High-Yielding Groundwater Areas Around the Nelson Mandela Bay Municipality

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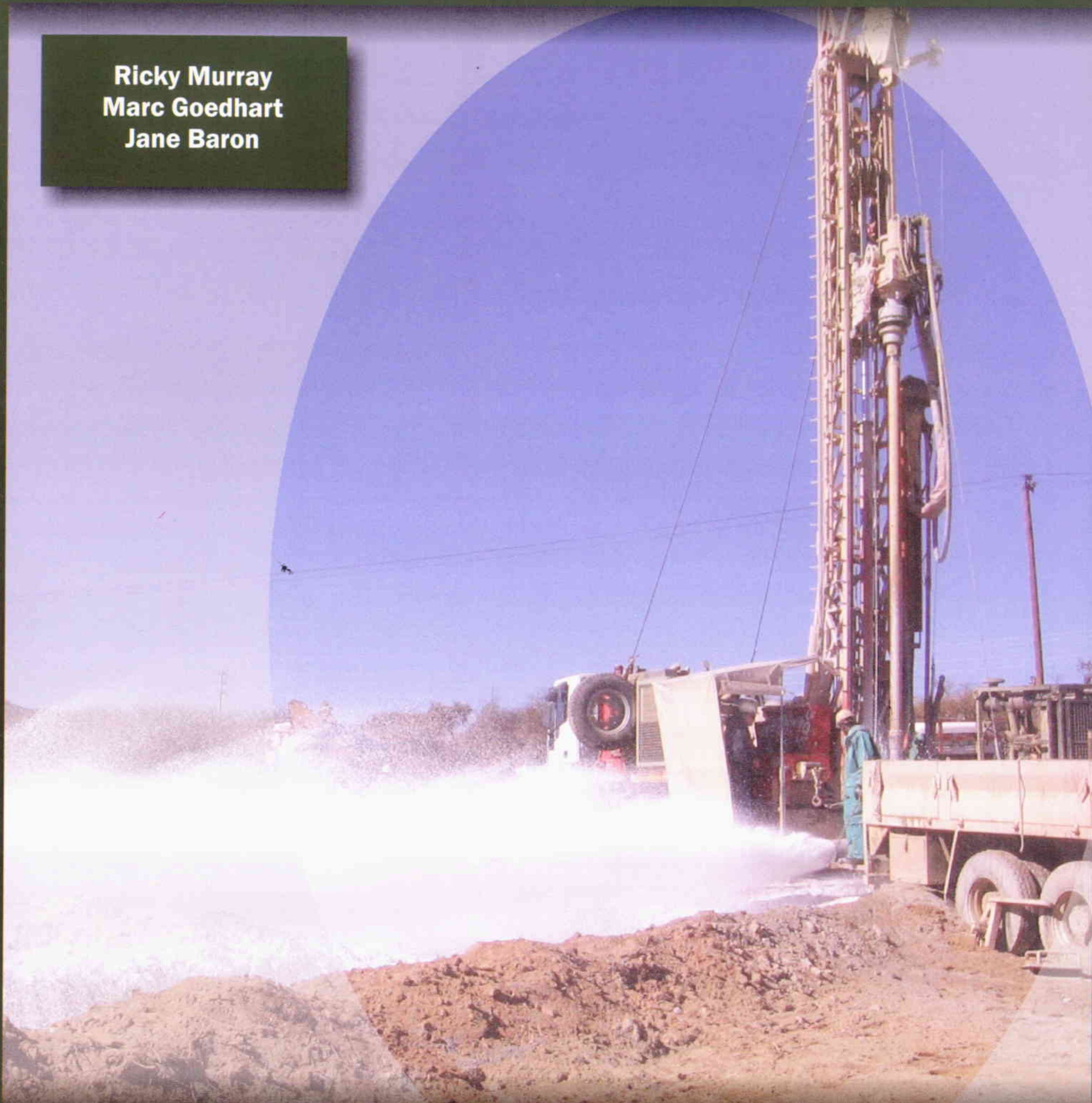

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Water Research Commission

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HIGH-YIELDING GROUNDWATER AREAS AROUND THE NELSON MANDELA BAY MUNICIPALITY

Prepared for the Water Research Commission

by

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1. INTRODUCTION

Traditionally, groundwater resources for municipal supplies are only assessed within a relatively small radius of cities/towns because of logistical and economical factors associated with pumping large distances. In the case of the Nelson Mandela Bay Municipality (NMBM), groundwater was largely written off as a potential bulk supply source because previous assessments focused on a relatively small area in and around the city. This study presents major aquifers and potential drilling target areas within an economically acceptable distance of exiting water supply infrastructure. Some of these areas are many tens of kilometres from the city, but are within a reasonable distance of existing supply pipelines and electrical energy sources. The study applied the concept of an "economic radius" rather than a "physical radius" from the point of need, and it presents a number of potentially high-yielding aquifers and drilling target areas. Although this study focuses on the NMBM, the concept of an economic radius should be applied to all municipalities – particularly those where existing bulk supply infrastructure stretches hundreds of kilometres from the town or city.

The NMBM has expressed an interest in establishing the potential for large-scale groundwater supplies – largely motivated by the projected water requirements that take the new Coega development into account. The NMBM's water requirements are estimated to increase from the current use of nearly 100 Mm^3/a to about 130 Mm^3/a by the year 2017. After assessing the groundwater potential for each identified area or "domain" the artificial recharge potential was also assessed, as this is an effective way of maximizing the conjunctive use of both surface- and groundwater. The locality of the study area and the Groundwater Domains are shown in Figures 1 and 2 respectively.

In terms of its broader application the study aims to show that groundwater resources can be considered far from the point of use, so long as the area is within an acceptable distance of existing water supply infrastructure.

Much of the work outlined here is based on that of Goedhart, Small and Hulley who, with support from the Water Research Commission and the Council for Geoscience, looked into groundwater in the Algoa Basin region (Goedhart *et al.*, 2004).

The final deliverable for this project was a poster for the NMBM of favourable groundwater areas. This report captures the information in the poster and is also written in a point-like fashion suitable for poster presentation.

Support for this project came from the NMBM, the Water Research Commission (*Project No K8/644: Development Of A GIS-Based Approach For Identifying High-Yielding Municipal Groundwater Exploration Target Areas*) and DWAF (*Project No 2004-240: Strategy Development: A National Approach to implement Artificial Recharge as part of Water Resource Planning*).

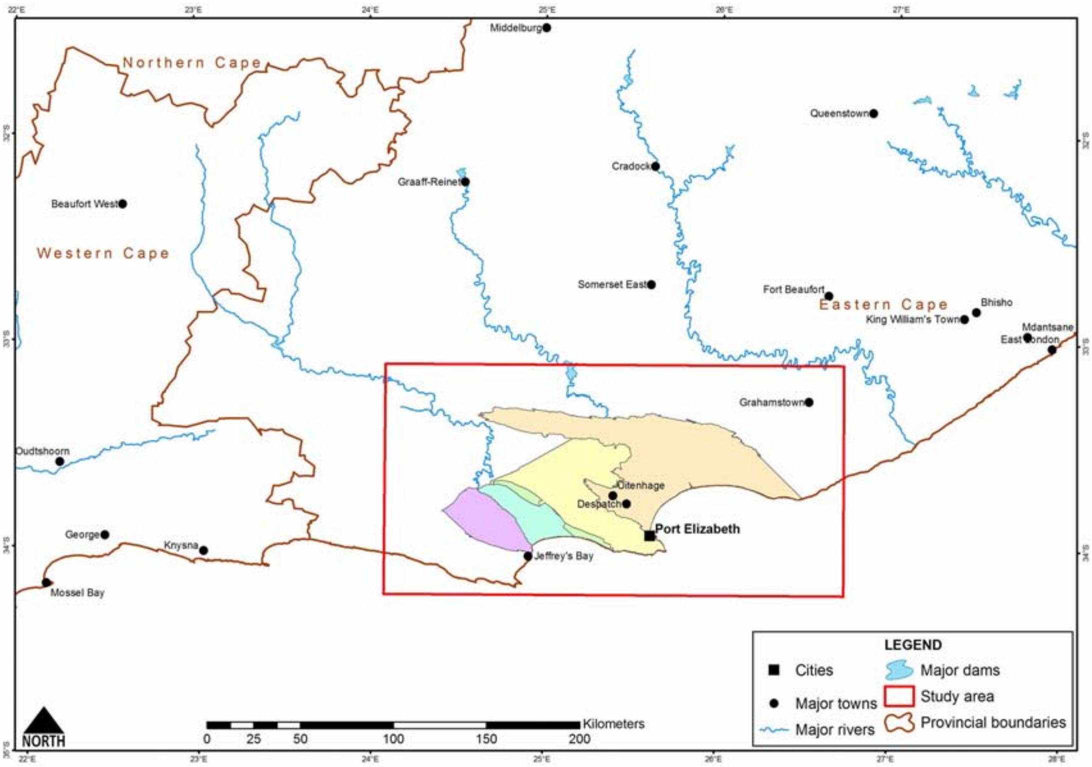


Figure 1 Study area

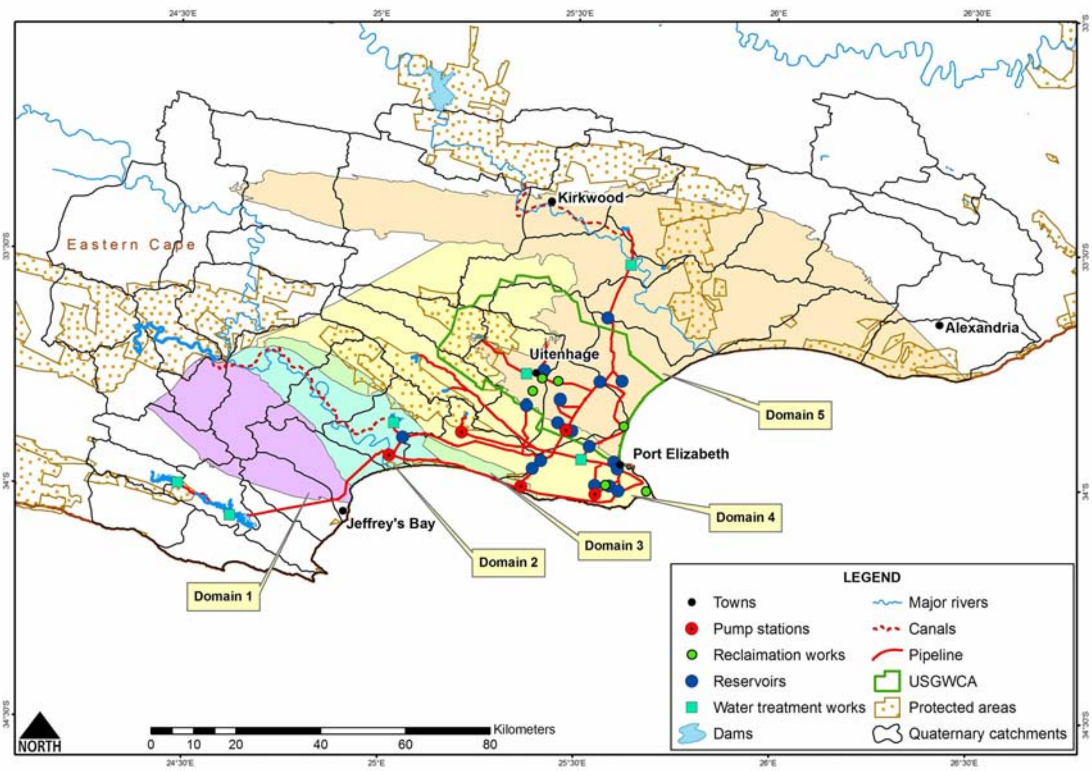


Figure 2 Groundwater Domains

2. GROUNDWATER DOMAINS

2.1 Domain 1: Jeffreys Arch

Potential targets

The general criteria required for targeting high yielding boreholes in the Jeffreys Arch Domain (Figures 3 and 4) appear to be the following:

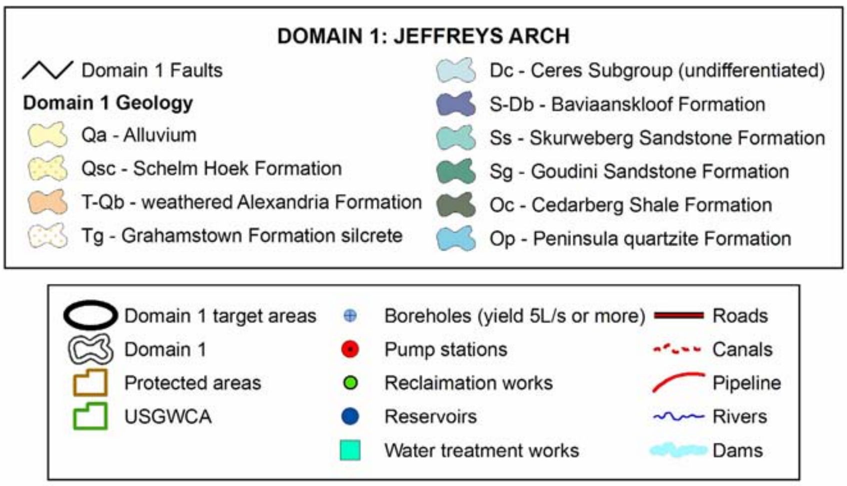
1. Anticlinorium in this area are composed of numerous secondary anticlines and synclines. The changes in fold limb orientations increase permeability and can increase groundwater residence time.
2. The drilling target areas must be well jointed and fractured. In Domain 1 NE-SW jointing dominates, but subordinate site-specific N-S and E-W joints should also play a role in groundwater flow.
3. Possible deep Table Mountain Group (TMG) structural targets under Cretaceous basin fill at the extreme SW margin.
4. High coastal recharge area.
5. Much exposed fractured bedrock in recharge area, with a thin soil cover.

Highlighted areas in order of priority

1. Plunging anticlinorium. Target synclines first.
2. Intersection of quartzitic sandstone syncline / anticline structures and the dominant NE-SW joint system. Geological evidence suggests the presence of artesian water.
3. Target Areas 3 & 4: Secondary anticlines and synclines. Target the synclines and change in bedding dip in combination with the dominant fracture system. Target Area 4 could be extended towards Humansdorp and Kruisfontein, should similarities with Target Area 2 be found.

COMMENT

Some data exists for Target Areas 1 & 2. This needs to be collated and verified prior to extending the model within a target area or to surrounding structures. Once this has been done, it may be worth investigating the S and SW boundary of this domain (for example, around Kuilsfontein and Humansdorp), where the geological conditions are similar to those at Zuurbron.



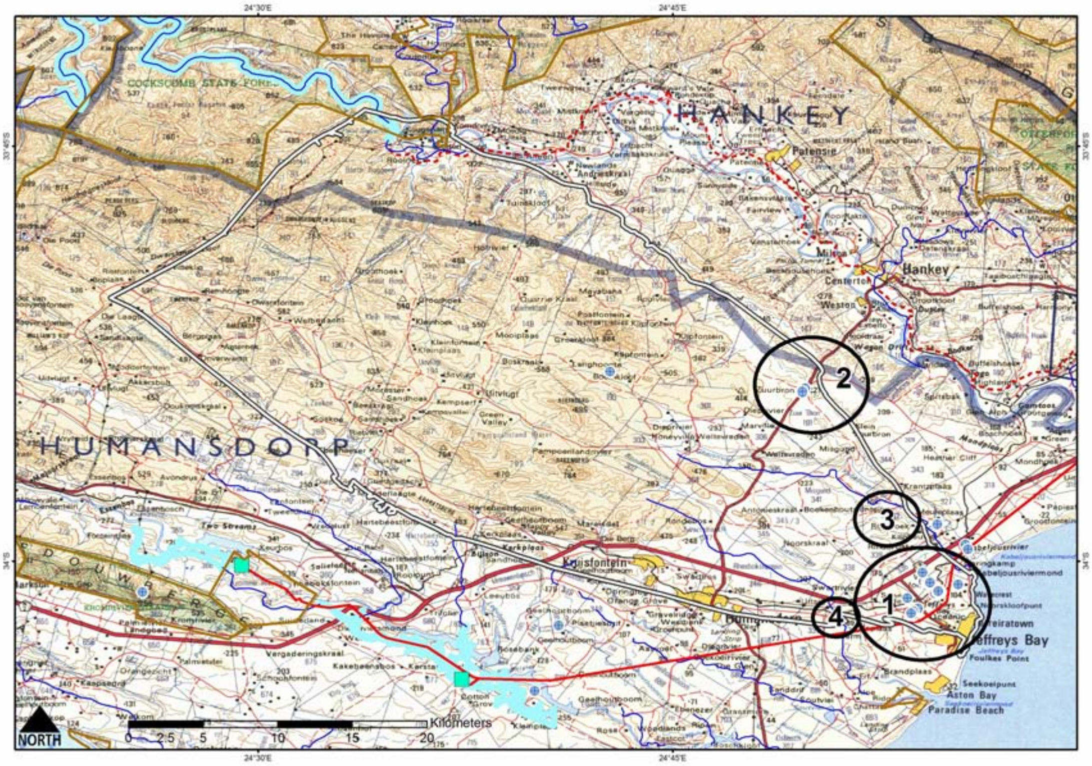


Figure 3 Domain 1 locality and drilling target areas

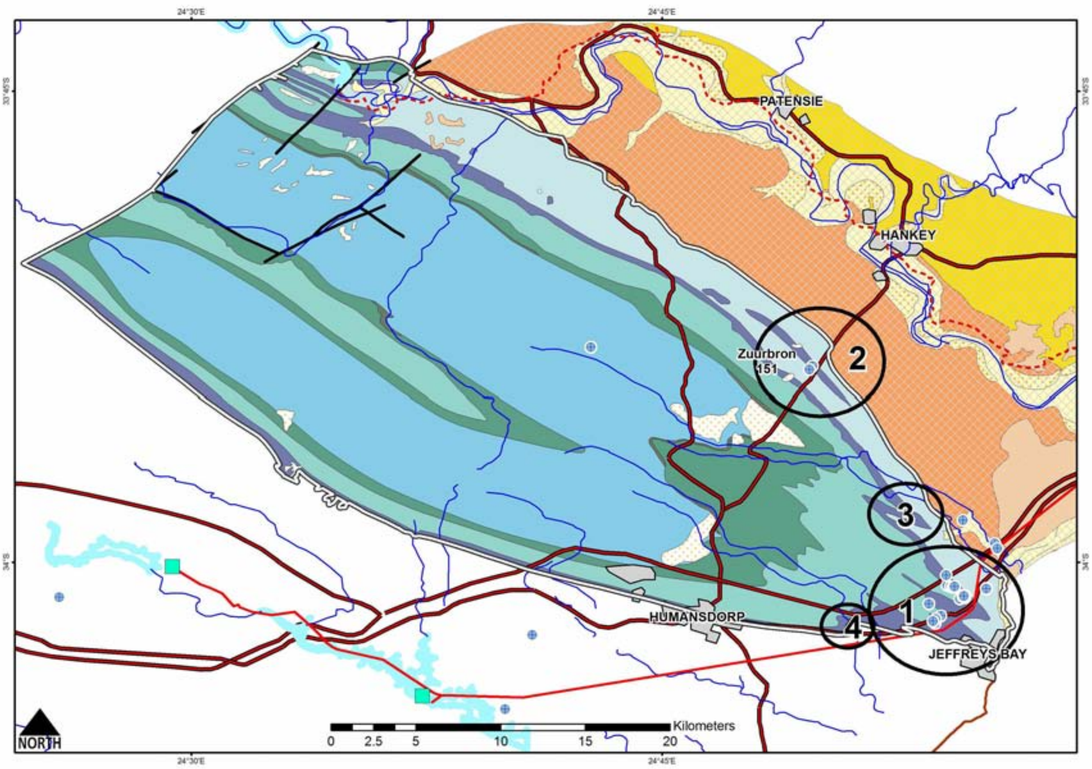


Figure 4 Domain 1 geology and drilling target areas

2.2 Domain 2: Gamtoos Basin

Potential targets

The high groundwater potential areas in the Gamtoos Basin (Figures 5 and 6) appear to be:

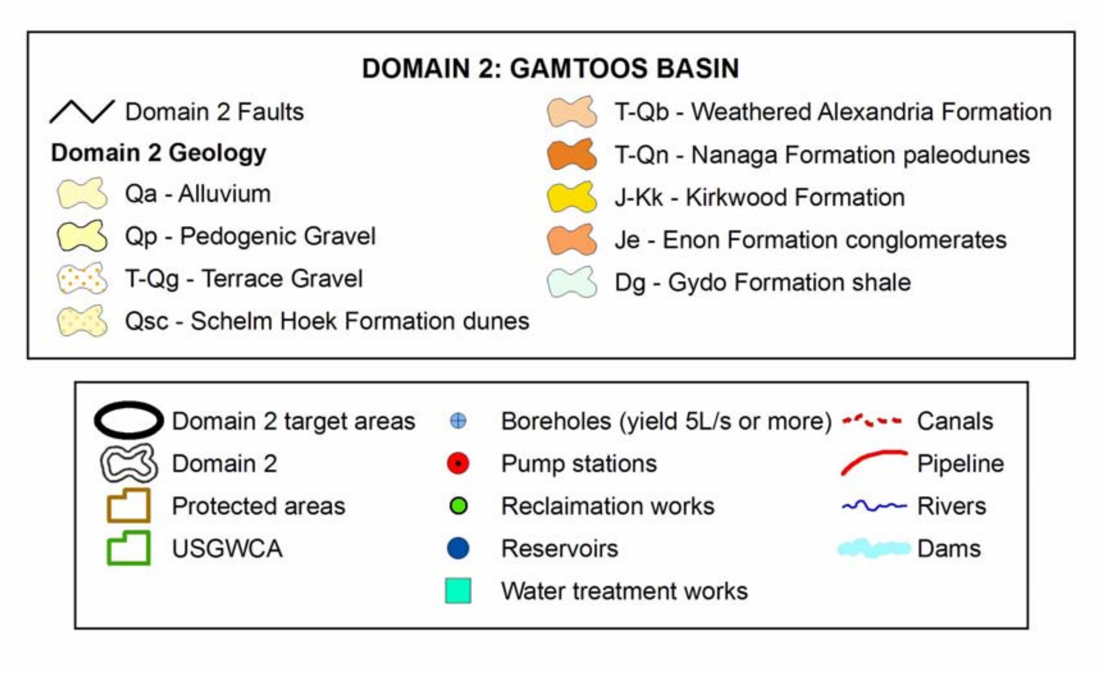
1. The Gamtoos boundary fault and associated faulting (largely unmapped).
2. The buried gravel terraces of the Gamtoos River.
3. The coarser-grained sand horizons in the upper Enon – lower Kirkwood Formations.
4. Seepage water at the base of the Tertiary and Quaternary cover sediments.
5. Possible fault-related lineaments in the basin – provided they are not clay-rich faults.

Highlighted areas in order of priority

1. The area encompasses mainly suspected buried alluvial aquifers, with the best target being the gravel terraces.

COMMENT

This area is largely unexplored. Excluding NE and SW boundaries, this domain has the lowest potential when compared to the other domains.



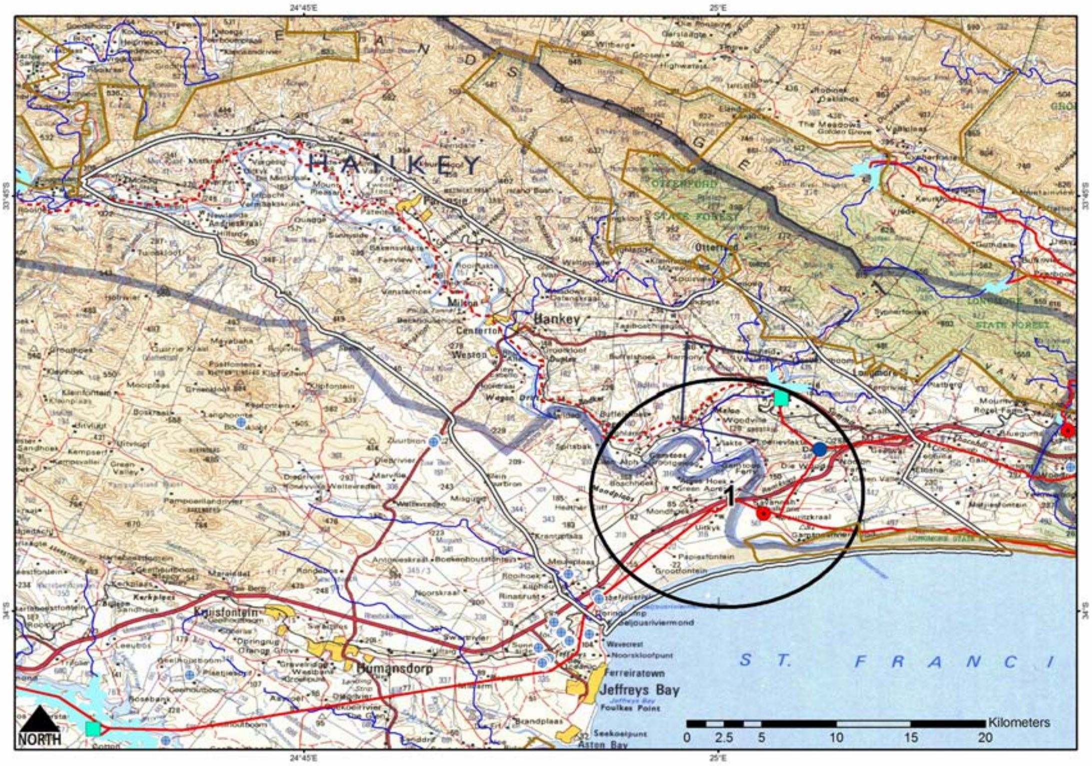


Figure 5 Domain 2 locality and drilling target areas

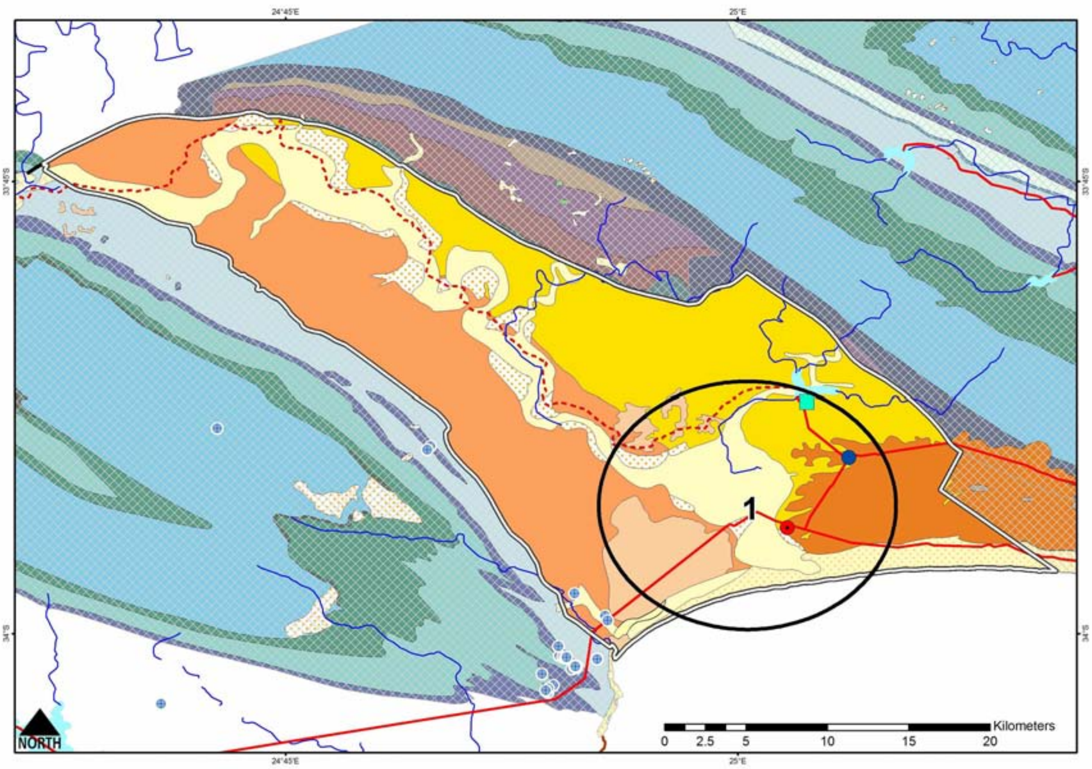


Figure 6 Domain 2 geology and drilling target areas

2.3 Domain 3: Pre-Cape Horst

Potential targets

In order of priority, the following target areas in Domain 3 (Figures 7 and 8) have been identified, but still require verification:

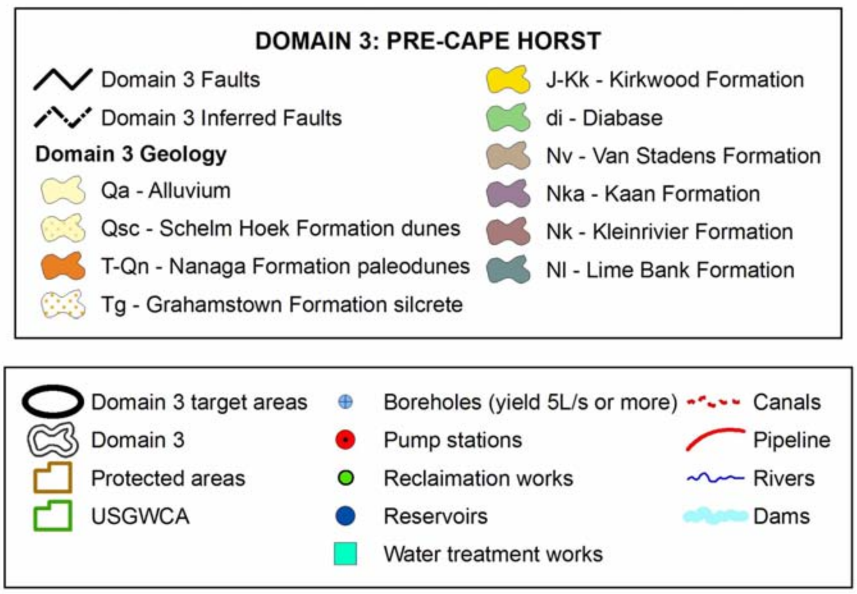
1. Boundaries to Domain 3 are all major faults. The associated fracture zones are potential groundwater targets. The intersection of the Elandsberg fault and the drainage from the adjacent higher-lying TMG rocks may hold greater potential than the Gamtoos fault.
2. The dominant NNE-SSW to NE-SW striking transfer faults cutting across the Gamtoos Group are potential groundwater targets.
3. Within the horst, the unit boundaries are typically thrust faulted (not shown), and, where brecciated, these contacts may form zones of high permeability.
4. There are some favourable calcareous and arenaceous lithologies within the Gamtoos Group. These rocks are highly deformed and fractured. They would need to be mapped to get an indication of recharge potential and fracture density, as they may form significant localised sources of groundwater.

Highlighted areas in order of priority

1. Target Areas 1 & 2: Elandsberg boundary fault. The geology of the southern side of this fault are phyllites - a good groundwater barrier. The northern side will therefore trap the recharged orographic rainfall in the NE-SW fractures. It will require detailed structural geological work to pin-point targets.

COMMENT

The boundary faults and transfer faults in this domain are largely unexplored. However, they may hold significant groundwater potential.



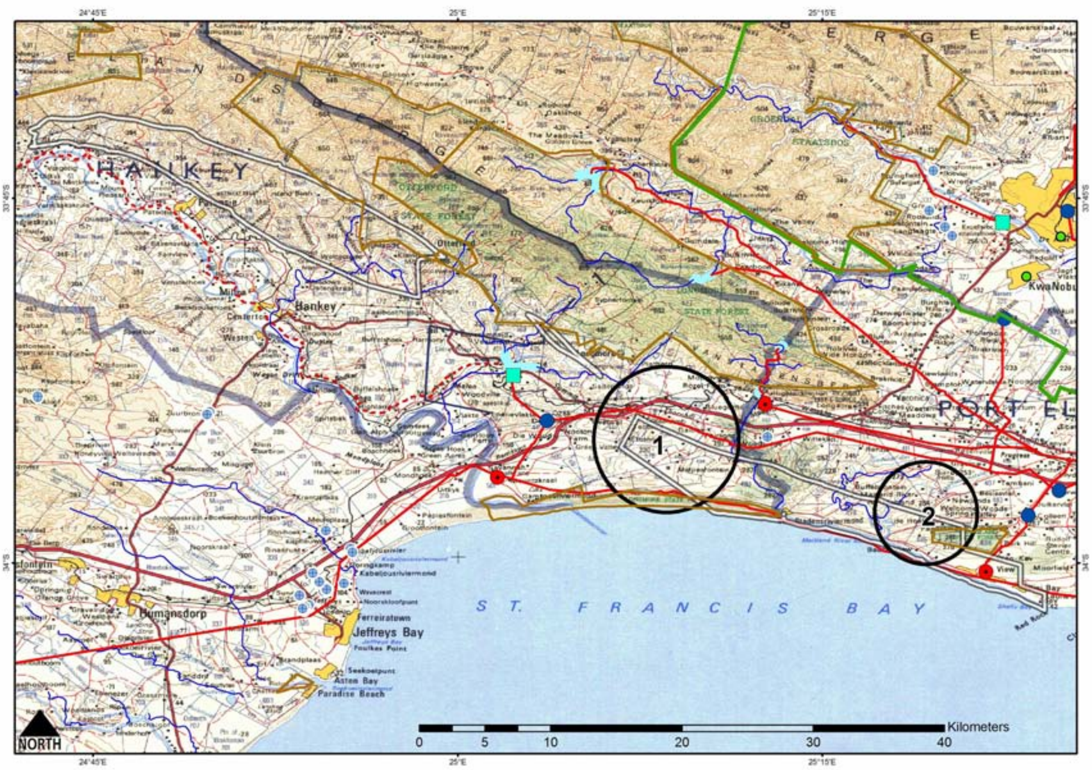


Figure 7 Domain 3 locality and drilling target areas

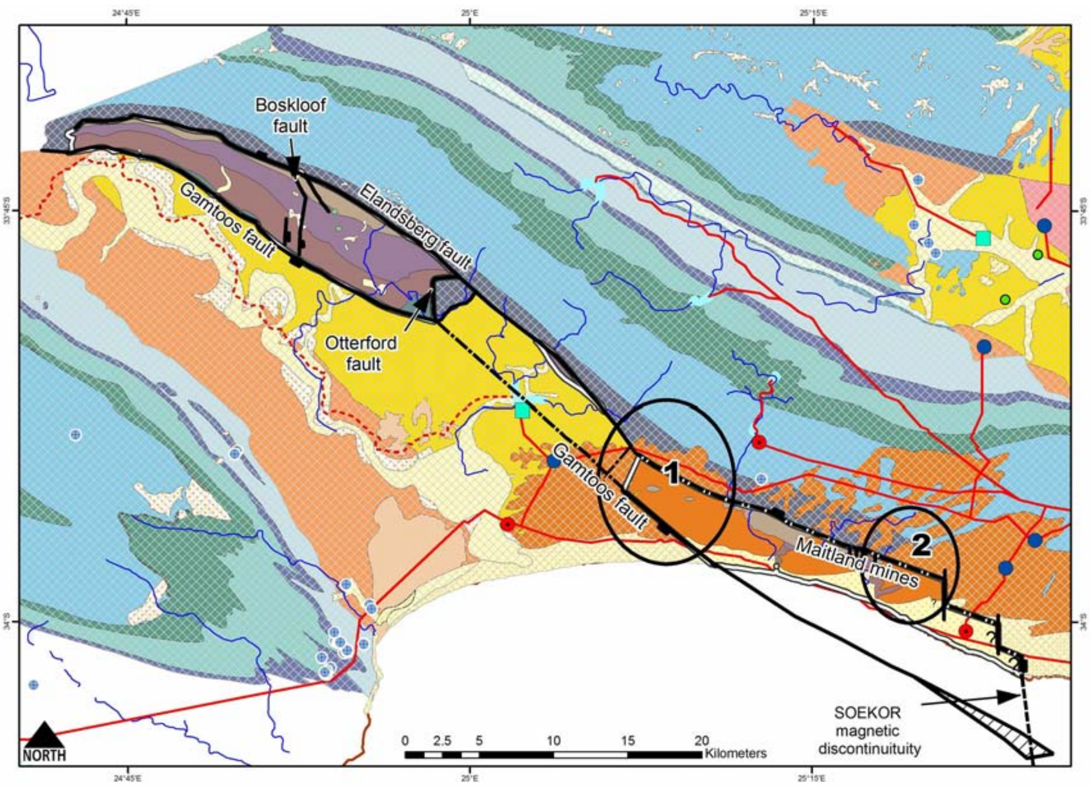


Figure 8 Domain 3 geology and drilling target areas

2.4 Domain 4: Elands - Winterhoek Arch

Potential targets

Within the fractured TMG aquifers forming the Elands-Winterhoek Arch (Figures 9 and 10), springs and borehole target features are similar to those described in Domain 1. However, there are larger fault structures and more complex folding and thrust deformation.

Potential targets include:

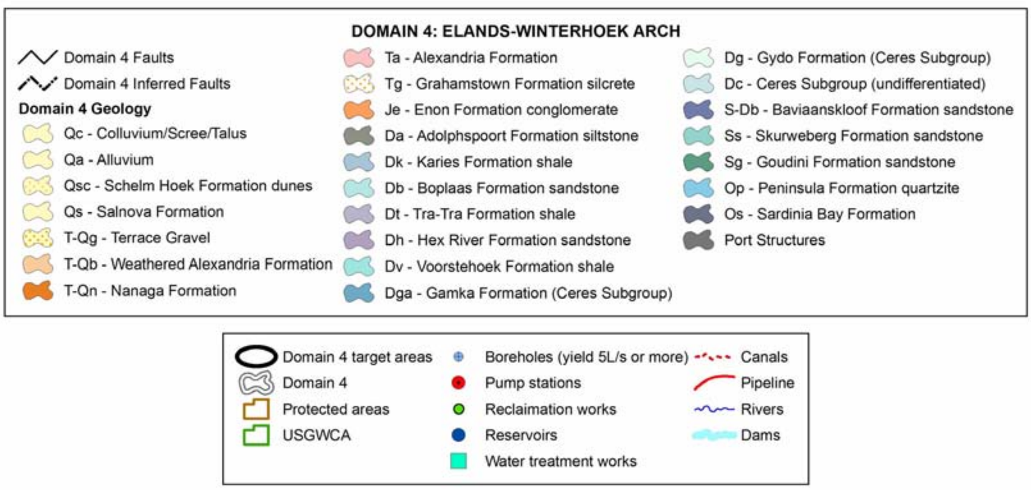
* Boundary faults. For example, the pre-Cape/Cape sheared contact.
* Large faults creating structural sub-domains within the TMG. For example the Baviaanskloof-Coega Fault and the Moregrove and Chelsea-Noordhoek Faults.
* Fractured hinge zones along fold closures, folds limbs, large thrust faults, fractures and joints in various orientations.
* Site-specific targeting requires detailed knowledge of the local structural geology, particularly folding, cleavage, thrust faulting, and fracture and joint characteristics. This area has a number of very high yielding boreholes (>10 L/s). The reason for these good yields is not fully understood. It is also likely that there are other potentially high-yielding structures that have not yet been targeted.

Highlighted areas in order of priority

1. Bushy Park. Fractured TMG on an overturned anticline in the root of a nappe.
2. & 3 Chelsea and Moregrove Fault – as outlined above.
4. Coega Fault. Good recharge area. The south side abuts the Cretaceous basin fill; the north side is TMG with NE-SW joints – a target area that appears to have high recharge, permeability and storage capacity.
5. KwaZunga Valley. TMG area and recharge to the Coega Fault.

COMMENT

This Domain appears to have huge potential for large-scale groundwater use, and there may be untapped aquifers at greater depth and in other, as yet, unidentified areas. Detailed geological mapping, borehole siting and exploration drilling would be required to confirm this.



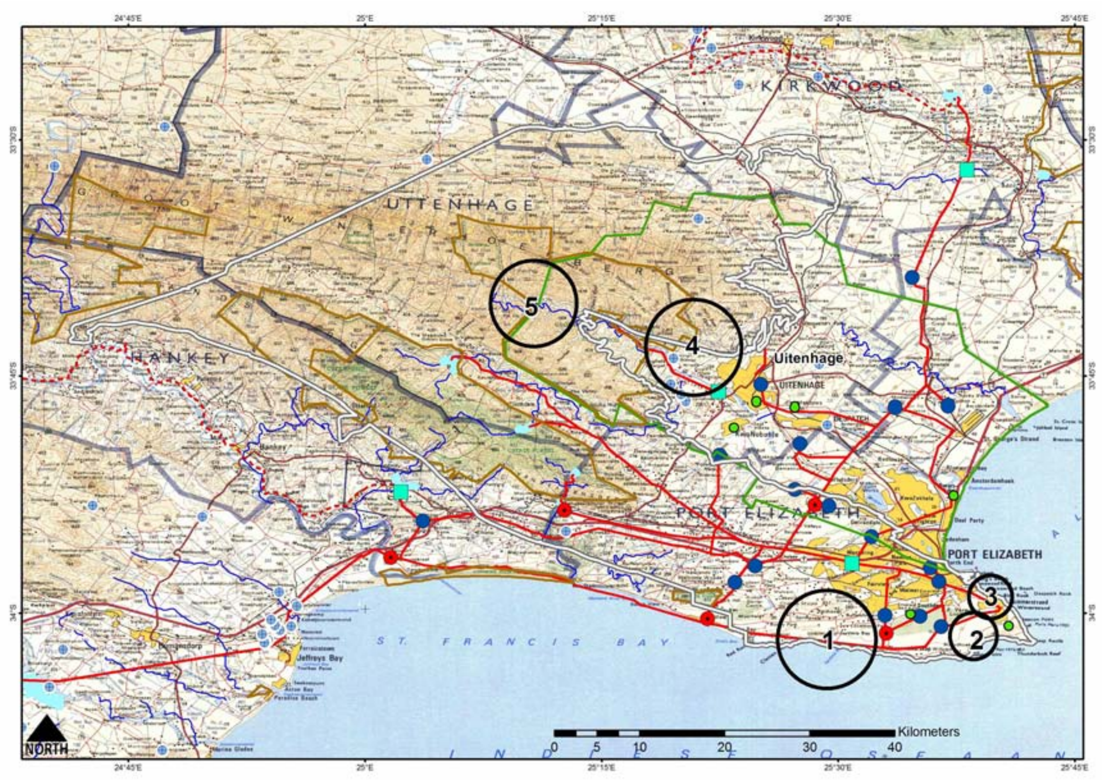


Figure 9 Domain 4 locality and drilling target areas

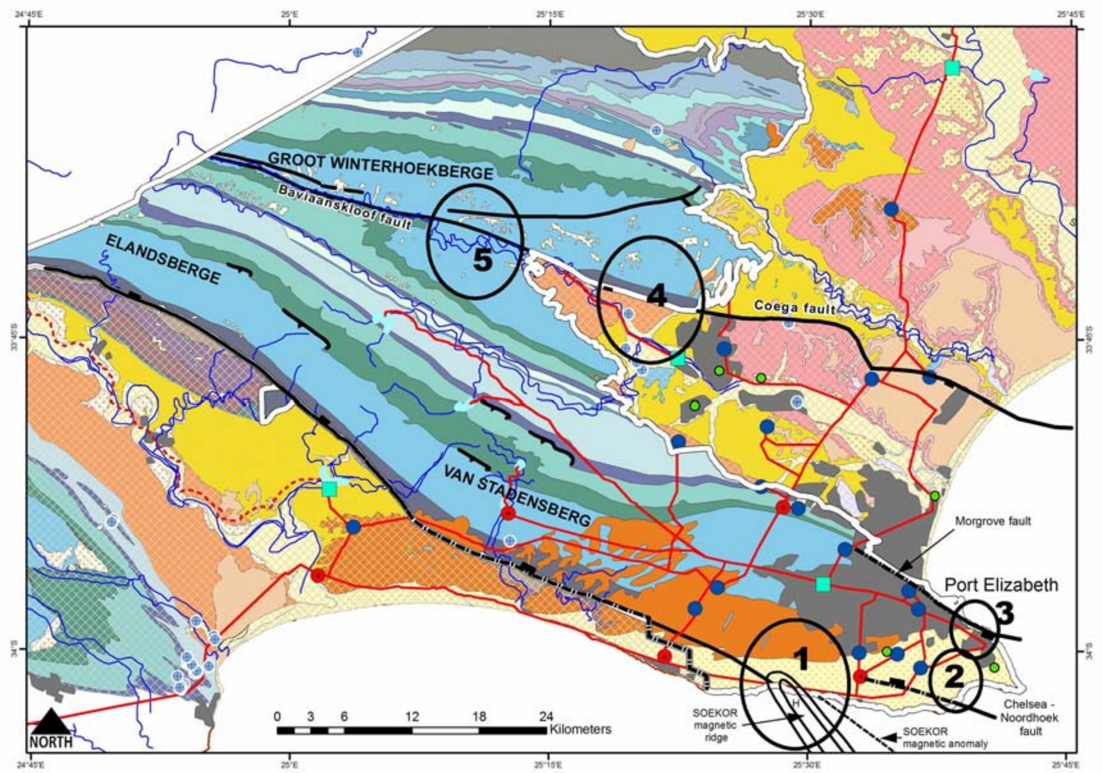


Figure 10 Domain 4 geology and drilling target areas

2.5 Domain 5: Algoa Basin

Potential targets

The Algoa Basin Groundwater Domain and prime drilling target areas are shown in Figures 10 and 11. These include the:

Uitenhage Subterranean Government Water Control Area (USGWCA)

The targets in the USGWCA are typically the underlying TMG, the Coega Fault, sandstone rich units in the Uitenhage Group, or fractures through them, and gravels in the semi-confined to unconfined alluvial aquifers. Similar features are also typically targeted in the basin outside the USGWCA, such in the Kirkwood area.

Zuney - Kaba area

Zuney valley is a small graben structure and a potential aquifer. A limited amount of exploration work has been done there by local engineering companies. Additional drilling should take place in this valley towards the central southern area, where the thickness of downfaulted Cenozoic sediment is expected to be greatest.

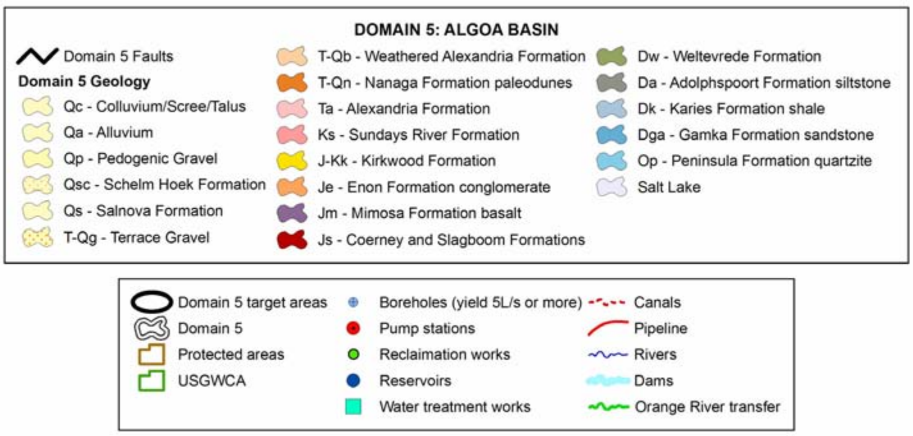
The Kaba trough marginal faults are likely groundwater targets. On the southern side, drilling is recommended at the southern end of the NE-SW orientated valleys. It is expected that downfaulted Cenozoic cover sediment and Cretaceous basin fill are bounded in the south by shales and thin sandstones of the lower Bokkeveld Group. This could form a subterranean reservoir or lens of groundwater against the fault that impedes the normal seaward flow of groundwater.

Highlighted areas in order of priority:

1. Kruisrivier - Uitenhage Group – local sandstone facies. Artesian/sub-artesian conditions.
2. Amanzi - Coega Ridge aquifer.
3. Coega Quarry (and associated artesian borehole/s).
4. Coega Fault.
5. Zuney Valley.
6. Kaba Trough.

COMMENT

Most targets outside the USGWCA are far from Port Elizabeth. The eastern targets may help alleviate water supply to Alexandria. However, these are partly within the new Greater Addo National Park.



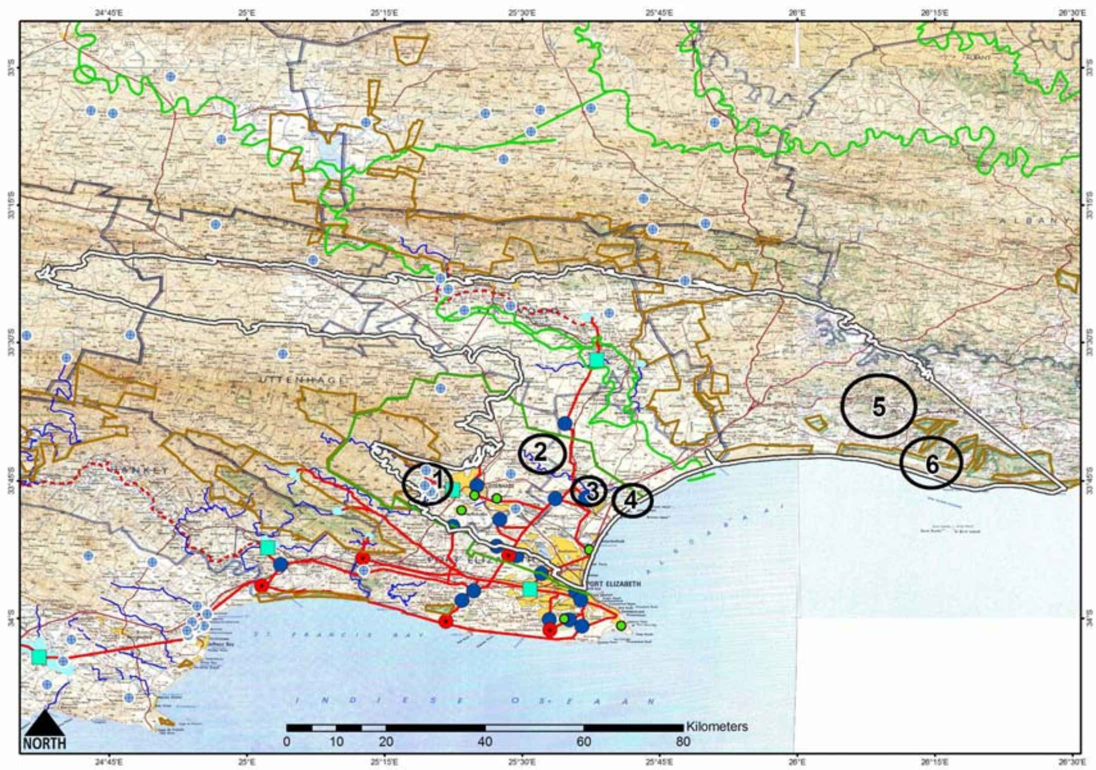


Figure 11 Domain 5 locality and drilling target areas

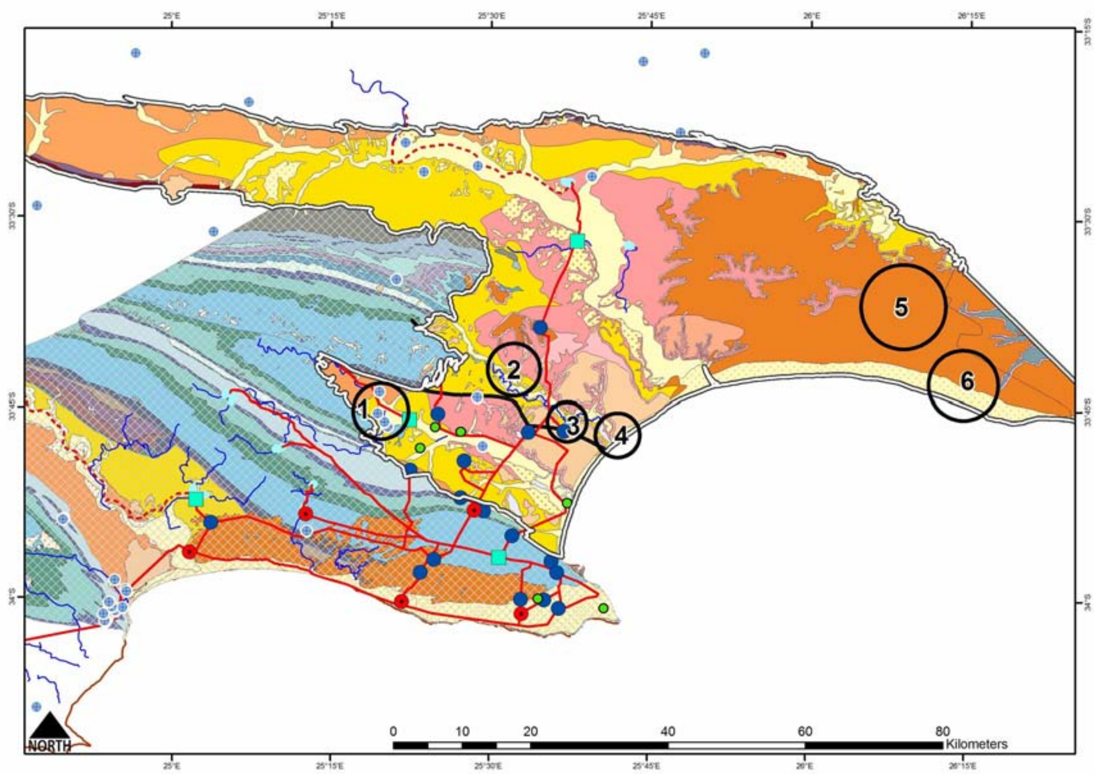


Figure 12 Domain 5 geology and drilling target areas

3. GROUNDWATER YIELD ASSESSMENT

In order to provide an estimate of the groundwater potential in the identified areas the following figures are provided for each Domain:

- Groundwater Harvest Potential (Baron, Seward & Seymour, 1998)
- Groundwater Resource Potential (DWAF, 2005a&b)
- Total borehole yield estimates

The **Harvest Potential** method was developed to provide a first estimate of the national sustainable groundwater resource. It takes into account recharge, storage and time periods between recharge events.

The **Groundwater Resource Potential** and **Groundwater Exploitation Potential** were developed during Groundwater Resource Assessment Phase II project, or **GRA II.** This is a GIS-based approach that was developed in the following manner: The volume of groundwater held in storage was determined; then the proportion of this that can feasibly be abstracted, and the proportion that should be abstracted in a single year in order to bridge drought cycles was established; then the proportion of this that should remain behind in the aquifer in order to meet specific management criteria (e.g. the Reserve, prevention of land subsidence, maintain water quality in the aquifer, etc.) was established; and finally, the current groundwater usage was estimated. Using these data sets is it possible to determine the remainder that can be allocated for further use. Ground-truthing of data sets was not done, and thus the method, at this stage, remains theoretical, but is the most recent regional estimates available.

The difference between the **Groundwater Resource Potential** (GRP) and the **Groundwater Exploitation Potential** (GEP) is that the GEP takes into account aquifer transmissivity and drilling accessibility in addition to the factors considered in the GRP. The GEP is thus a more conservative, and probably a more realistic groundwater potential estimate.

The Harvest Potential and the GRA II values given for each domain, were obtained by proportioning the yields to the domain areas. The results should be considered as rough, first estimates of each domain's groundwater potential.

More specifically, the output from GRAII was used to calculate the volumes used in the estimated groundwater potential for each domain. GRAII was disseminated as either shapefiles with volumes per quaternary catchment or as raster datasets with a 1X1 km^2 cell size. When data was provided per quaternary catchment, values were calculated using ArcView by clipping the catchment data with the domain data. Variable values were assigned based on the proportionate area of the domain within the catchment. This method was applied for the following datasets: Existing use, Recharge (normal/dry years) and Contribution to river baseflow.

For the raster datasets, ArcView Spatial Analyst was used to summarize the zones, where the zones were defined by the domain shapefiles. ArcView creates a new table to contain the summary statistics which include Average, Summary, Minimum, Maximum, Standard Deviation and Variance. The summary statistic was used for the following datasets: Groundwater Resource Potential (normal / dry years) and Groundwater Exploitation Potential (normal / dry years).

Borehole yield estimates are based on the assumption that a successful production borehole can yield 0.25 Mm^3/a. This is equivalent to about 8 L/s of continuous abstraction per borehole. In many areas these production boreholes may have to be deep (~300 – 500 m) in order to intersect the drilling target 200 – 300 m below the water table, and to maximise available natural sub-surface storage if artificial recharge is implemented. In reality the yield of successful production boreholes may vary from about 4 – 12 L/s, but on average they are assumed to be 8 L/s. With artificial recharge it is assumed that this yield can increase to 0.375 Mm^3/a, or about 12 L/s of continuous abstraction.

For artificial recharge to be successful as a seasonal water supply "booster", more boreholes would be required, as a high rate of artificial recharge (borehole injection) would need to be achieved during the winter injection months and a high rate of abstraction would need to take place in the summer months when the demand is higher. Assuming artificial recharge takes place over the 6 winter months and abstraction over the 6 summer months, it would require pumping at 24 L/s to abstract 0.375 Mm^3/a. It is likely that more than one borehole would be needed to achieve this.

In considering borehole density, it is assumed that they would need to be spaced at least 1 km apart. In reality it may not be possible to locate prime drilling targets at this borehole spacing, and the groundwater development zones may need to be extended; or in some areas, they simply will not be able to yield the estimated volumes.

It must be noted that the estimates provided below are rough, and are aimed to provide first order estimates if the domains were fully developed for groundwater supply.

3.1 Domain 1: Jeffreys Arch

Table 1. Estimated groundwater resource potential for Domain 1

Area	860 km^2
Existing use[1]	1.2 Mm^3/a
Recharge (normal years)[1]	22.1 Mm^3/a
Recharge (dry years)[1]	16.0 Mm^3/a
Harvest Potential	46.0 Mm^3/a
Contribution to river baseflow[1]	11.4 Mm^3/a
Groundwater Resource Potential (normal years)[1]	15.5 Mm^3/a
Groundwater Resource Potential (dry years)[1]	8.8 Mm^3/a
Groundwater Exploitation Potential (normal years)[1]	**5.7 Mm^3/a**
Groundwater Exploitation Potential (dry years)[1]	3.3 Mm^3/a
Borehole yield without artificial recharge and continuous abstraction (~20 boreholes)	**5 Mm^3/a**
Borehole yield with artificial recharge and 6-month/a abstraction (>20 boreholes)	7.5 Mm^3/a

[1]Estimated using GRA II data (DWAF, 2005)
Best estimates of groundwater potential are in bold

Estimated groundwater potential for Domain 1:
5 - 6 Mm^3/a

The portion of this available for current use would need to take existing use into account, and it must be noted that the south-eastern part of the Domain in the region of Jeffreys Bay, is already heavily used. If the estimate of 1.2 Mm^3/a is a reasonable figure for existing use, then it leaves about **4 – 5 Mm^3/a for future development**.

3.2 Domain 2: Gamtoos Basin

Table 2. Estimated groundwater resource potential for Domain 2

Area	642 km^2
Existing use[1]	0.2 Mm^3/a
Recharge (normal years)[1]	21.6 Mm^3/a
Recharge (dry years)[1]	15.6 Mm^3/a
Harvest Potential:	24.7 Mm^3/a
Contribution to river baseflow[1]	6.4 Mm^3/a
Groundwater Resource Potential (normal years)[1]	17.2 Mm^3/a
Groundwater Resource Potential (dry years)[1]	11.0 Mm^3/a
Groundwater Exploitation Potential (normal years)[1]	**9.6 Mm^3/a**
Groundwater Exploitation Potential (dry years)[1]	6.1 Mm^3/a
Borehole yield without artificial recharge and continuous abstraction (~10 boreholes)	**2.5 Mm^3/a**
Borehole yield with artificial recharge and 6-month/a abstraction (>10 boreholes)	3.75 Mm^3/a

[1]*Estimated using GRA II data (DWAF, 2005)*
Best estimates of groundwater potential are in bold

Best estimate of the groundwater potential for Domain 2:

3 - 10 Mm^3/a

3.3 Domain 3: Pre-Cape Horst

Table 3. Estimated groundwater resource potential for Domain 3

Area	199 km^2
Existing use[1]	0.01 Mm^3/a
Recharge (normal years)[1]	6.9 Mm^3/a
Recharge (dry years)[1]	5.0 Mm^3/a
Harvest Potential	8.4 Mm^3/a
Contribution to river baseflow[1]	2.3 Mm^3/a
Groundwater Resource Potential (normal years)[1]	5.5 Mm^3/a
Groundwater Resource Potential (dry years)[1]	3.8 Mm^3/a
Groundwater Exploitation Potential (normal years)[1]	**2.3 Mm^3/a**
Groundwater Exploitation Potential (dry years)[1]	1.5 Mm^3/a
Borehole yield without artificial recharge and continuous abstraction (~20 boreholes)	**5 Mm^3/a**
Borehole yield with artificial recharge and 6-month/a abstraction (>20 boreholes)	7.5 Mm^3/a

[1]*Estimated using GRA II data (DWAF, 2005)*
Best estimates of groundwater potential are in bold

Best estimate of the groundwater potential for Domain 3:

2 - 5 Mm^3/a

Note that the recharge estimate is based on the domain area only, but in this case, the domain is likely to receive recharged water from the high-lying areas to the north-east. The recharge values presented here, and the groundwater resource and exploitation potential values, are thus likely to be conservative.

3.4 Domain 4: Elands - Winterhoek Arch

Table 4. Estimated groundwater resource potential for Domain 4

Area	2328 km^2
Existing use[1]	1.7 Mm^3/a
Recharge (normal years)[1]	53.3 Mm^3/a
Recharge (dry years)[1]	37.8 Mm^3/a
Harvest Potential	98.5 Mm^3/a
Contribution to river baseflow[1]	18.6 Mm^3/a
Groundwater Resource Potential (normal years)[1]	46.9 Mm^3/a
Groundwater Resource Potential (dry years)[1]	31.7 Mm^3/a
Groundwater Exploitation Potential (normal years)[1]	**13.6 Mm^3/a**
Groundwater Exploitation Potential (dry years)[1]	9.2 Mm^3/a
Borehole yield without artificial recharge and continuous abstraction (~30 boreholes)	**7.5 Mm^3/a**
Borehole yield with artificial recharge and 6-month/a abstraction (>30 boreholes)	11 Mm^3/a

[1]*Estimated using GRA II data (DWAF, 2005)*
Best estimates of groundwater potential are in bold

Best estimate of the groundwater potential for Domain 4:

8 - 14 Mm^3/a

3.5 Domain 5: Algoa Basin

Table 5. Estimated groundwater resource potential for Domain 5

Area	4213 km^2
Existing use[1]	5.9 Mm^3/a
Recharge (normal years)[1]	48.2 Mm^3/a
Recharge (dry years)[1]	33.5 Mm^3/a
Harvest Potential	101.4 Mm^3/a
Contribution to river baseflow[1]	5.5 Mm^3/a
Groundwater Resource Potential (normal years)[1]	45.1 Mm^3/a
Groundwater Resource Potential (dry years)[1]	30.3 Mm^3/a
Groundwater Exploitation Potential (normal years)[1]	**17.0 Mm^3/a**
Groundwater Exploitation Potential (dry years)[1]	11.4 Mm^3/a
Borehole yield without artificial recharge and continuous abstraction (~30 boreholes)	**7.5 Mm^3/a**
Borehole yield with artificial recharge and 6-month/a abstraction (>30 boreholes)	11 Mm^3/a

[1]*Estimated using GRA II data (DWAF, 2005)*
[2]*It is assumed that the number of production boreholes could be twice as many as in the smaller domains*
Best estimates of groundwater potential are in bold

Best estimate of the groundwater potential for Domain 5:

8 - 17 Mm^3/a

If the estimated existing use is reasonably accurate, and about 6 Mm^3/a is already being abstracted from this area on a sustainable basis, then the **remaining portion for future use is estimated to be 2-11 Mm^3/a**.

4. CONCLUSIONS

This report concludes a desk study. Prime groundwater development areas were identified and grouped into five hydrogeological domains. Within each of the domains specific groundwater exploration target areas were identified and prioritised. No ground-truthing was done to verify the target areas. It is likely that some of the areas may be unsuitable for groundwater development for a variety of reasons, and it is equally likely that there are a number of other areas that could be developed for large-scale groundwater supply.

The total groundwater potential for each domain was estimated using the GRA II data sets and by assuming the number of high-yielding boreholes that could be obtained in each domain. This latter approach is based largely on estimates of the number of prime drilling targets that can be located. It was not based on a remote sensing analysis and the identification and weighting of individual drilling targets. Thus in some areas there may be fewer prime drilling targets, and in other areas, more. The purpose of this exercise was to provide a first-order estimate of the groundwater potential, and thus it will not be correct, but it should serve as a good starting point. A summary of the groundwater potential of all five domains is presented in Table 6.

Table 6 Total groundwater potential in all five hydrogeological domains

Groundwater Exploitation Potential (normal years)	**48 Mm^3/a**
Groundwater Exploitation Potential (dry years)	32 Mm^3/a
Borehole yield without artificial recharge and continuous abstraction	**28 Mm^3/a**
Borehole yield with artificial recharge and 6-month/a abstraction	41 Mm^3/a
Existing use	9 Mm^3/a

As a starting point, and from this information, it would be best to assume that the groundwater resources in these areas, if well developed, could give about **30 Mm^3/a**.

With use and scientific monitoring, it would be possible to establish whether the upper estimates of 40 – 50 Mm^3/a could be attained on a sustainable basis.

Current groundwater use is very coarsely estimated to be about **9 Mm^3/a** (using GRA II data). This leaves about **20 Mm^3/a** available for future development.

Current NMBM use is approximately **100 Mm^3/a**. Based on the above estimates, it means that groundwater has the potential to provide about **20%** of the city's current requirements.

The recommended process for establishing the true groundwater potential is as follows:

1. NMBM should decide the minimum annual groundwater yield that makes groundwater development worthwhile. In doing this, other factors besides yield need to be taken into account, such as the value of an assured supply to meet seasonal peak demands and the value of a back-up to surface water.
2. Identify one or two hydrogeological domains to undertake pilot studies.
3. Identify prime drilling target areas by undertaking a detailed remote sensing study of these areas and by obtaining on-the-ground information.
4. Assess the groundwater potential in about five of the prime target areas after undertaking an environmental study of these areas. This would require drilling and borehole testing (pumping) as well as a Basic or more detailed environmental study.
5. Put the prime areas into production and monitor groundwater and environmental effects of abstraction.
6. Repeat this process with new areas, and consider artificial recharge as a means to increase the assured yield or a means to provide additional supplies during summer months.

5. REFERENCES AND RELEVANT LITERATURE

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