annual basis with the knowledge that it can be rapidly replenished every summer.

2. THE ARTIFICIAL RECHARGE POTENTIAL

The increase in the assured yield of the aquifer cannot be given at this stage, since current usage is not known. However, the storage volume of the aquifer must be substantial (rough estimates puts it in the order of 700 Mm^3) and thus the potential to utilise this storage in a conjunctive way with surplus surface water from the Mzimvubu River make this a very attractive proposition.

3. THE CONCEPTUAL SCHEME

The most favourable option would be to divert river water into specially designed recharge trenches that run along the up-slope side of the basin where the soil type is suitable and where there is good hydraulic connection to the main basin. This should not require any treatment prior to infiltration, although settling of particulate matter in basins may be needed. If this is not an option, and if the water is of suitable quality, borehole injection up-gradient and in the centre of the basin could be considered.

Without knowing how the natural recharge system works, and how the aquifer responds to abstraction and natural recharge, it is difficult to provide a plan of how the recharge-abstraction cycle would go. In principle, the idea would be to "feed" the aquifer for far longer periods and at far greater rates than natural recharge, thereby creating the opportunity to abstract at higher rates and for longer periods of the year.

4. KEY ISSUES THAT AFFECT THE VIABILITY OF THE SCHEME

The pre-feasibility study would need to focus on the following key issues:

1. Understanding the existing operation of the aquifer. This would entail establishing current usage, borehole water level responses to abstraction and natural recharge.
2. Getting a reasonable estimate of the aquifer's storage capacity and the potential gains in aquifer yield if artificial recharge were to be practiced on a large scale.
3. Establishing if the institutional aspects could be reasonably sorted out. Since numerous farmers have access to the existing groundwater, a system that benefits those who practice artificial recharge would need to be put in place.
4. Establishing whether the increased yield of the system makes economic sense.

5. RECOMMENDATIONS

This is one of the few areas in South Africa where there is both a substantial and dependable water source for artificial recharge and a sizeable aquifer that could receive and store the water. The steps required to get an indication of the viability of the scheme are:

1. Conduct a detailed hydrocensus to locate boreholes; establish borehole, yields, depths, geology and water strikes; establish water levels and water quality; and get an estimate of groundwater abstraction.
2. Implement a monitoring system to establish a time-series of borehole water levels and if possible, abstraction volumes.
3. Implement a monitoring system to develop an understanding of natural recharge.
4. Establish flows in the Mzimvubu.
5. Identify areas of potential artificial recharge.
6. Provide a first order assessment of the economics of implementing large-scale artificial recharge.
7. Liaise with stakeholders to establish the institutional issues that would affect the implementation of such a scheme.

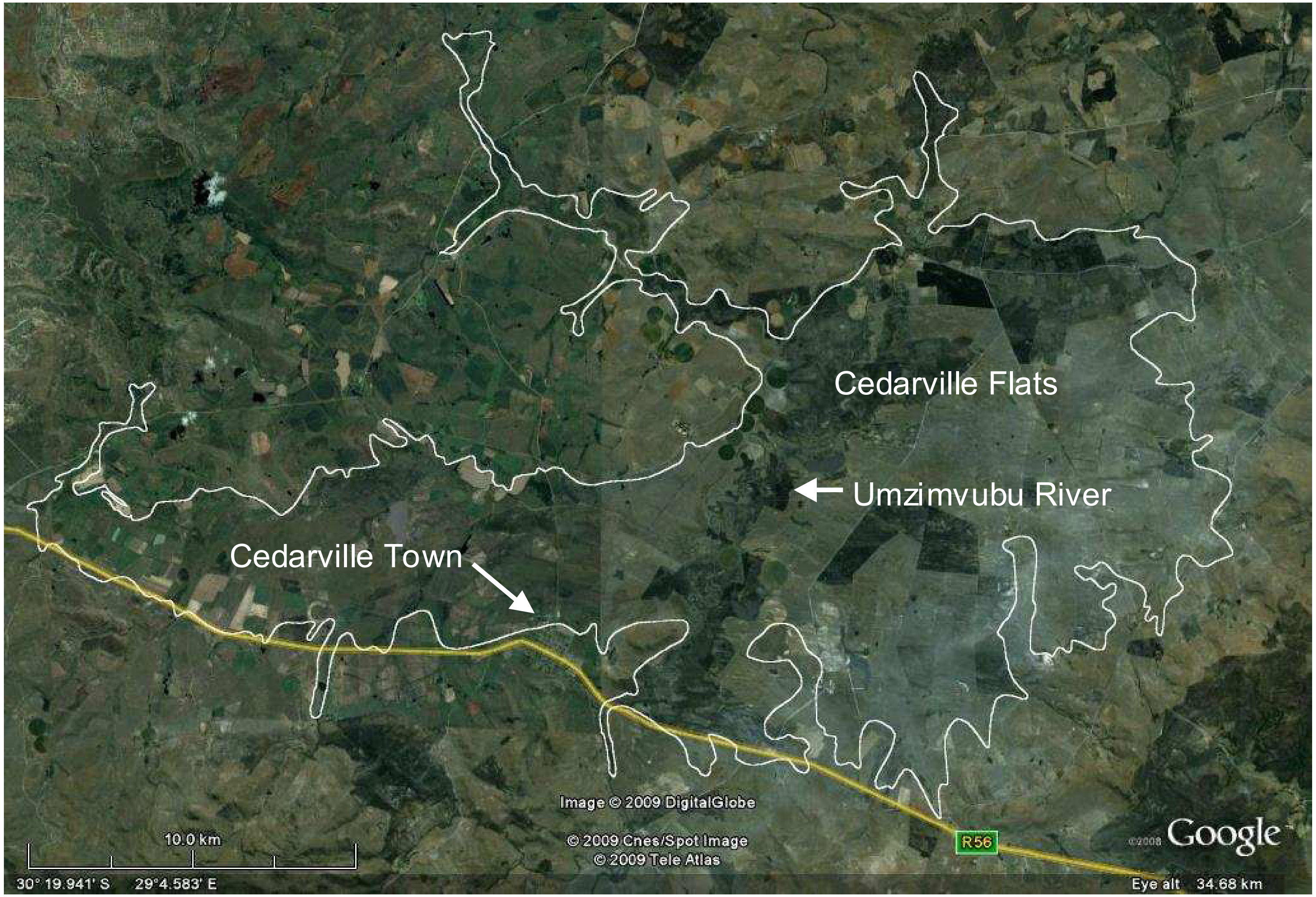


Figure A3.1 The Cedarville Flats showing the outline of the alluvium

Appendix 4: The Klein Karoo: A plan to raise heavily depressed water levels

1. INTRODUCTION

The wellfields under consideration are in the Vermaaks River catchment in the Eastern Section of the Klein Karoo Rural Water Supply Scheme (KKRWSS) They serve the town of Dysselsdorp. Artificial recharge is proposed in two wellfields, namely the Vermaaks and the Voorsorg wellfields (**Figures A4.1**). Both aquifer transmissivities and borehole yields are high, and this allows for abstraction to be in excess of natural recharge. Over the years estimates of sustainable borehole yields have come down as a result of this, and the most recent estimates are (Woodford, 2008):

Vermaaks Wellfield:	505 000 m^3/a
Voorsorg Wellfield:	79 000 m^3/a
Total:	584 000 m^3/a

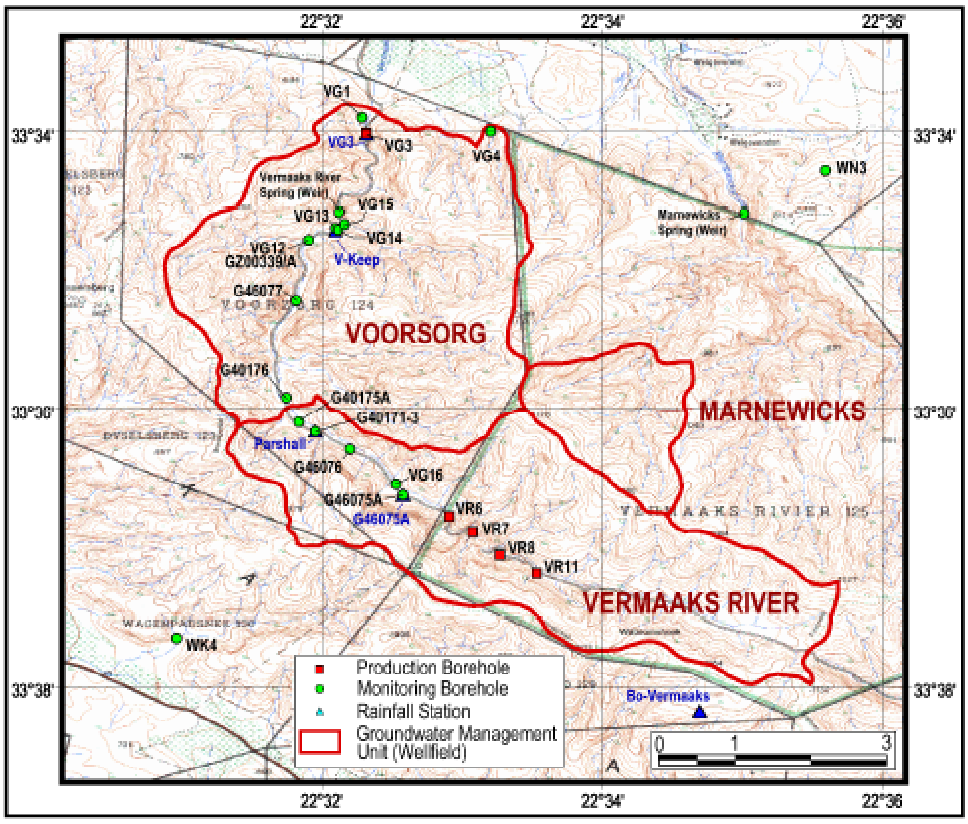


Figure A4.1 Borehole locations in the Vermaaks River Catchment (from Woodford, 2008)

The intention of artificial recharge would be twofold:

i) To raise the water table in the Vermaaks Wellfield. The water levels in the upper Vermaaks Aquifer have dropped by tens of meters over the years and raising them would be of great environmental benefit to the area.

ii) If possible, and only if the first objective can be achieved as well, would be to increase the aquifer's yield.

Artificial recharge would have the aim of meeting these objectives by injecting flood runoff into as many boreholes as possible. A rough target injection rate would be in the order of 100 000 m^3 per annum.

Two options have been considered to augment the groundwater supplies using artificial recharge:

- Recharge the Peninsula Formation in the Vermaaks Wellfield
- Recharge the Nardouw Formation in the Voorsorg Wellfield.

Option 1: Recharge the Peninsula Formation (Vermaaks Wellfield)

The Peninsula Formation Aquifer consists fractured sandstones of the Table Mountain Group. Water levels in boreholes in the Vermaaks Wellfield have declined since abstraction began in early 1990s. An example is borehole VR6 where the water levels have dropped by about 30 m (blue line in **Figure A4.2**).

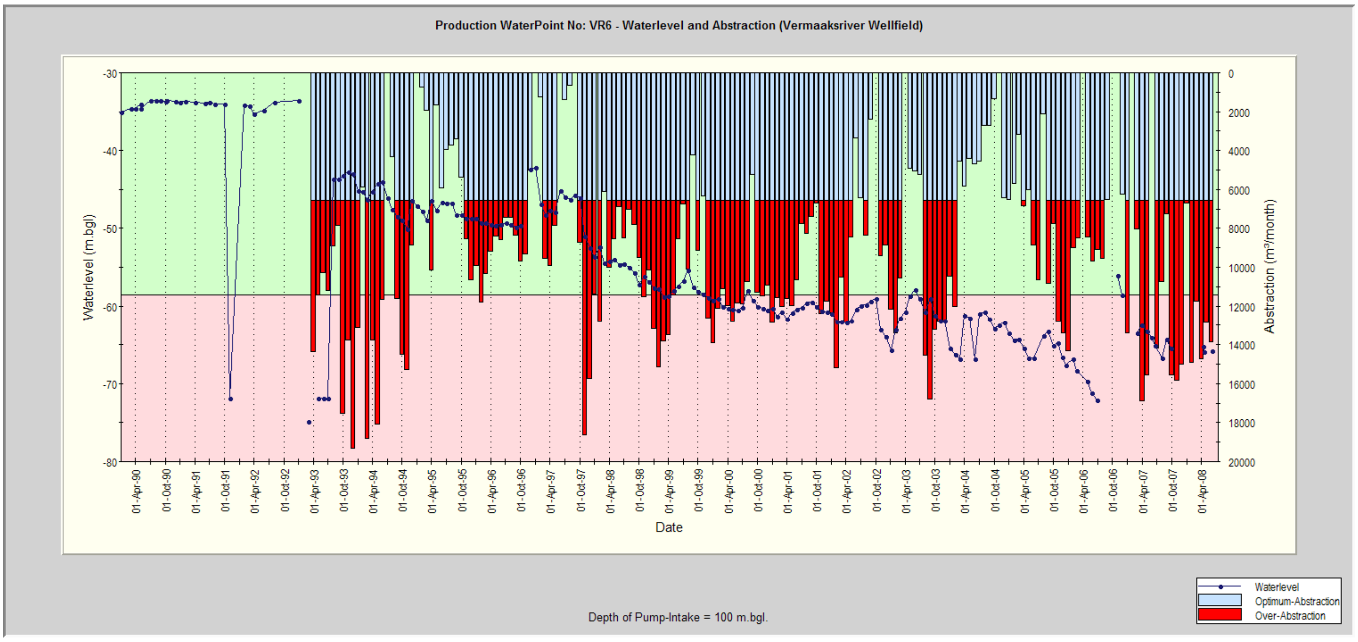


Figure A4.2 Water levels in borehole VR6, Vermaaks Wellfield (from Woodford, 2008)

The artificial recharge plan would entail diverting runoff into one or more of the boreholes in the Vermaaks Wellfield. If necessary the water would be fed through a sand filter prior to injection. The injection rates would be at each borehole's maximum capacity as the injection period would usually be short due to the rapid runoff from the steep catchment. **Table A4.1** gives an estimate of the artificial recharge potential. This is based on pumping test data, and in particular, the step-test data.

Option 1: Recharge the Peninsula Formation (Vermaaks Wellfield)

The Peninsula Formation Aquifer consists fractured sandstones of the Table Mountain Group. Water levels in boreholes in the Vermaaks Wellfield have declined since abstraction began in early 1990s. An example is borehole VR6 where the water levels have dropped by about 30 m (blue line in **Figure A4.2**).

Table A4.1 Estimated Artificial recharge potential in the Vermaaks Wellfield

Borehole number	Injection rate (l/s)	Injection rate (m^3/day)	Injection volume over 7 days (m^3)
VR 6	15	1 300	6 050
VR 7	35	3 000	15 120
VR 8	15	1 300	6 050
VR 11	10	860	6 050
Total	**75**	**~6 500**	**~45 000**

Option 2: Recharge the Nardouw Aquifer (Voorsorg Wellfield)

Like in the Vermaaks Wellfield, the Voorsorg Wellfield also consists of fractured TMG sandstones, but the plan in this area would be to increase abstraction from the Voorsorg Wellfield to create space for increased natural and artificial recharge. Often there is not space in the aquifer to store surplus water which is why this aquifer would need to be pumped more than the currently recommended rate. Borehole VG3, located in the Voorsorg Wellfield (**Figure A4.3**) shows that the water levels lie between 10 - 20 mbgl with recommended abstraction (~7000 m^3/month/ blue bar graph), but drop down to as much as ~40 mbgl with abstraction greater than this (red bar graph). The intention would be to keep the water levels down so that when water is available for recharge, there is space in the aquifer to receive it.

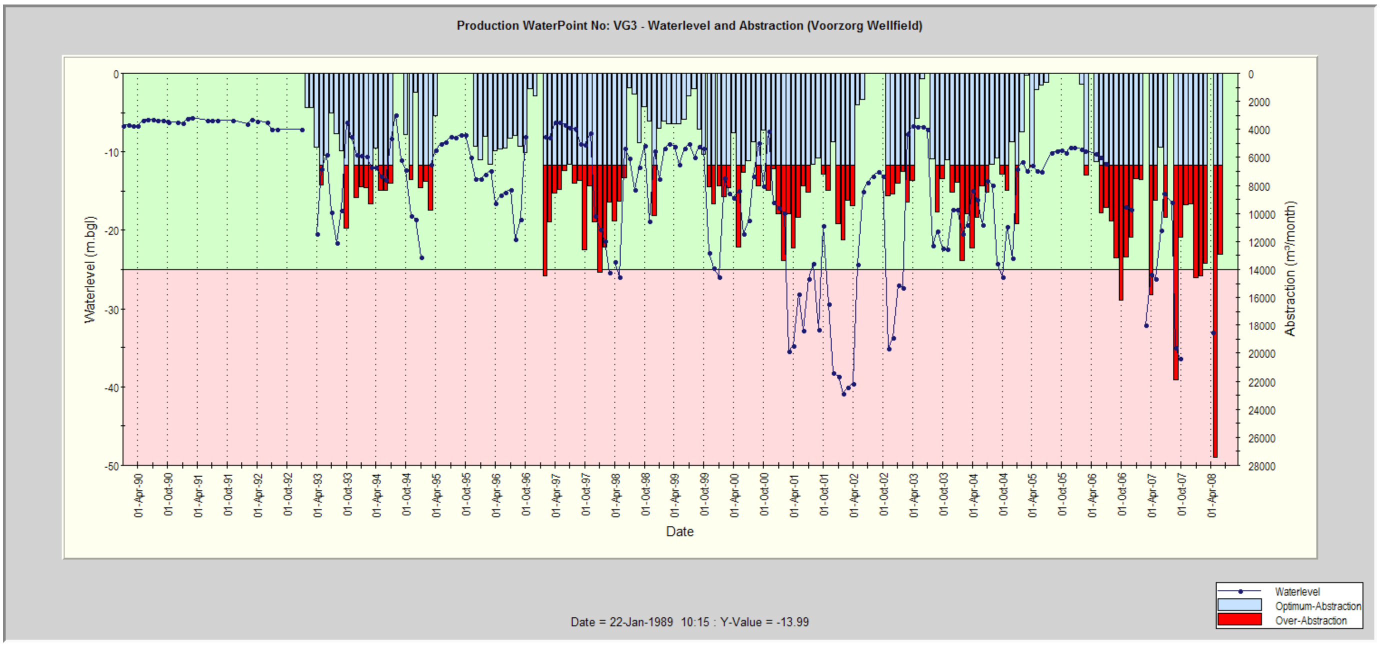


Figure A4.3 Water levels in borehole VG 3, Voorsorg Wellfield (from Woodford, 2008)

At present there are only two abstraction borehole in the lower aquifer (VG3 and GZ00339 which was put into production in 2008), however, if other existing boreholes or additional new boreholes in this area were drilled and utilised, it would potentially increase the yield of the aquifer significantly. The estimated injection rates, assuming four boreholes, are given in **Table A4.2**.

Table A4.2 Estimated Artificial recharge potential in the lower aquifer

Borehole number	Injection rate (l/s)	Injection rate (m^3/day)	Injection volume over 7 days (m^3)
VG 3	10	860	6 050
Existing/new 1	10	860	6 050
Existing/new 2	10	860	6 050
Existing/new 3	10	860	6 050
Total	**40**	**~3 400**	**~ 24 000**

2. AVAILABILITY OF WATER FOR RECHARGE

A key question is: Is there enough water to recharge the aquifers? From **Figure A4.4** it appears as if there is usually not enough water, but every now and then, and since daily flow reading commenced in 2004, there have been three occasions where there has been enough water to artificially recharge the aquifers - twice the stream flowed at more than 50 l/s and once about 25 l/s (**Figure A4.5**). The 2006 high flow event resulted in elevated flows for a 6 week period peaking at a flow of 200 l/s while the 2007 event lasted 2 months and peaked at 600 l/s. If rainfall events are changing to be more erratic and more intense as is commonly thought with climate change, then opportunistic artificial recharge may be a good solution to what might be becoming less reliable natural recharge.

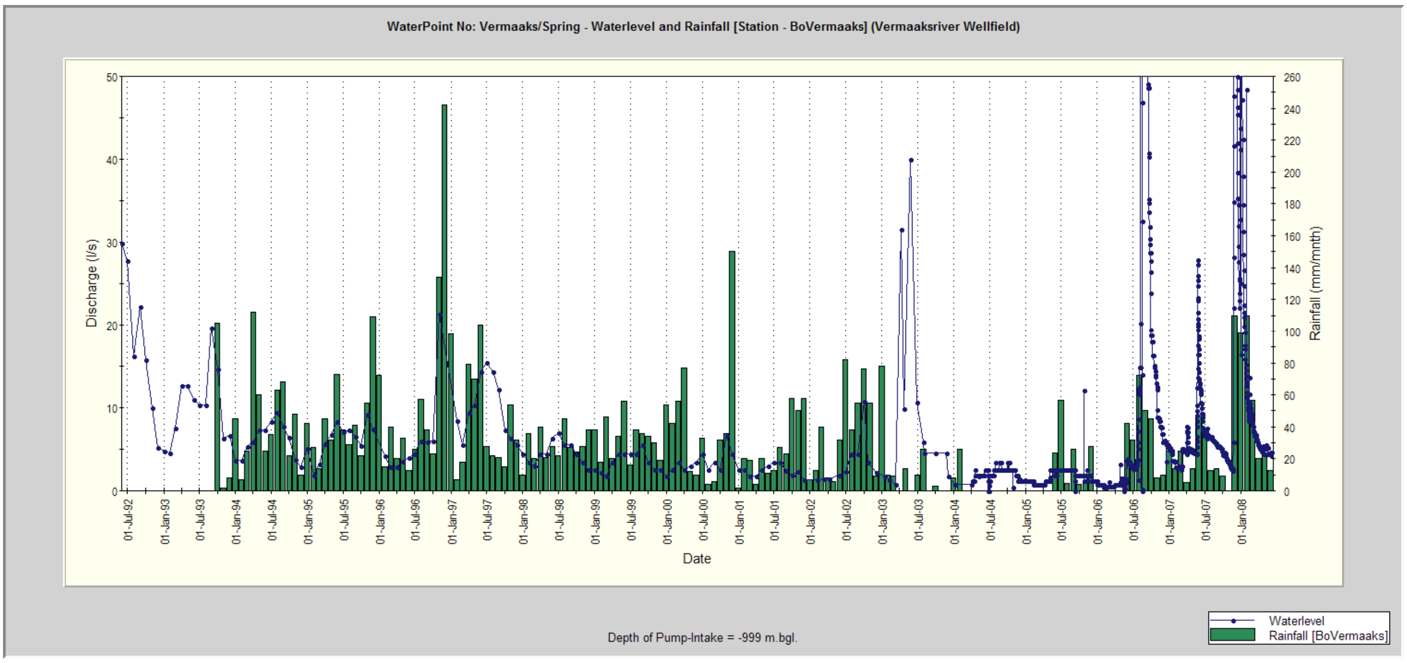


Figure A4.4 Rainfall and stream flow in the Vermaaks River (from Woodford, 2008)

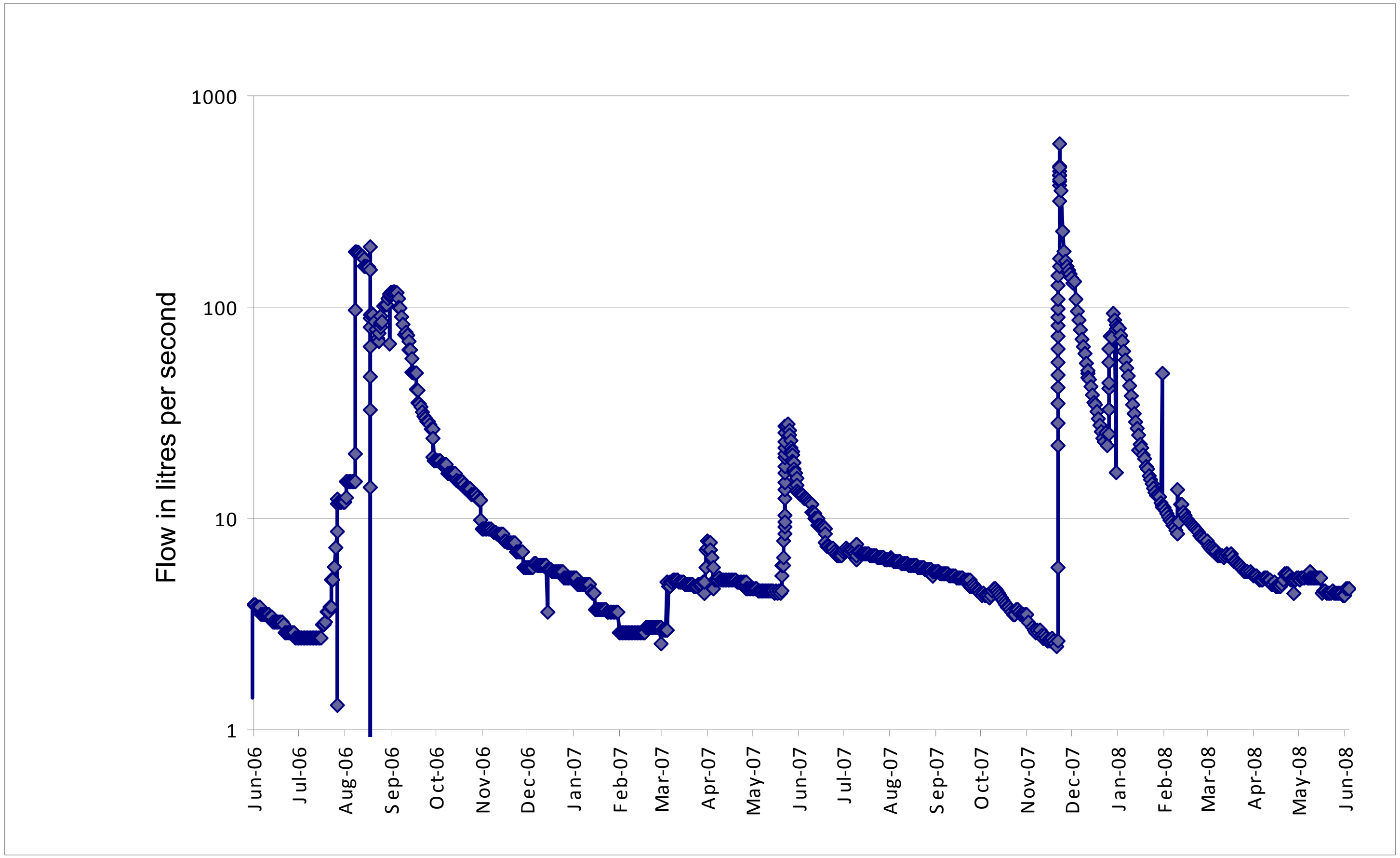


Figure A4.5 Stream flow in the Vermaaks River showing high flow events between 2006 and 2008 (from Woodford, 2008)

The flow in the stream that could be available for artificial recharge has been estimated for the four boreholes of the Vermaak Wellfield in two ways: A theoretical estimate, based on WR2005, and using measured flows from the Weir J3H043. **Table A4.2** describes the WR 2005 estimate and **Table A4.3** describes the estimate derived from the measured flows. The WR2005 estimate is double the measured value and this is could be due to inaccuracies in the measurement of high flow events.

Taking Option 1: Recharge of the Peninsula Formation (Vermaaks Wellfield) as an example, and using the more conservative measured estimate with an allowance for baseflow, it appears as if a minimum of 90 000 m^3/a would be available for artificial recharge. If all this water was available during one 7-day flood event the river would flow at about 150 l/s and if it was available during a 14 day flood event, it would flow at about 74 L/s. The injection target of 45 000 m^3 over seven days, as mentioned in **Table A3-1**, could be met if the injection boreholes could receive the estimated injection rates, and in some years, water may be available to do this more than once or for a longer period.

The estimated potential artificial recharge rates would be a small fraction of the annual flow in the Vermaaks River (12% of MAR) and would only take place during winter when the riverine alluvium is saturated (as rainfall first saturates the alluvium before runoff takes place). The environmental impact of reduced flow in the river would likely be negligible compared to the substantial environmental benefits of raising the water table in the aquifer.

Table A4.3 Source water availability based on WR2005

Description	Value	Unit	Source
Quaternary Catchment	J33E		
Mean Annual Runoff (MAR)	24.3	Mm^3/annum	WR2005
Mean Annual Precipitation (MAP)	446	mm	WR2005
Quaternary Area	329	km^2	WR2005
Portion of Quaternary J33E at Borehole VR6 (Lowest borehole in Option 1: Recharge the upper aquifer (Vermaaks River Wellfield)			
Mean Annual Runoff (MAR)	0.722	Mm^3/annum	Proportional - calculated
Mean Annual Precipitation (MAP)	501	mm	Measured at VR16
Area	8.7	km^2	Arcview; 1:50 000 Topographical map
MAR Volume	721,826	m^3/annum	

Flow in the stream based on MAR		
Flood event lasting 7 Days	1,193.50	l/s
Flood event lasting 14 Days	596.75	l/s
Flood event lasting 21 Days	397.83	l/s
Flood event lasting 28 Days	298.37	l/s

Table A4.4 Source water availability based on measured flows

Description	Value	Unit	Source
Measured cumulative flow at Weir J3H043	367,694.71	m^3/annum	June 2005 to June 2008 measured
Area	23.5	km^2	Arcview; 1:50 000 Topographical map
Estimated average baseflow at weir	4	l/s	Estimated from consistent minimum flow at the weir
Estimated average baseflow at weir	126,144	m^3/annum	
Stream flow (of which a portion could be available for recharge)	241,551	m^3/annum	
Proportion available to VR6 (by area)	**89,425**	**m^3/annum**	**12% of MAR**

Flow in the stream based on measured flow reduced for baseflow		
Flood event lasting 7 Days	148	l/s
Flood event lasting 14 Days	74	l/s
Flood event lasting 21 Days	49	l/s
Flood event lasting 28 Days	37	l/s

This artificial recharge concept can be relatively easily tested at Borehole VR11 where there are two boreholes that are not equipped (VR9 and VR10). Both could be used as an injection boreholes and VR11 could be used for monitoring. The abstraction point and the 150 m long gravity pipeline would have a limited environmental impact as they are located adjacent to the existing road. The layout is shown in **Figure A4.6**.

Figure A4.6 Layout of proposed gravity pipeline to injection boreholes VR 9 and VR10

4. KEY ISSUES THAT AFFECT THE VIABILITY OF THE SCHEME

The pre-feasibility study would need to focus on the following key issues:

1. The availability of water for recharge. This may not be too big an issue, since in relation to Option 1 (Recharge the Peninsula Formation), the cost of supplying existing boreholes with gravity-fed artificial recharge water would be small, and if any opportunistic recharge would be of value.
2. Identifying the best injection boreholes and their injection capacities.
3. Environmental concerns around:
    a. Option 1: Constructing a gravity-fed recharge scheme for the Peninsula Formation Aquifer (ie capturing streamflow and diverting it to the injection boreholes)
    b. Option 2: Lowering borehole water levels in the Nardouw Aquifer.
4. Borehole clogging relating specifically to iron bacteria (and possibly other forms of clogging).
5. Operation and maintenance requirements.
6. The economics of the scheme in relation to the expected environmental benefits.

5. CONCLUSIONS AND RECOMMENDATIONS

The artificial recharge options presented here involve small-scale, simple interventions that could significantly increase the yield of the aquifers. During a 2-week rainfall event, and assuming artificial recharge at 75 l/s in the Vermaaks Wellfield, the recharged volume would be in the order of 100 000 m^3, or 20% of the wellfield's annual average yield.

Option 1 which involves recharging the Peninsula Formation Aquifer would ensure that the water levels are as high as possible in the aquifer, which from environmental and supply perspectives, is clearly favourable. Option 2 would need more careful thought as the impacts of maintaining a lowered water table while waiting for the recharge events need to be carefully assessed. The immediate recommendation is to conduct a pre-feasibility study that addresses the main concerns around the recharge volumes and environmental issues.

References

Woodford, AC. 2008. Klein Karoo Rural Water Supply Scheme. Monitoring and Management Report. 2007/2008 Monitoring period. Technical Report No 357308/8 prepared for the Oudtshoorn Municipality by SRK Consulting, Cape Town.

WR2005. Water Resources of South Africa, 2005 Study. Report to the WRC by B J Middleton & A K Bailey, July 2008.

Appendix 5: Albertinia: A cost saving option that incorporates seasonal sub-surface storage

1. INTRODUCTION

Albertinia is a small town in the Western Cape Province with a population of about 5000 people (2001 census data) and water requirements of about 1400 kl/day (~16 l/s) (SSI, 2008). Recently the plans for 749 low-income houses were approved – this amounts to a third of the current number of houses in the town. The water requirements are likely to increase significantly and a variety of options have been identified (SSI, 2008). One option that is not described in the SSI 2008 report is to obtain water from an existing farm dam about 20 km north of the town. If this option is pursued, it may be possible with artificial recharge to reduce the size of the conveyance infrastructure (pumps and pipelines) and thus save significantly on the capital costs. This water would then be used to recharge the aquifer during winter when the demand is low.

The artificial recharge plan would involve transferring water from the planned dam, treating the water and injecting it via boreholes into the existing wellfield where the water levels are depressed due to regular abstraction (**Figure A5.2)**. Artificial recharge would take place during winter when the dam is full, when the treatment plant is under-utilised, and when the town's water demand is at its lowest.

Currently the town draws its water from two springs and six boreholes (drilled into the Nardouw Formation), although one borehole (SDR) is seldom used due to its high iron concentration (Andreas Michaels, Hessaqua Municipality *pers comm*.). **Figure A5.1** shows the location of the main spring and the municipal boreholes (AG1 – AG 4 are all located within 100 m of one another, and are immediately south of the town). **Table A5.1** gives permitted use and abstraction in 2007/8. From these figures it is evident that actual use was about half the permitted use and well short of the 2005 demand estimate of 1400 kl/day. However, with the new housing plan and other envisaged developments, it appears as if new sources will be required. The 2027 demand projections are 3500 – 4000 kl/day (SSI, 2008).

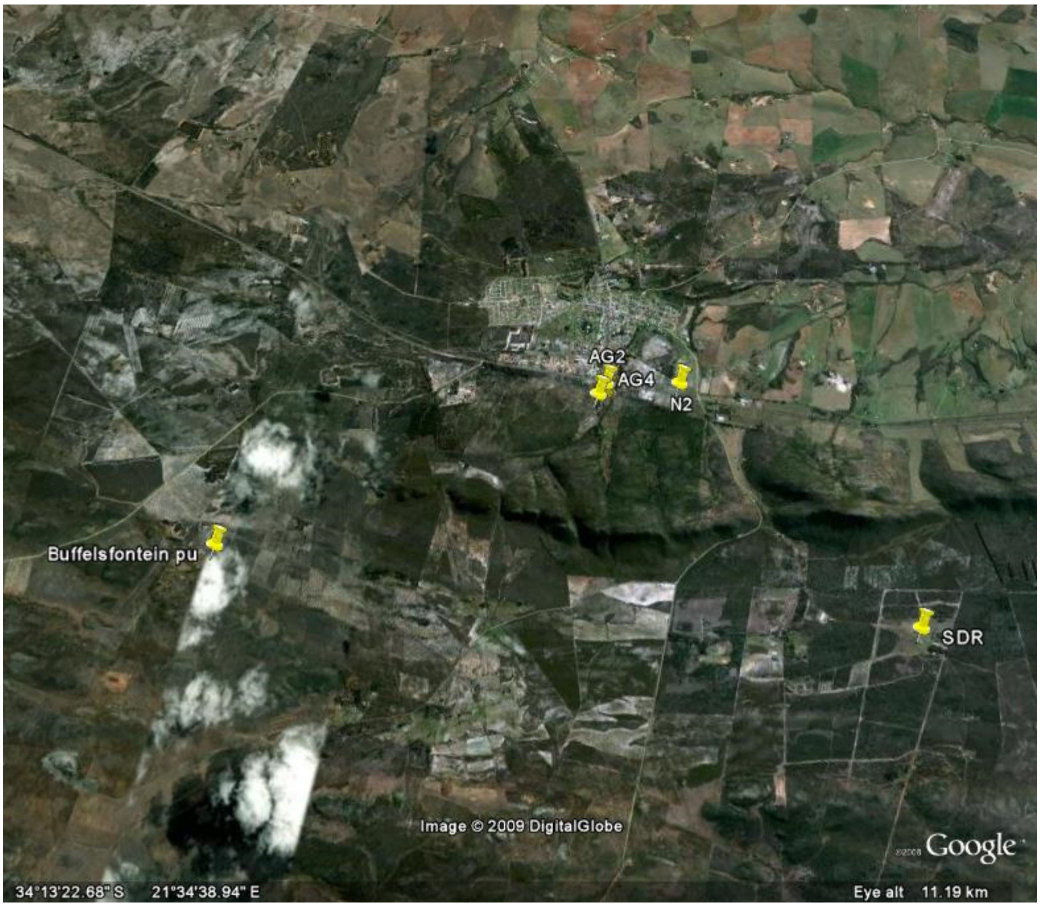


Figure A5.1 Location of municipal boreholes (Albertinia is the town north of the AG boreholes)

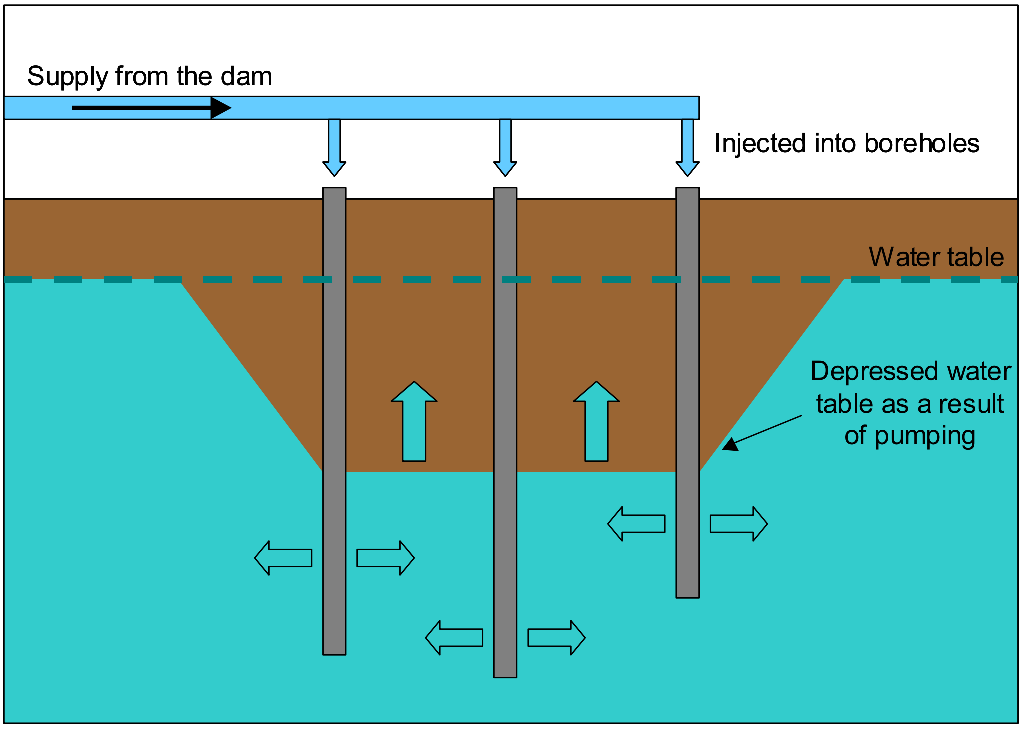


Figure A5.2 Schematic diagram of borehole injection scheme

2. THE ARTIFICIAL RECHARGE POTENTIAL

Continual groundwater abstraction from the AG1 – AG4 area has resulted in a cone of depression in this area. Without a network of monitoring boreholes around the wellfield, it is not possible to determine the extent of this cone, but it does not extent to borehole N2 which is 1 km east of the wellfield (see Figure A5.2). Figure A5.2 shows that the water levels in and around the pumped boreholes are about 20 – 30 m below the natural groundwater levels. At borehole N2 the water levels are generally about 40-50 mbgl and at AG1 they are about 70-80 mbgl. The volume of water that has been displaced is not much – assume a 500 m radius cylinder of aquifer has been dewatered by 30 m, and assume a storage coefficient of 0.001-0.003 – this equates to only about 24 000 – 70 000 m^3. Most of the groundwater comes from recharge and inflow from the surrounding areas to the wellfield. The surrounding areas are not stressed at all as can be seen in the stable water levels in GZ00333 (3.2 km SE of the wellfield) and GZ00330 (4.3 km E of the wellfield). See **Figures A5.3** and **A5.4**.

Source	Permitted Abstraction			Actual Abstraction (07/08)		
	(l/s)	(Ml/a)	(kl/d)	(l/s)	(Ml/a)	(kl/d)
Buffelsfontein	5,0	157,68	430,0	4,37	138,2	377,5
AG1 Borehole	2,5	78,84	216,0	1,96	61,9	169,2
AG2 Borehole	1,5	47,30	129,6	0,85	27,0	73,7
AG3 Borehole	2,5	78,84	216,0	0,91	28,8	78,7
AG4 Borehole	3,5	110,37	302,4	0,56	17,7	48,5
SDR borehole	2,0	63,07	172,8	0,44	3,8	37,6
N2 borehole	1,2	37,84	103,7	0,07	2,3	6,2
Fontein	2,0	63,00	172,8	0,60	19,1	52,2
TOTAL	**20,2**	**651,94**	**1 786,0**	**9,8**	**308,8**	**843,7**

Table A5.1 Permitted and actual abstraction

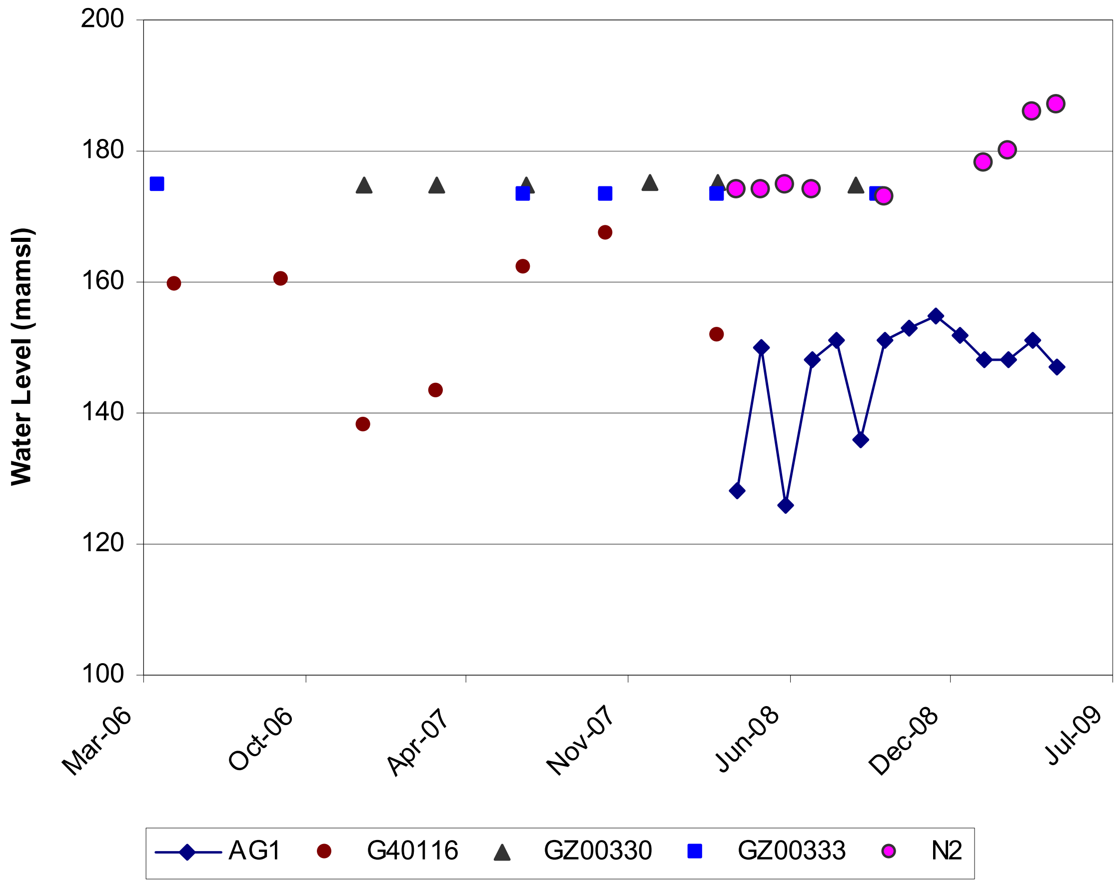


Figure A5.3 Borehole water levels
(Elevations estimated from Google Earth)

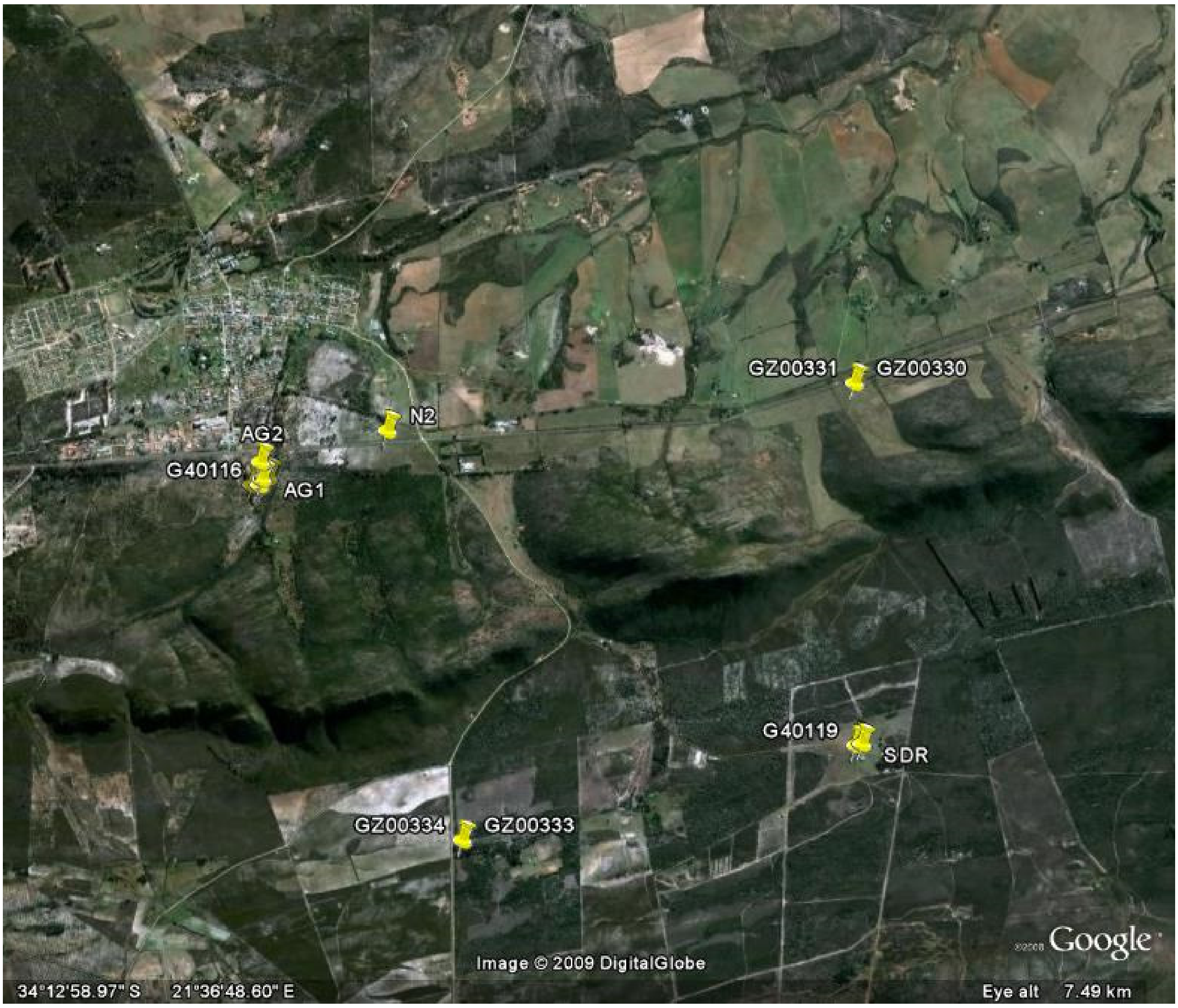


Figure A5.4 Location of municipal boreholes and monitoring boreholes

The value of artificial recharge would be twofold:

1. The potential cost saving on conveyance infrastructure
2. Having the ability to ensure the aquifer is full prior to the onset of summer

Whilst the first point makes economic sense, the second may be of greatest value if climate change predictions of greater variability in rainfall hold true.

3. THE POTENTIAL COST SAVINGS IN CONVEYANCE INFRASTRUCTURE

A hypothetical example is given below to show that a **savings of between 11 and 17 l/s** in conveyance infrastructure could be realised with artificial recharge. Assume the year 2027 demand of 3500 kl/day or 1.3 Ml/annum (SSI, 2008) is broken into 910 000 kl (70%) in summer (4986 kl/day), and 390 000 kl (30%) in winter (2137 kl/day). **Table A5.2** provides three scenarios:

1. The dam supplies the summer backlog
2. Artificial recharge during winter and high groundwater abstraction in summer
3. No artificial recharge but 70% of permitted groundwater use in summer and 30% in winter

The key assumptions are:

1. Groundwater can provide the permitted rate of 416 million litres per annum (SSI, 2008)
2. Groundwater can supply this over 6 summer months provided the aquifer is full prior to summer (ie if the aquifer has been fully replenished by artificial recharge)
3. The aquifer will be able to receive 50 kl of artificially recharged water. (By utilising more groundwater in summer, space will be created in the aquifer for artificial recharge).
4. For Scenario 3 it is assumed that groundwater can provide 70% of the permitted water over summer

With artificial recharge, groundwater would be pumped heavily in summer and the aquifer would be recharged in winter. At this stage the potential artificial recharge volume is not known, but in this scenario, greater space in the aquifer would be created by higher abstraction over summer. Using this scenario, the conveyance infrastructure from the dam would need to be able to cater for 28 l/s as opposed to 39 – 45 l/s without artificial recharge. At these flows, this equates to being able to reduce the pipe size from a 315 mm diameter to a 250 mm diameter which is a significant saving over the 23 km distance from the dam source.

Table A5.2 Water supply scenarios with the dam and artificial recharge

	Scenario 1 Dam provide the balance kL	Scenario 2 Artificial recharge kL	Scenario 3 Alternative to Scenario 1 kL
Summer			
Groundwater	208000	466000	291200
Dam water	702000	444000	618800
Total	910000	910000	910000
Winter			
Groundwater	208000	0	124800
Dam water	182000	390000	265200
Additional dam water for artificial recharge	0	50000	0
Total	390000	440000	390000
Dam needs to be able to supply (kL/day)	3847	2433	3391
L/s	**45**	**28**	**39**

However, noting the capacity of the Weyer catchment, the existing dam capacity and the restrictions on obtaining a water use licence, it is highly unlikely that the Weyer Dam would be able to provide the stated 2027 water demand. Planning done by MVD Consulting Engineers describes the planned surface water infrastructure sized to provide only 5.5 l/s. In this scenario the use of artificial recharge would enable the pipeline to be used to its full capacity in summer and winter, storing the surplus winter water in the aquifer.

4. THE TYPE OF ARTIFICIAL RECHARGE

The dam water would need to be settled to get rid of suspended particles and then it would be injected into the existing abstraction boreholes or into newly drilled injection boreholes near the existing abstraction boreholes. The injection rate would need to be 3.2 l/s continuously over the 6 winter months in order to recharge a volume of 50 000 kl.

5. KEY ISSUES THAT AFFECT THE VIABILITY OF THE SCHEME

Prior to undertaking an artificial recharge feasibility study two key issues would need clarification:

i) Why the municipality uses less than half of their permitted abstraction.
ii) Why additional groundwater sources in the TMG aquifer close to the town cannot be used.

If artificial recharge appeared a suitable option, key factors to assess in a pre-feasibility study would be:

- If artificial recharge is needed. The key issue here is: Could more groundwater be abstracted from the aquifer by increasing the existing boreholes' rates or by drilling additional boreholes away from the current wellfield? (See points i and ii above).
- The cost savings of artificial recharge.
- Establish artificial recharge volumes. This would entail establishing a better understanding of the aquifer's response to existing groundwater abstraction.
- Establish water compatibility (ie water quality issues associated with sub-surface blending)
- Establish borehole clogging potential.

6. CONCLUSIONS AND RECOMMENDATIONS

Artificial recharge would only be a viable option if the cost savings on conveyance infrastructure warranted it. In the case of the City of Windhoek, artificial recharge saved them in excess of R 1billion in conveyance infrastructure. In this case the economics may not be as attractive, but it may be worthwhile, particularly if the uncertainty of climate change can be incorporated into the costing model.

REFERENCES

SSI. 2008. Water resource study for the urban supply of water in Hessequa Municipality.

MVD. 2007. *Albertinia: Ondersoekverslag na alternatiewe waterbronne vir Albertinia* – February 2007. Report by MVD Consulting Engineers for the Hessaqua Municipality.

Appendix 6: Vanrhynsdorp: The potential for large-scale irrigation in an arid area

1. INTRODUCTION

The town Vanrhynsdorp receives a reliable supply of water from the Olifants River, however, the farmers upstream (east) of the town rely on groundwater for irrigation. This arid area is characterised by hot dry summers and mild winters with a mean annual precipitation of less than 186 mm/a. Natural groundwater recharge is very limited. Despite this, aquifer storage together with the limited recharge to the dolomitic aquifer has over the years provided a reliable source of water for the farmers. The groundwater levels are however dropping and the water quality, which is fairly saline (EC in the region of 100 – 300 mS/m), is deteriorating, and the long-term sustainability of the aquifer is in question. Fortunately, the conditions appear very favourable for artificial recharge - for two main reasons:

1. The dolomitic marble aquifer contains boreholes with high yields. This means that artificial recharge by means of borehole injection can be at high rates and therefore in a short time large volumes of water can potentially be transferred underground.
2. A reliable, underutilised water sources, the Doring River, is nearby.
3. The salinity of the source water is very low (~25 mS/m) and would dilute the saline groundwater.

The drawback of this option is the cost. Water would have to be transferred across a catchment divide and it would have to be treated to reduce the turbidity prior to recharge (**Figure A6.1)**. Both these factors imply significant expenditure, but if the farming activity could be modified to produce "top-end" crops that thrive on hot dry summers with large-scale irrigation, then this option could transform this land into a promising agricultural area. An alternative option of capturing flash floods in the catchment would be far less expensive, but the potential benefits would also be far less.

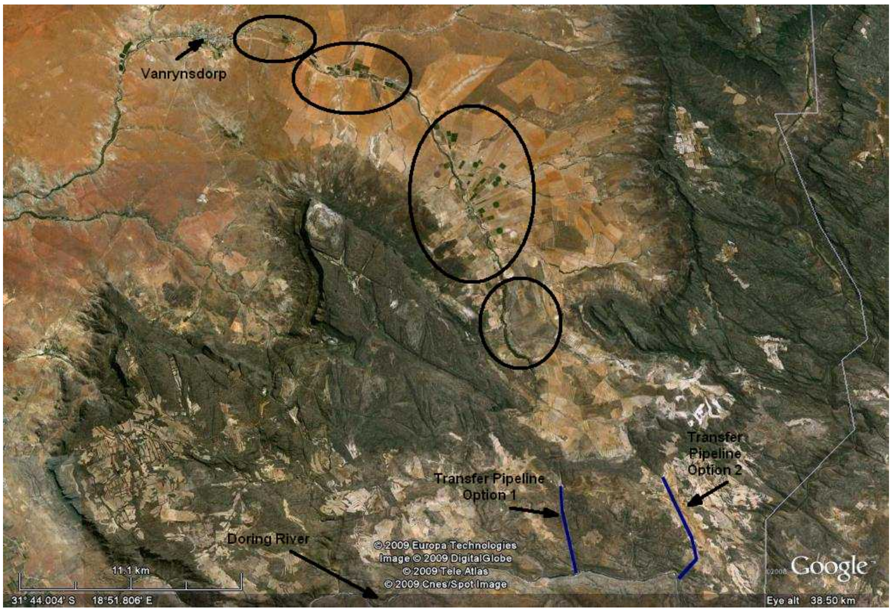


Figure A6.1 Location of current irrigation areas and transfer pipeline options from the Doring River

2. THE AR POTENTIAL

Aquifer storage potential

The storage potential of the dolomitic aquifer is not known, however, it is likely to be substantial considering the rate of groundwater abstraction for irrigation and the low rainfall and natural recharge potential. The water levels have dropped over a large area by about 5 m in 10 years(or ~0.5 m/a on average) (**Figure A6.2**), and thus the aquifer currently has a sizeable volume of "dewatered" aquifer material that can be replenished. A rough estimate of this is about 2 Mm^3, assuming the aquifer is 20 km x 4 km in area with a storage coefficient of $5x10^{-3}$.

Replenishing groundwater levels would only be the first step in the overall plan. The main aim of artificial recharge would be to provide a reliable volume of water between September and April for irrigation purposes. Annual crop requirements for a mixture of wine grapes, table grapes and vegetables is in the order of 12 000 m^3/ha/a of which about 96% is required during the eight months between September and April. These are the approximate figures taken from a detailed study on the irrigation potential of the nearby Atties Karoo (PGWC, 2006).

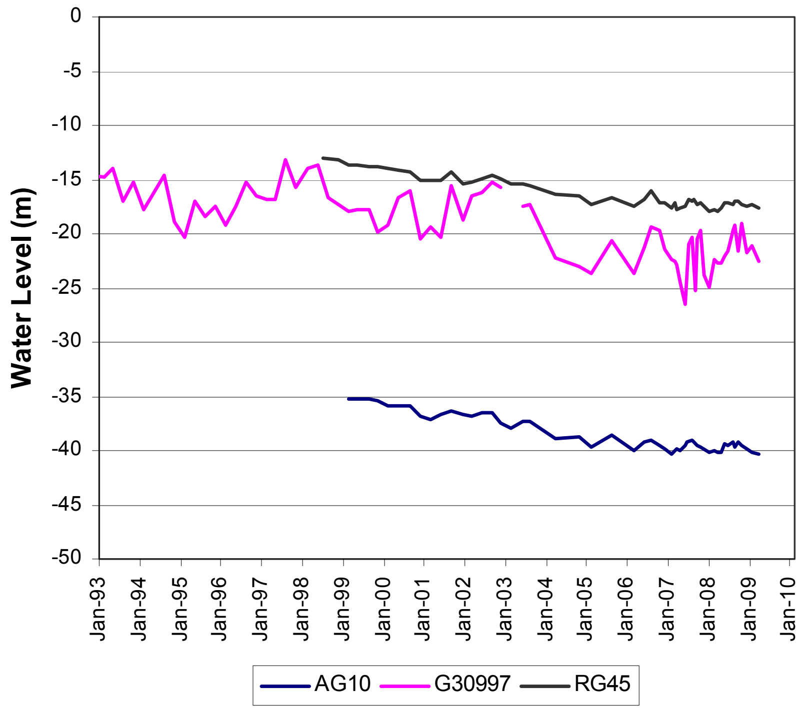


Figure A6.2 Boreholes water levels East of Vanrhynsdorp showing a general decline over the years

(AG10 is far east of Vanrhynsdorp in the upper catchment; G30997 is immediately east of town; and RG45 lies between the two)

Assuming the soils in the area east of Vanrhynsdorp are suitable for intensive irrigation, 100 ha would require 1.2 Mm^3/a. Assuming a target abstraction of 2.4 Mm^3/a of artificially recharged water (to irrigate 200 ha), and assuming each borehole can provide a continuous supply of 10 l/s, it would take 12 boreholes to supply this volume. If the alluvium along the Troe-Troe River is suitable for artificial recharge trenches or basins, then these would be the best method, if not, the same boreholes used for abstraction could be used for injection (although a few more may be needed if the period over which the water is available is less than 8 months).

Source water potential

The Doring River, with a MAR of 382 Mm^3/a (PGWC, 2006), has no dam on the river although studies have been conducted to assess dam sites and yields. This is a winter rainfall area, and virtually all this water flows out to sea. **Figure A6.3** shows the mean monthly flows in the Doring River at gauge E2H003. Any volume that can be stored in winter for use in summer would be of value. The 2.4 Mm^3/a example used above is not even 1% of the MAR – ideally the annual artificial recharge volume should be far greater than this.

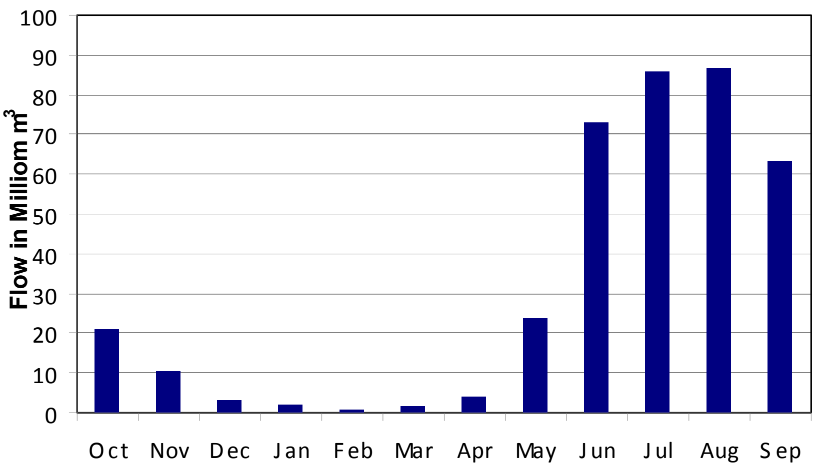


Figure A6.3 Mean monthly flows in the Doring River at gauge E2H003

An alternative source of water for artificial recharge would be the Troe-Troe River during high flow periods. The river only has a MAR of 4.6 Mm^3/a and high flow periods are infrequent and sporadic. Average monthly flows in the Troe-Troe River at gauge E3H001 located downstream of Vanrynsdorp are shown in **Figure A6.4**.

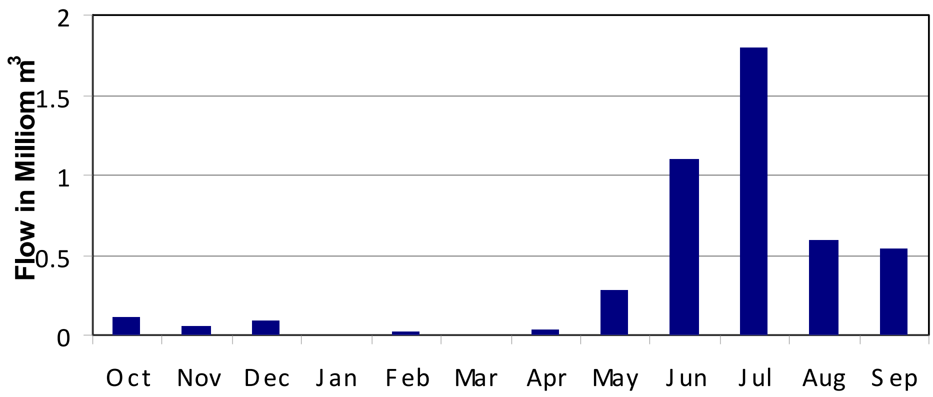


Figure A6.4 Average monthly flows in the Troe-Troe River at gauge E3H001 located downstream of Vanrynsdorp

3. THE CONCEPTUAL SCHEME

The scheme would require transferring water from the Doring River over the catchment divide into a tributary of the Troe-Troe River from where it would flow to the aquifer for recharge (see **Figure A6.1**). The water would have to be pumped up a vertical elevation difference of about 470m over a distance of 5 km. A soil survey and study of the infiltration potential would be necessary to establish whether recharge my means of basins or trenches would work, as this would require the least treatment to reduce the turbidity of the water prior to recharge. The river bed of the Troe-Troe River is contains clean quartzitic sand that may well provide a direct link for recharge to the dolomites. Clean sand is found in cavities at depth far from the river, and this suggests that there may be a good link between the sands and the dolomitic aquifer, and that infiltration along the river course could be an option. If not, the far more expensive option of borehole injection would be necessary, and this would require that most of the turbidity is removed otherwise the boreholes would clog with fine particulate matter.

The cycle of recharge and abstraction would entail diverting the winter runoff from the Doring River to the aquifer over the 4 to 6 months when water is available, and then abstracting it from the aquifer during the summer months.

The second option utilising the Troe-Troe River peak flows would also be dependent on the suitability of using infiltration basins or trenches and diverting water into these during high flow periods. The observed river flows indicate that this would probably only be viable in one out of every three years.

4. KEY ISSUES THAT AFFECT THE VIABILITY OF THE SCHEME

The key issues that affect the viability of this scheme are:

- Is there a need? Linked to this is whether the area east of Vanrhynsdorp is suitable for intensive agriculture.
- Can the aquifer receive the water at the required rates?
- Is it economically viable to transfer water to this area (with the high pumping heads) and reduce the turbidity so that it is suitable for recharge?

REFERENCE

PGWC. 2006. Provincial Government Western Cape: Department of Agriculture: Western Cape. 2005. Main Report. Draft Final. Prepared by Arcus Gibb (Pty) Ltd as part of Contract No. 259-2000/2001. Western Cape Olifants/Doring River Irrigation Study. PGWC Report No. 259/2004/02.

Appendix 7: Lamberts Bay: The potential for using an aquifer for balancing storage

1 INTRODUCTION

Within the northern Sandveld area there are four towns that are entirely dependent on groundwater for their domestic supply. For the towns of Graafwater and Leipoldtville, the supply is able to meet demand; however for Lamberts Bay and Elands Bay both the water quantity and quality, in terms of supply, have been problematic. These problems are being addressed but the option of artificial groundwater recharge to their sandy aquifers should be considered for these two towns.

The town of Lamberts Bay faces water shortages, especially in the summer period, when there is a significant increase in the town's demand. Currently groundwater is abstracted from the Wadrif Aquifer to the south of the town (titled "Area 1"), however the area to the north-east of Lamberts Bay has also been explored (titled "Area 2") as part of a study to address all the possibly supply options to Lamberts Bay (**Figure A7.1**). Other supply options that have been tabled for Lamberts Bay include the desalination of sea water and the piping of water from the Clanwilliam Dam.

2 OPTION 1: SMALL – MEDIUM SCALE ARTIFICIAL RECHARGE OF THE CENTRAL WADRIF

There are two options in this area:

i) Artificial recharge to the Lower Wadrif (the previous wellfield)
ii) Artificial recharge to the Central Wadrif (the current wellfield)

The location of these two areas is shown in **Figure A7.2**. The Lower Wadrif Aquifer is labeled "Previous wellfield" and the Central Aquifer is labeled "Current wellfield".

This aquifer is located in a low rainfall region situated on the arid west coast. The surface flow of the Langvlei River is very low and typically only flows after concurrent years of good rainfall. Abstraction of water from the Jakkalsvlei River is not seen as a viable option as the flow itself – when it occurs – has significant ecological value. Water used for artificial recharge will need to be piped into the area from the Clanwilliam Dam on the Olifants River.

Figure A7.1/…

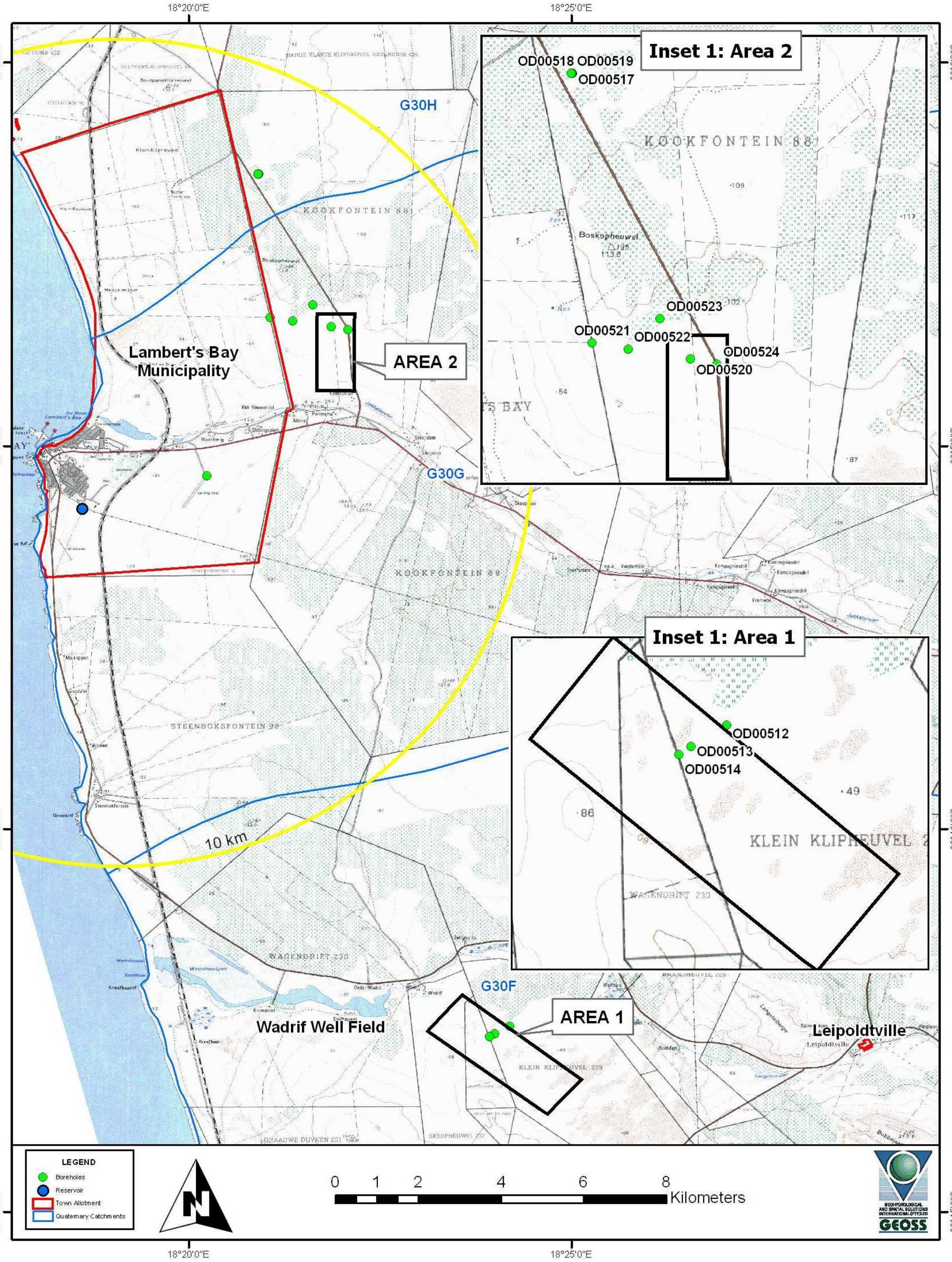


Figure A7.1 Wellfield options for the town of Lamberts Bay (Area 1 = existing wellfield

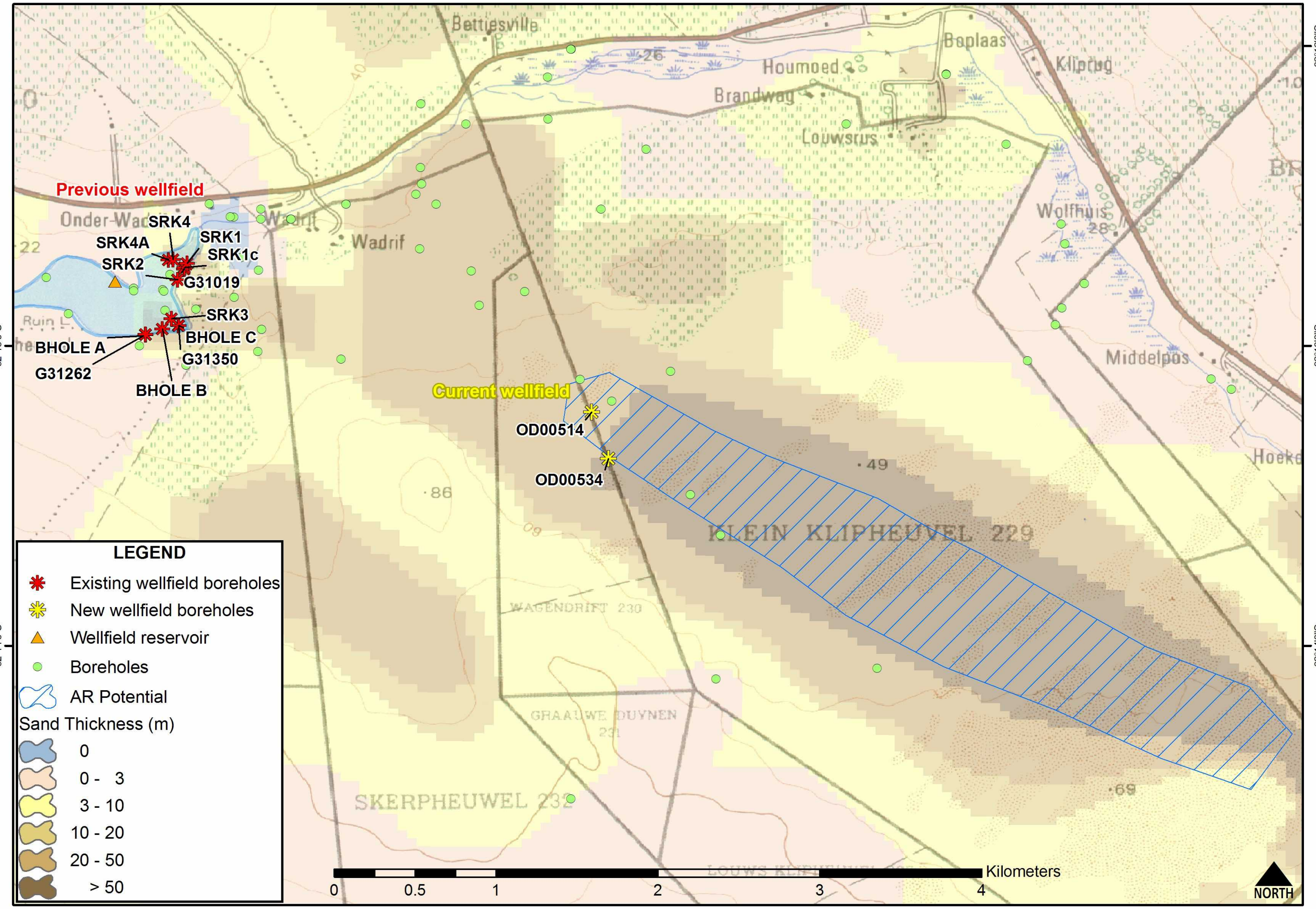


Figure A7.2 Lower and Central Wadrif wellfields used for the supply of water to Lamberts Bay (Area 1 in Figure A1) and Area 2 = possible new wellfield)

i) Artificial recharge to the Lower Wadrif

The wellfield in this area has been decommissioned because of poor quality groundwater. The deterioration of water quality has been a result of two activities:

a. Groundwater abstraction that resulted in the lowering of water levels and the consequent induction of more saline water into the wellfield, and
b. Natural, infrequent high rainfall that results in the mobilization of salts from the salt pan which in turn affects the groundwater salinity.

The aim of artificial recharge would be to enable the re-commissioning of the wellfield by ensuring groundwater levels are maintained between optimum elevations.

The groundwater levels are shown in **Figure A7.3** for both the lower and central Wadrif aquifers. Due to the good rainfall in 2007 and 2008 standing rain water in the normally dry Wadrif salt pan resulted in the mobilization of salts which leached into the aquifer. This was exacerbated by the unusually high water table at this time, which allowed for a short travel path to the aquifer for the recharging surface water. This resulted in an increase in the salinity of the groundwater from ~200 mS/m to ~700 mS/m (**Figure A7.4**).

Thus for the lower Wadrif, if artificial recharge is to be considered, it must be done at the very eastern end of the lower Wadrif wellfield, possibly using boreholes SRK1 and Borehole C. The objective of artificial recharge would be to maintain groundwater levels between specific elevations so that abstraction can continue without the deterioration in water quality that can arise from both depressed and elevated water levels. Key to this would be ensuring that the water quality deterioration that arises from the more common lowered water levels is prevented. Once the groundwater quality improves with artificial recharge, the wellfield could be reconsidered for use at an abstraction rate that maintains the water quality between acceptable limits. The problem does exist that from time to time (with exceptionally high rainfall events), the salinity problem associated with the salt pan will cause the groundwater quality to temporally deteriorate.

Figure A7.3/…

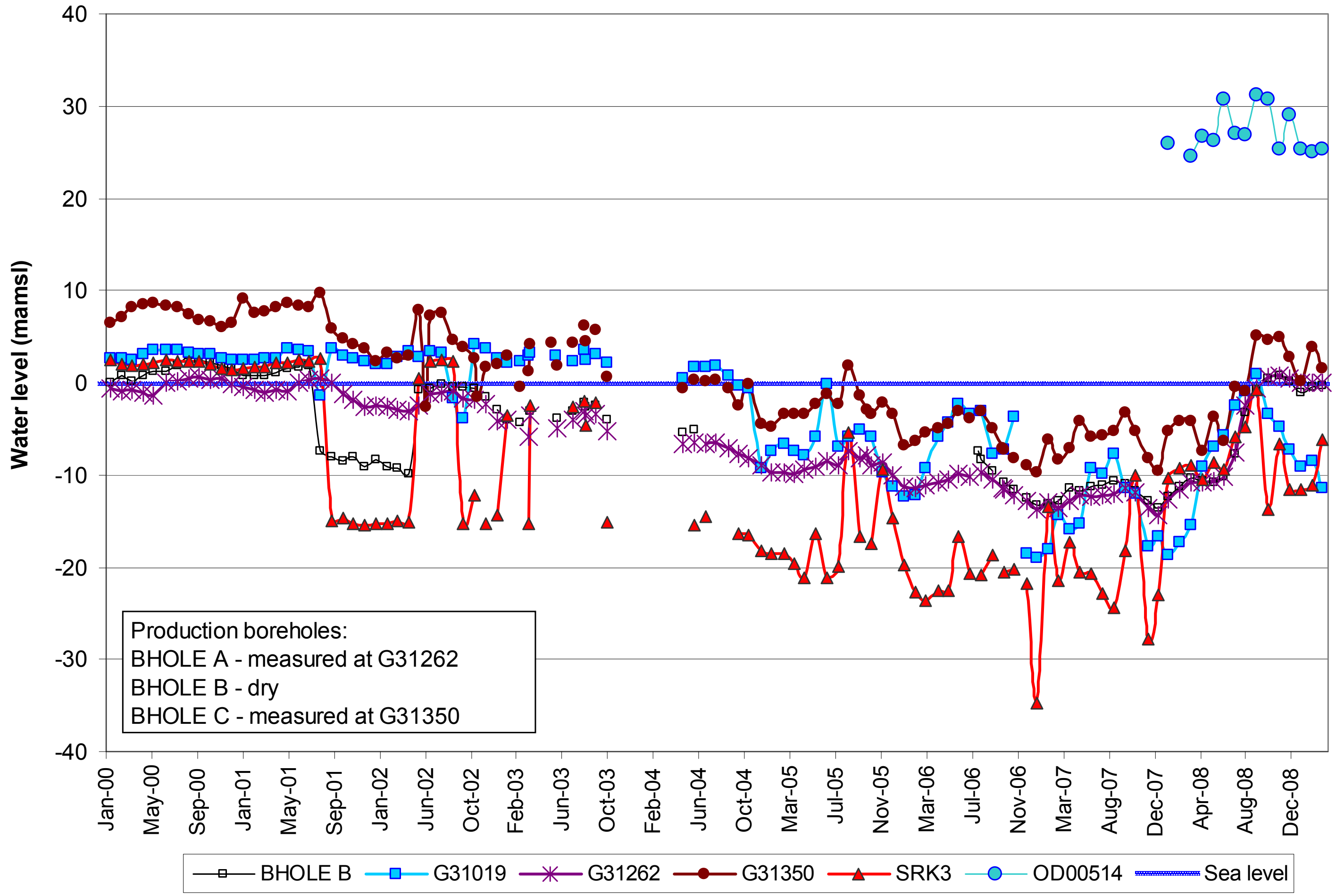


Figure A7.3 Groundwater level for lower and central Wadrif aquifer

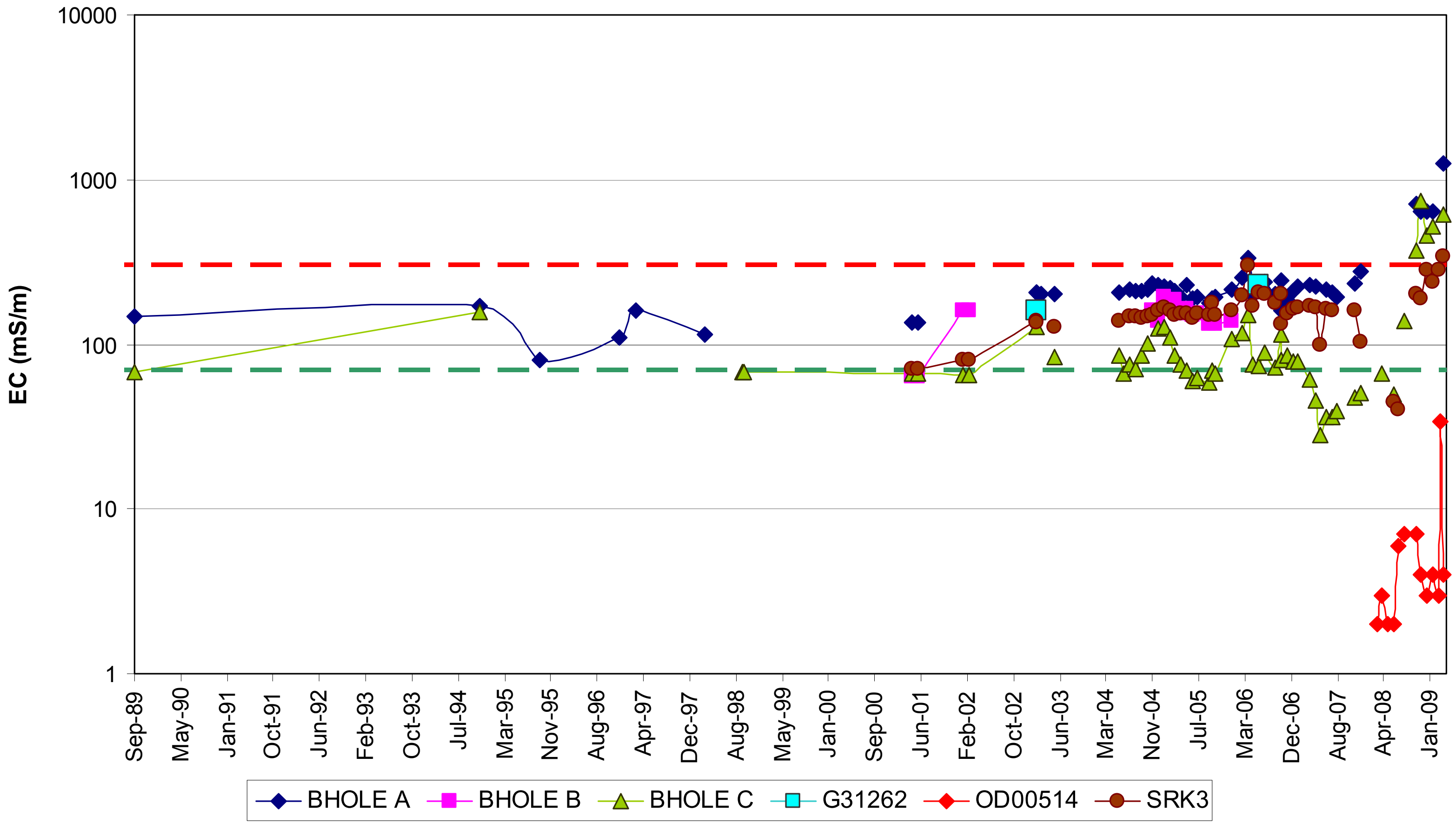


Figure A7.4 Water quality for the lower and central Wadrif aquifer

ii) Artificial recharge to the Central Wadrif

Unlike the Lower Wadrif where groundwater salinity is relatively saline, the Central Wadrif is characterised by fresh groundwater (EC ~40 mS/m). The aim of artificial recharge in this area would be to twofold: i) To store water in the aquifer during winter for use in summer; and ii) To assist in the rehabilitation of the environment. The scheme would require transferring water from the Clanwilliam Dam when surplus water is available in winter for use in summer when the demand is high. This would require drilling injection boreholes either in or up-gradient of the existing wellfield, and supplying them with treated surface water. Infiltration basins in the wellfield area would not be an option because the aquifer is semi-confided due to an overlying clay layer. The exiting Lamberts Bay production boreholes are used continually and would not be available as dual injection/recovery boreholes. The environmental benefits would be realised if over the long term more water was transferred into the aquifer than was abstracted. Over the years nearly all the springs and wetlands have dried up, and this could be reversed if the recharge volumes and cycles were planned for both water supply and environmental rehabilitation purposes.

The main benefit of artificial recharge would be to utilise the aquifer as balancing storage, transferring water during winter when the demand is low and when the Olifants River is flowing strongly, and then extracting the water during the high demand summer months. The surface water supply pipelines and pumping infrastructure could be optimally sized rather than sized to meet the peak summer demand. Alternatively, artificial recharge could be used as balancing storage for a desalination scheme with the same objective.
The artificial recharge potential would largely depend on the number of boreholes drilled for recharge purposes. One injection borehole should be able to receive about 20 l/s (~1800 m^3/day). Assuming the aquifer is suitable for receiving water via injection boreholes (which would require testing), and assume five injection boreholes are drilled, then about 9000 m^3/day or about 1 Mm^3 could be recharged over a four-month winter period of artificial recharge.

Key issues relating to Option 1:

- The source water and its and availability for recharge
- The positioning and number of injection boreholes
- The economic viability of the scheme
- The timing of the recharge/abstraction cycle.

3 OPTION 2: LARGE SCALE ARTIFICIAL RECHARGE TO THE UPPER- CENTRAL WADRIF

The aim would be to heavily utilize the aquifer during summer (far more than its sustainable yield) for both town and irrigation supplies, and to fully replenish the aquifer during winter from the Clanwilliam Dam. This would require transferring large volumes of water to the upper and possibly the central Wadrif (to areas as yet identified) for recharge to the entire Wadrif Aquifer. This option would require a detailed investigation to assess its feasibility, however, the potential for large-scale seasonal storage may be an attractive option. The storage capacity of an area 20 km in length, 5 km in width and 30 m deep, using a storage coefficient of 10% is 300 Mm^3. By comparison, this is nearly five times the additional volume that would be realized by raising the Clanwilliam Dam wall 5 m (63 Mm^3). Ideally it would be best to locate areas where the clay layer is absent so that artificial recharge by means of infiltration basins could take place, as this would require the least pre-treatment (settling only).

The key factors that would affect the rate of artificial recharge and the annual recharge volume (over the winter months), are:

- The rate at which the aquifer can receive the water
- The availability of the source water
- The rate at which water can be retrieved form the aquifer via boreholes.

Any one of the above factors could be the limiting factor of the scheme's potential. Assuming the availability of the source water and the ability of the aquifer to receive water are not the limiting factors, then the number of high-yielding boreholes that would be needed to supply 10 Mm^3/a for example, would be about 30 if each could supply 2000 m^3/day over 6 summer months (assuming each borehole can deliver 1800 m^3/day).

This option would entail transferring water from the Clanwilliam Dam to the Jakkals River catchment from where it would flow to the recharge area. The water would have to be pumped up a vertical elevation difference of about 330m over a distance of 19 km.

Key issues that affect the viability of the scheme:

- The viability of transferring water from the Clanwilliam Dam to the upper Wadrif would need to be assessed
- The recharge mechanism and location of the recharge facilities would need to be established
- The economic viability of the scheme would need to be assessed.

4 OPTION 3: SMALL – MEDIUM SCALE ARTIFICIAL RECHARGE OF THE NORTH-EAST AQUIFER

The aquifer targeted for development lies about 6 km north east of Lamberts Bay (**Figures A7.1** and **A7.5**). The aim of recharging this area would be to increase the aquifer's yield in summer. The aquifer is currently not being utilized for town supply, however the boreholes have been drilled and the supply scheme is ready for implementation. A bonus would be to add artificial recharge to the implementation plan at the onset.

The potential artificial recharge rate would be in the region of 15 l/s (~ 1300 m^3/day) per borehole. Additional injection boreholes would need to be drilled as all the existing boreholes will likely be used for the groundwater abstraction. An advantage of artificial recharge to this area is that the aquifer is not intensely utilized for farming like some of the other areas are.

Recharge water would need to be brought to this area. This aquifer lies immediately to the north of the Jakkalsvlei River and the flow in this river is even less than the Langvlei River. When this river flows it also has significant ecological value. As with the previous options, source water would have to be brought from either the Olifants River or obtained from desalination.

An advantage at this site is that because this wellfield has not yet been developed, the infrastructure design can accommodate artificial recharge from the onset, if artificial recharge proves to be feasible.

Key issues that affect the viability of the scheme:

- The source water and its and availability for recharge
- Borehole clogging will need to be taken into account as this aquifer is characterized by high iron and manganese concentrations.

5 CONCLUSION AND RECOMMENDATIONS

The availability of fresh water in this area is severely limited and finding a source of water for artificial recharge is a major constraint. Source water would have to come from one of the following:

- The Olifants River
- Desalination
- Groundwater sources in the TMG aquifer

The benefit of utilizing artificial recharge is that it can provide storage close to where the water is needed and fulfill a balancing function between winter and summer demands for any of the sources that may be developed for the area. This translates into smaller and cheaper infrastructure components, but greater running costs, as additional costs would be incurred in injecting and re-abstracting the recharged water.

The existing Lamberts Bay wellfield (central Wadrif)

The introduction of an artificial recharge scheme would be beneficial. Groundwater is used both for municipal supply and for agricultural purposes. In addition it plays an important ecological function. Thus there would be benefit if groundwater levels can be raised. In the area, especially in summer, there is additional aquifer storage capacity. However the challenge remains that, due to the low rainfall within the areas and very limited surface water flow within the Langvlei River, water to be used for recharge would have to be piped into the catchment area and recharge would have to be via dedicated artificial recharge boreholes.

Lower Wadrif wellfield

For this wellfield, which is no longer being used as a source of domestic supply for Lamberts Bay, artificial recharge would be beneficial if the water levels can be raised and the water quality improved. In the longer term the wellfield could be used again (at a low abstraction rate) to supplement the water supply to Lamberts Bay. The issue of the source water for recharge to the central Wadrif is the biggest problem.

The possible sources of recharge water need to be investigated with associated costings, to be able to evaluate the economic viability of groundwater recharge in the Wadrif area.

Aquifer to the north-east of Lamberts Bay

A groundwater supply from this aquifer is under consideration, but it should be noted the water will require treatment prior to use. This option is cheaper than desalination of sea-water. If this wellfield is to be developed then planning for artificial should be included if the source water for recharge can be addressed.

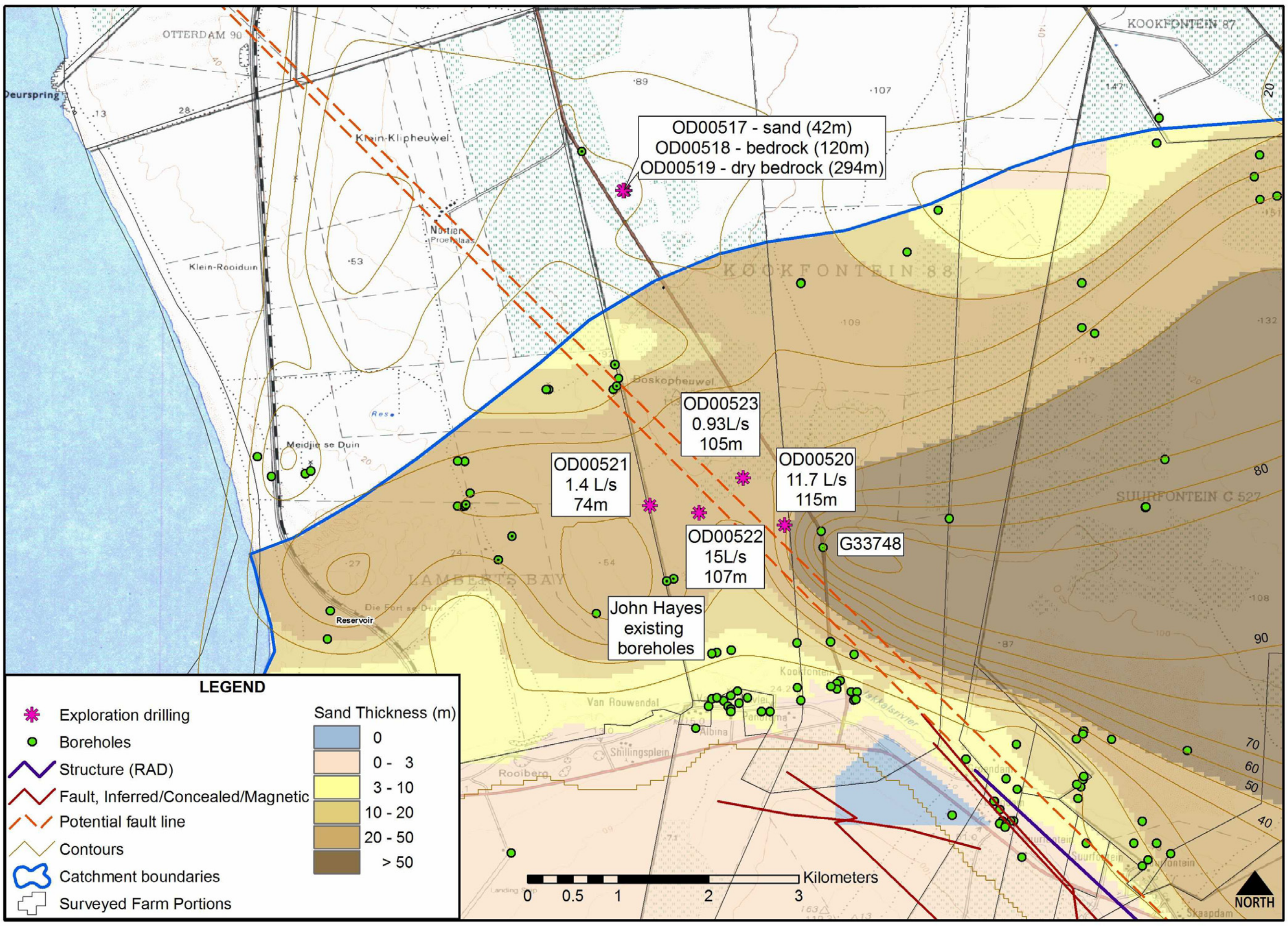


Figure A7.5 Potential wellfield to the north-east of Lamberts Bay (Area 2)

Appendix 8: Elands Bay: Artificial recharge potential in an unsaturated aquifer

1 INTRODUCTION

The town of Elands Bay obtained its water from seven boreholes (R1 to R7) in the past (**Figure A8.1**). Boreholes R1, R2 and R3 are situated in the dune field to the north-east of Elands Bay. The groundwater yields are acceptable although quite low, and the water quality is also acceptable. The boreholes have been in use for many years and are very important for the town supply. Their abstraction rates and volumes cannot be increased because any further drop in water levels could induce saline water into the aquifer (the water levels are currently at or below sea level). Boreholes R4 to R7 are situated to the north of the Elands Bay/Redelinghuis road at an elevation similar to that of Velorenvlei. The water quality from these boreholes is very poor and for this reason the boreholes need to be decommissioned as part of the water supply. Three new production boreholes have been drilled further to the east (OD00525, OD00526 and OD00528). These boreholes are in a different aquifer to the previous seven boreholes and have only recently been brought into use. **Figure A8.1** shows the position of the boreholes in relation to Elands Bay. Potato farming occurs in the area and groundwater is abstracted for irrigation purposes as well.

The yields of the Elands Bay production boreholes are shown in **Table A8.1**.

Table A8.1 Borehole Yields

Borehole ID	Yield (ℓ/s)	Annual Yield (m^3/a)	Comment
R1	1.3	39,000	Dune field
R2	0.9	29,112	Dune field
R3	1.9	57,864	Dune field
R6	0.5	15,636	North of road reserve
R7	1.4	41,928	North of road reserve
OD00525	6.5	102,492[1]	Waaihoek
OD00526	3.7	58,342	Waaihoek
OD00527	9.0	141,912	Waaihoek

All the boreholes abstract groundwater from a primary aquifer. **Figure A8.2** and **Figure A8.3** show the groundwater level and groundwater quality variation with time for the production boreholes.

Figure A8.1/…

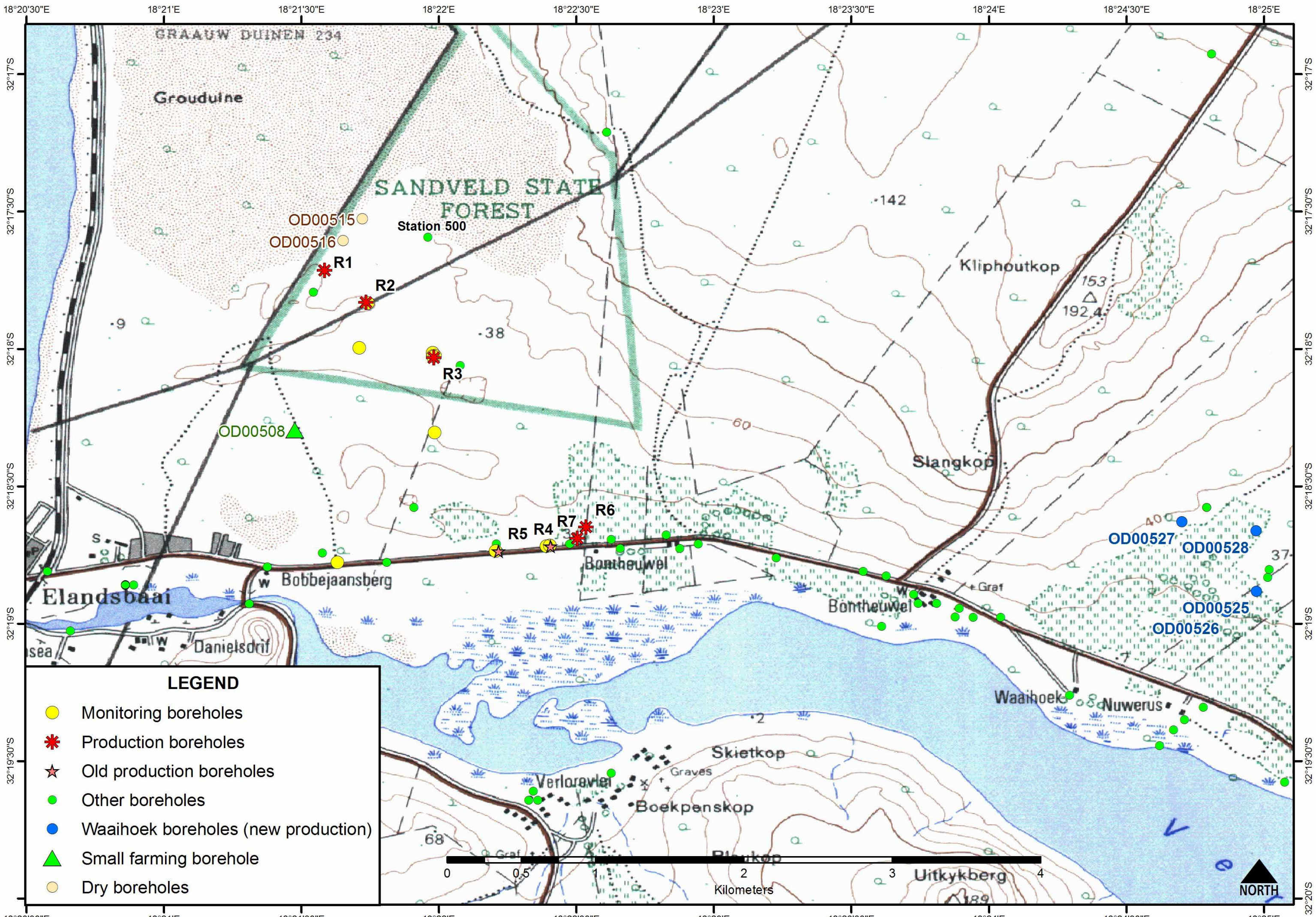


Figure A8.1 Location of boreholes for Elands Bay

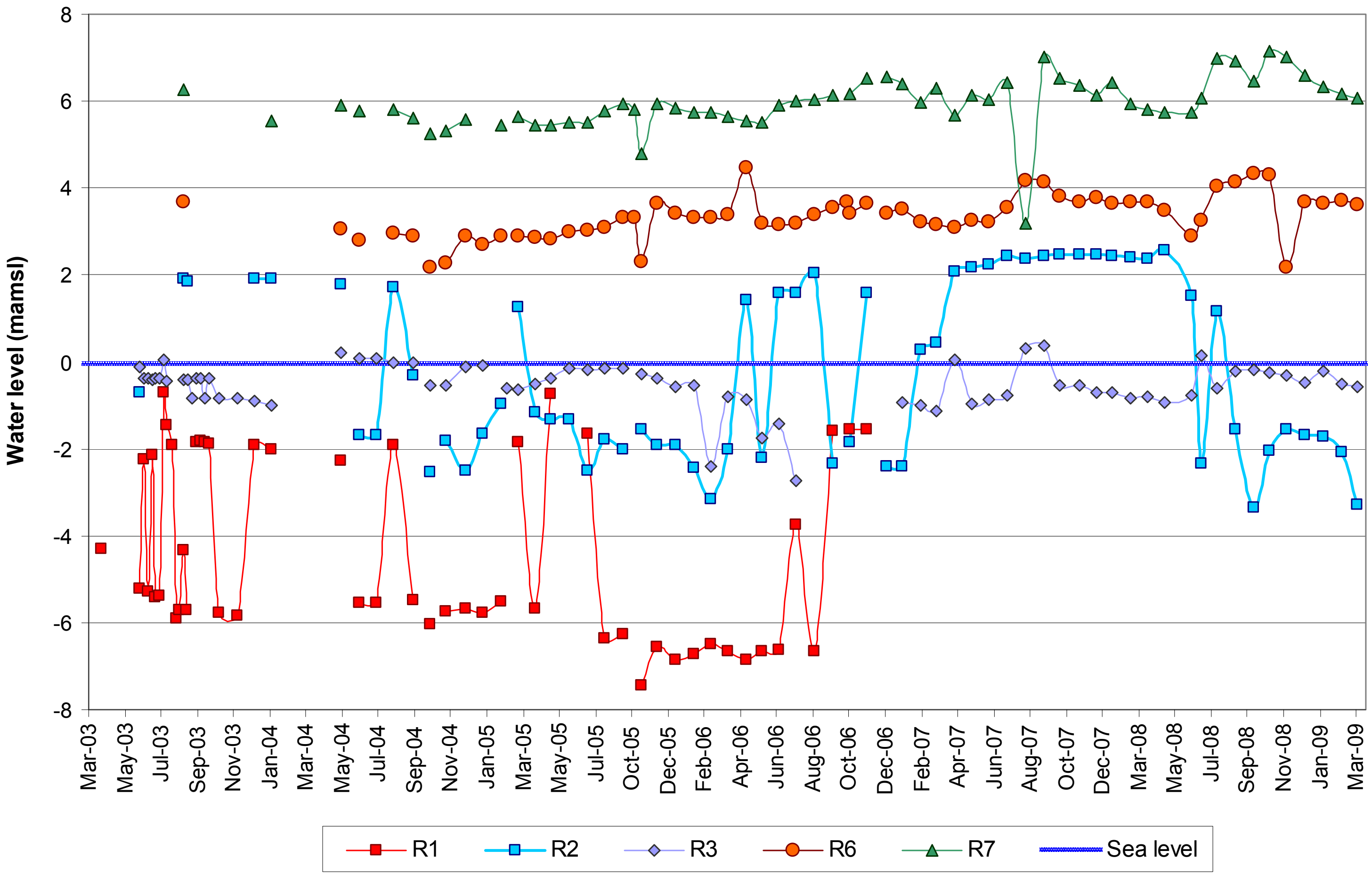


Figure A8.2 Groundwater levels at Elands Bay boreholes

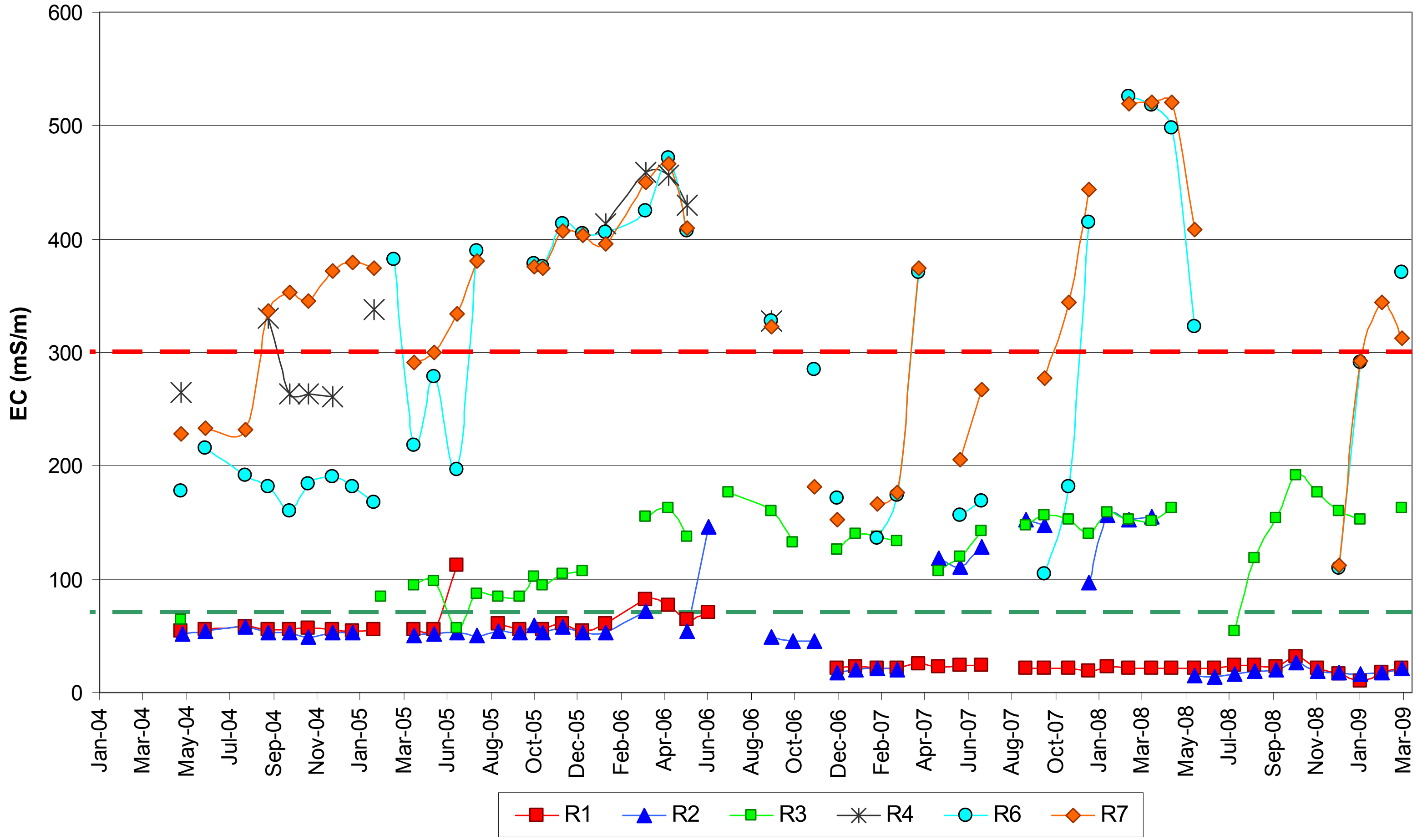


Figure A8.3 Groundwater quality at Elands Bay boreholes

Since water quality issues needed to be addressed at two of the R boreholes (R6 and R7) and additional good quality was required, groundwater exploration took place in the dune field area to the north of borehole R1. Two good drilling sites were identified and drilled. Promising aquifer material was intersected, but the groundwater levels were below the good aquifer material. The boreholes were classified as "dry". Thereafter exploration commenced on the Waaihoek Farm.

The two exploration boreholes (OD00515 and OD00516) north of R1, hold great promise for aquifer recharge. These boreholes are up gradient of boreholes R1, R2 and R3 – thus recharging the area will have significant benefit. The volume of groundwater that is currently being abstracted from R1, R2 and R3 cannot be increased as the water levels are at or below sea level and must not be allowed to drop further.

As the Waaihoek wellfield was only commissioned recently, more data needs to be collected. In principal, however, this wellfield area will also benefit from recharge as the area is used both for municipal supply and agricultural purposes.

For the two dune field boreholes the estimated artificial recharge potential is about 900 m^3/d (based on the characteristics of the sand material that constitute the potential aquifer), whilst in the Waaihoek area this is approximately 1 700 m^3/d (based on the recommended abstraction rate of the three existing production boreholes).

2 AVAILABILITY OF WATER FOR RECHARGE

Elands Bay is located on the arid west coast with rainfall <100 mm/a. The aquifers are predominantly recharged by inflow from deep seated faults systems. The potential source of recharge water could be from the Velorenvlei itself. However such a comment is made with caution and the water would only be abstracted when Velorenvlei is in flood and flowing out to sea. The water quality of Velorenvlei varies seasonally with the electrical conductivity (EC) of the vlei being highest during summer (EC >400 mS/m) and lowest in winter (EC <200 mS/m). The level of the vlei is monitored by DWA, thus the 'flood' volumes can be calculated. The CSIR is compiling an estuary management plan for Velorenvlei and this will also address the water quality variations of the vlei.

DWA have three monitoring stations at Velorenvlei, one at the start of the vlei at Redelinghuis, one at Bonteheuwel mid way along the vlei and another at the mouth at Elands Bay. Unfortunately these stations only monitor water quality and have only a few readings recorded (15 in total spanning 27 years). The EC values range from over 800 to 12 mS/m but there is insufficient data to make any conclusions. Anecdotal accounts are that the river seldom flows out to sea but it did so in 2008 for the first time in seven years.

The only gauge that does record water level data in the catchment is located on the Kruis River at Tweekuilen, over 26 km upstream from Redelinghuis, which is itself about 20 km upstream of Elands Bay. The flow data from this station indicates that the average flows peak at 3 Mm^3 during August (**Figure A8.4**). It is assumed that this flow fluctuation is carried through to Velorenvlei but it is so far upstream of the vlei that it is not possible to make any conclusions about the flow in the vlei.

The seasonal water quality variation of the Verlorenvlei would have to be well understood before it could be considered as a possible artificial recharge source. However, it is unlikely that using Verlorenvlei as a source of recharge water would be environmentally acceptable because of the existing water use from the vlei, the infrequent flooding events and because the vlei is an integral component of a Ramsar site.

As with Lamberts bay, artificial recharge could provide balancing storage close to where the water is needed but source water would probably have to come from one of the following:

- The Olifants River
- Desalination
- Groundwater sources in the TMG aquifer

Treated sewage effluent is not a potential artificial recharge source, as it is already used to irrigate the sports field.

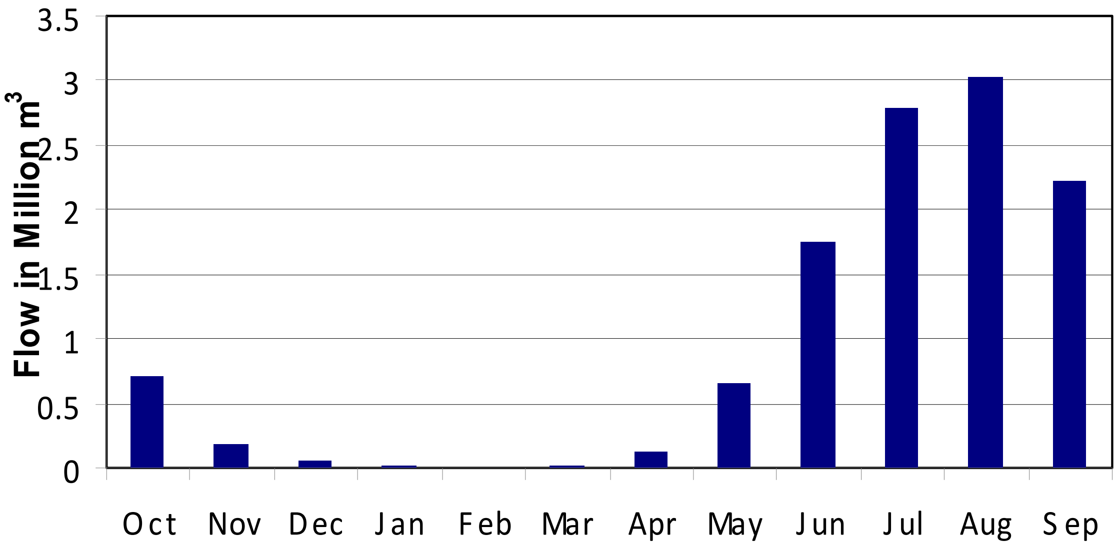


Figure A8.4 Average monthly flows in the Kruis River at gauge G3H001 at Tweekuilen (MAR 60.9 Mm^3/a)

3 KEY ISSUES THAT AFFECT THE VIABILITY OF THE SCHEME

The key issues are:

- The source water for recharge would have to be established
- If the volume of flood events make water form Verlorenvlei and option, this source would have to be very carefully assessed, as the vlei is a key component of a Ramsar site. The water quality would also have to be established to see if it is suitable for recharge.
- Estimated recharge volumes needs to be determined
- The economics of an artificial recharge scheme would have to be compared with other water supply options.

4 CONCLUSION AND RECOMMENDATIONS

Groundwater constitutes the entire water supply to Elands Bay which is located in a low rainfall area. There are two boreholes (OD00515 and OD00516) that could be solely dedicated to artificial recharge in the Velorenvlei Reserve within the dune field. These boreholes intersect good, high conductivity aquifer material that site above the water table, and are directly up-gradient of three production boreholes. Like the Lamberts Bay options, the potential for artificial recharge is limited by the availability of a suitable water source for recharge, however, if this can be sorted out, then the conditions appear very favourable to use the local aquifer in the dune fields of the Velorenvlei Reserve to provide balancing storage close to where the water is needed.