Groundwater Complete

# KELLERSHOOGTE: REPORT ON GEOHYDROLOGICAL INVESTIGATION AS TECHNICAL INPUT TO THE WATER USE LICENSE APPLICATION

## OCTOBER 2020

**Contact Details:**
**Phone: 0844091429**
**Fax: 0866950191**
**P.O. Box 448**
**Riversdal**
**6670**
**gcomplete@outlook.com**

Compiled by: Gerdes Steenekamp, B.Sc. Hons Geohydrology

Reviewed by: Gerhard Steenekamp, M.Sc. Geohydrology Pr.Sci.Nat.(400385/04)

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| ABBREVIATION | | MEANING |
|---|---|---|
| mbs | - | **Meters below surface** |
| mamsl | - | **Meters above mean sea level** |
| $m^2/s$ | - | **Meter squared per second** |
| l/s | - | **Liters per second** |
| l/h | - | **Liters per day** |
| km | - | **Kilometer** |
| ha | - | **Hectare** |
| DWS | - | **Department of Water & Sanitation** |
| I&APs | - | **Interested & affected persons** |
| MAP | - | **Mean annual precipitation** |
| WULA | - | **Water Use License Application** |
| mm/a | - | **millimeters per year** |
| GQM | - | **Groundwater Quality Management** |

# KELLERSHOOGTE: REPORT ON GEOHYDROLOGICAL AS TECHNICAL INPUT TO THE WATER USE LICENSE APPLICATION: OCTOBER 2020

## EXECUTIVE SUMMARY:


Groundwater Complete was contracted by Villjee Keller Trust to conduct a groundwater specialist study as input to their Section 21.a. water use license application (WULA) for farm Gamtoosberg 170/19 and 172/4, Oudtshoorn, Western Cape Province (hereinafter referred to as Kellershoogte).

Kellershoorgte has a lawful registered water use from two boreholes (KBH01 and KBH04 in **Figure 1**) to the volume of 19 500 cubic meters per year ($m^3/y$) and from the Kandelaars River a volume of 127 500 $m^3/y$. During the major recent drought, the groundwater table lowered drastically in response to abstraction and the yields of the two boreholes decreased significantly. No water was available for irrigation from the Kandelaars River for more than 2 years.

Two deeper boreholes (KBH02 and KBH03) were drilled in the vicinity of the existing boreholes with the aim of accessing deeper aquifers that are not currently exploited by other groundwater users. The two deeper boreholes had good groundwater yields at depth with acceptable salinity and were therefore equipped to use for irrigation of fruit trees. The water use from the two new boreholes, however, commenced without licensing. This report is compiled as technical input to the water use licence application process for the two new boreholes but includes the testing and sustainable yield estimation of one of the old boreholes as well.

<u>The geohydrological environment can be summarised as follows:</u>

- The geology in the Kellershoogte area created a highly varying secondary, fractured rock aquifer system with multiple unconnected or poorly connected aquifers.
- The area is underlain by Cape Supergroup sedimentary rocks.
- The Cape Supergroup is known for deformation and creating the Cape Fold Belt mountain ranges. The deformation can also form high-yielding fractured aquifers.
- The static groundwater level depth varies greatly due to the poorly connected aquifers and ranges between 9 mbs and 50 mbs.
- Estimates with various methods of the effective aquifer recharge at Kellershoogte vary between 0.2-5% of the mean annual precipitation. Water level response during 2021 indicated a value closer to the high end, namely around 3% of rainfall.

<u>The baseline assessment, geology and aquifer test results led to the following conceptual model:</u>

- The study area where water supply boreholes are situated is located on the northern leg of a more-or-less east-to-west anticline that dips towards the north beneath the project area.
- The sandstone, wacke and arenite layers generally act as aquifers, yielding a serviceable amount of water.

- The shale, siltstone and mudstone layers act as aquicludes or groundwater barriers, that do not allow movement between upper and lower layers.
- Due to the dipping/sloping nature of the geology the groundwater recharge to the deeper aquifers does not take place around the borehole but to the south of the borehole where the aquifer outcrops.
- Shallow static groundwater levels simply represent piezometric pressure levels of the specific semi-confined fracture system intersected by each borehole.
- Aquifer recharge to the deeper boreholes plays such a significant role in borehole yield that pump test results alone could not be used for the sustainable yield recommendation.

<u>Conclusions and recommendations from the impact assessment are provided below:</u>
If the recommended sustainable yields per borehole are not exceeded, the proposed groundwater abstraction is expected to neither have any significant effects on groundwater availability of nearby groundwater users, nor would it have lasting adverse impacts on the groundwater system.

The pumping tests have shown that after extensive pumping:

- The Kellershoogte boreholes have very little water level impact on each other.
- Nearly no interaction (water level response) could be measured between the shallow and the deeper aquifers in the Kellershoogte boreholes.
- There was even very little (a few centimetres) interaction between the two deep boreholes during the pump testing in the deep aquifer.
- No water level response was measured in the nearest neighbouring user borehole.
- There is no shallow (primary or secondary) aquifer present in the study area;
- There is no alluvial aquifer present around the Kandelaars river in the study area.
- There is no base flow interaction between the groundwater and the Kandelaars River in the project area – the river acts as a losing stream and groundwater abstraction has no influence on the hydrology or fresh water ecology of the river.
- At the end of an extreme drought the estimated sustainable yields of the two deep boreholes were less than 20% of the yield calculated after good rainfall occurred and the aquifer was adequately recharged.

Based on the DWS classification, the total sustainable yield (i.e. the applied-for volume) can be classified as Category C or large scale with respect to the property size and far exceeds the annual recharge on the property surface area. The applied-for use is, however, still supported on the basis that:

- unexploited groundwater will be used instead of over-stressed surface water resources in the area;
- the abstraction will mainly occur from deeper aquifers that are not currently used by any nearby user;
- extensive testing showed that other groundwater users will not be significantly affected; and
- the applied-for groundwater use represents a mere 1.4% of the exploitable groundwater potential in the catchment.

Results of pump test program at different times (at the end of the drought and after good rains) and sustainable yield estimation from the tests are summarised below:

| Description | Pump testing during 2021 drought | | | Pump testing in 2022 after good rainfall | | |
|---|---|---|---|---|---|---|
| **Borehole** | KBH02 | KBH03 | KBH04 | KBH02 | KBH03 | KBH04 |
| **Sustainable Yield (l/h for 12 h/d)** | 21600 | 17280 | 11520 | 144 000 | 151 000 | 11 520 |
| **Yield ($m^3/a$)** | 94 600 | 75 700 | 50 450 | 630 000 | 661 000 | 50 450 |
| **Total ($m^3/a$)** | **220 750 $m^3/a$** | | | **1 341 000$m^3/a$** | | |

The following conclusions were reached, and recommendations are made from these results:

- The aquifer parameters (transmissivities) and recommended sustainable yields at the end of the drought and after good rainfall using the same methodology, equipment and algorithms yielded results that differed by an order of magnitude.
- It is apparent that the availability of groundwater depends greatly on the climatic conditions during the few months preceding the testing.
- The pump rates in the table below are thus put forward as sustainable yields considering all factors.
- It is however, suggested that the pumps be installed not deeper than 120 mbs to provide an available drawdown of around 100m at best. This should prevent the drawdown of the piezometric heads to below the main water-yielding fractures and thus prevent over-pumping and damage to the aquifer(s). Such a pump setup may mean that less water can be abstracted in periods of prolonged drought and pump rates will have to be managed accordingly.

The recommended sustainable yields of the different boreholes considering severe dry and above-normal wet conditions and maximum pump depth of 120 mbs are as follow:

| Borehole | KBH02 | KBH03 | KBH04 |
|---|---|---|---|
| Sustainable Yield (l/h for 12 h/d) | 40 000 | 45 000 | 11 520 |
| Yield ($m^3/a$) | 175 200 | 197 100 | 50 450 |
| **Total ($m^3/a$)** | **422 750 $m^3/a$** | | |

# 1 INTRODUCTION

Groundwater Complete was contracted by Viljee Keller Trust to conduct a groundwater specialist study as input to their Section 21.a. water use license application (WULA) for farm Gamtoosberg 170/19 and 172/4, Oudtshoorn, Western Cape Province (hereinafter referred to as Kellershoogte).

Kellershoorgte has a lawful registered water use from two boreholes (KBH01 and KBH04 in **Figure 1**) to the volume of 19 500 cubic meters per year ($m^3/y$) and from the Kandelaars River a volume of 127 500 $m^3/y$. During the major recent drought, the groundwater table lowered drastically in response to abstraction and the yields of the two boreholes decreased significantly. No water was available for irrigation from the Kandelaars River for more than 2 years. Two deeper boreholes (KBH02 and KBH03) were drilled in the vicinity of the existing boreholes with the aim of accessing the deeper aquifer that is not exploited by nearby groundwater users. The two deeper boreholes had good groundwater yields at depth with acceptable salinity and were therefore equipped to use for irrigation of fruit trees. The water use from the two new boreholes, however, commenced without licensing. This report is compiled as technical input to the water use licence application process for the two new boreholes.

The boreholes are located on portions 6, 9 and 19 of the farm Gamtoosberg 170, which is situated approximately 10 kilometres south-south-west of Oudtshoorn in the Western Cape Province. The proposed site is situated next to the R328, where the road crosses the Kandelaars River. A map showing the location of the farm and subsequent boreholes is provided in **Figure 1**.

This report is compiled as technical input to the water use licence application process for the two new boreholes as well as one of the pre-existing boreholes. Extensive aquifer testing was conducted on all three boreholes.

***Notes**:*

- *The main aims of this study are to:*
    - *determine the long-term sustainable yields of all the boreholes intended for future sources of groundwater supply; and*
    - *estimate the potential impact of the sustainable use of the boreholes on the groundwater availability of nearby lawful users.*

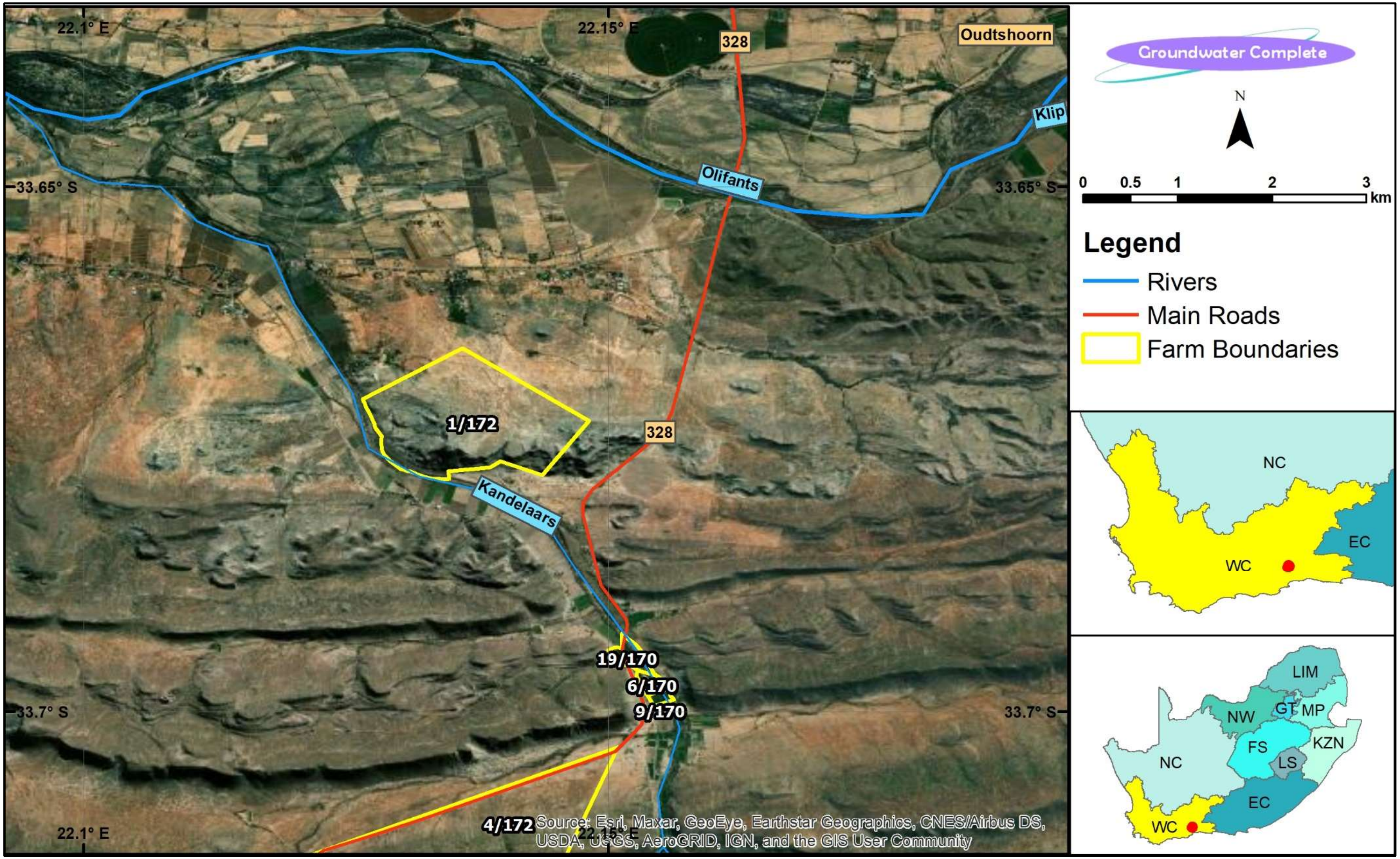


**Figure 1: Locality map showing the project area around Kellershoogte.**

# 2 GEOGRAPHICAL SETTING

## 2.1 SURFACE TOPOGRAPHY AND WATER COURSES

The study area is situated in the Klein Karoo region of Western Cape, South Africa. The highest surface elevations in and around the project outline include hills to the south-east at around 460 mamsl, while the lowest elevations are in the Kandelaars River valley at around 280 mamsl to the north. The elevation of the boreholes at Kellershoogte itself is at around 300 mamsl.

The water courses in the vicinity of the proposed abstraction area drain predominantly to the north. The Kandelaars River is situated to the east of the proposed production boreholes within the boundary of the farm. The Kandelaars River has its headwaters in the Outeniqua/Langeberg Mountains some 20 km to the south and is a tributary of the Olifants River, which flows westwards as a tributary of the Gourits River.

***Notes:***

- *The Kandelaars River in the project area is non-perennial and only experiences flow in the wet season or for limited periods after rainfall events. It has not had regular flow for the last three years.*
- *At Kellershoogte the river does not receive any groundwater baseflow – it is a **losing stream** in the project area as will be shown with discussion of water levels in sections 4 and 6.*

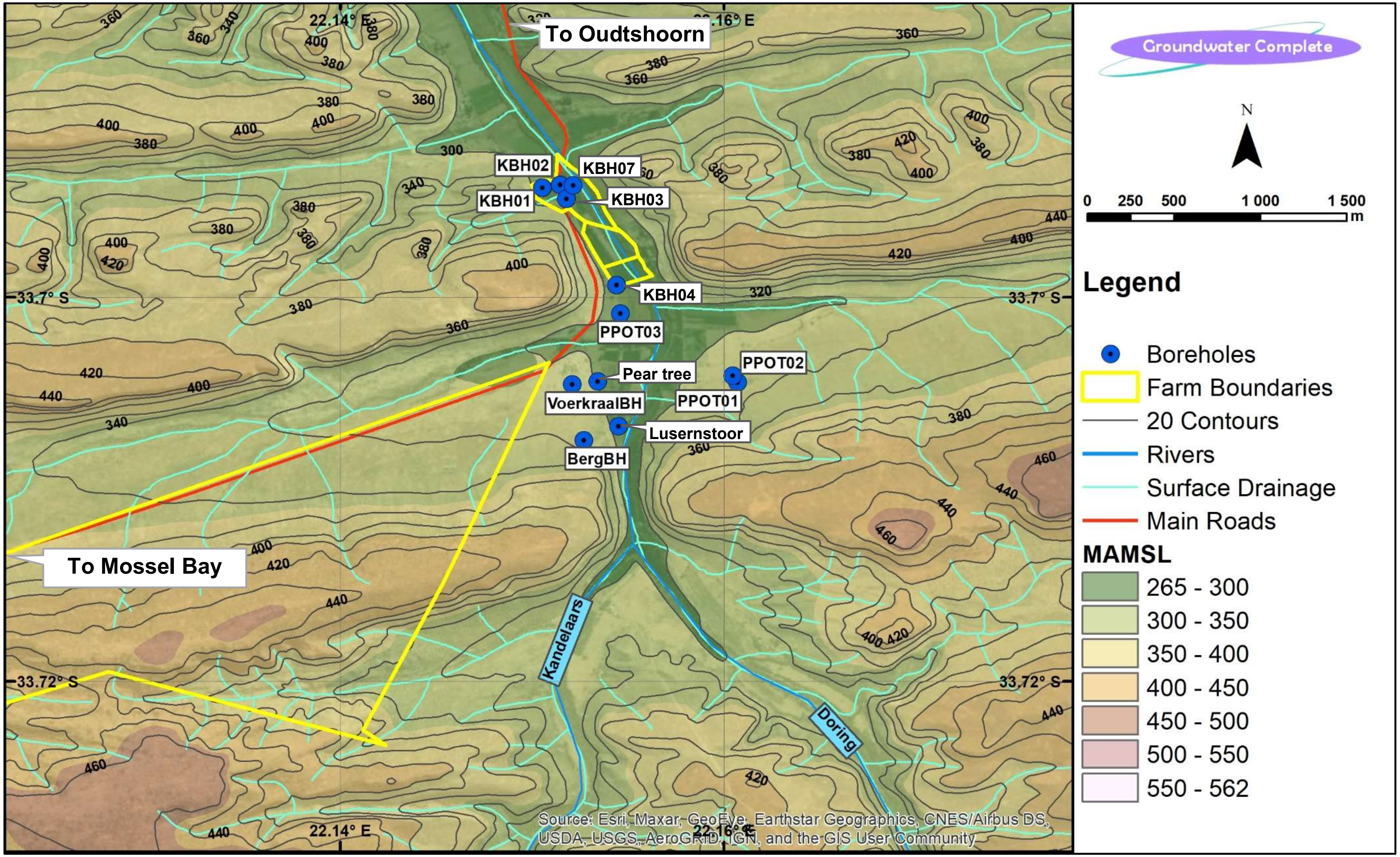


**Figure 2: Surface elevations and water courses**

## 2.2 CLIMATIC CONDITIONS

The annual rainfall was obtained from the Oudtshoorn Research Farm with daily rainfall data made available from 1992 to 2021. The project area is located within a rain scarce region that received 224 mm/a on average during this period. The region's rainfall season is spread out more-or-less evenly throughout the year **(Figure 3)**.

Starting in approximately 2015 the region experienced a severe drought with annual rainfall decreasing to below average (**Figure 4). Figure 4** shows that 2019 and 2020 were exceptionally low rainfall years and the effect on groundwater levels (recharge) was more pronounced as they came at the end of three already below-average rainfall years. To provide some perspective – the combined rainfall of 2018, 2019 and 2020 was less than the 2021 rainfall, which mostly occurred within the last three months of the year. The drought conditions were only alleviated towards the end of 2021 with three months of above-average rainfall occurring from October to December of 2021. The effects and implications of (1) the severe drought and (2) the good rainfall of the end of 2021 on groundwater availability will be indicated clearly in the pump test analysis and sustainable yield recommendation.

Average daily temperatures vary from approximately 28 $^{0}$C in the summer to ± 18 $^{0}$C in the winter. Average night temperatures vary from approximately 16 $^{0}$C in the summer to ± 5 $^{0}$C in the winter **(Figure 5)**

Evapotranspiration is high (around 2000 mm/a) and results in an environmental moisture deficit throughout the year **(Figure 3)**.

***Notes:***

- *The project area has a net environmental moisture deficit for the entire year.*

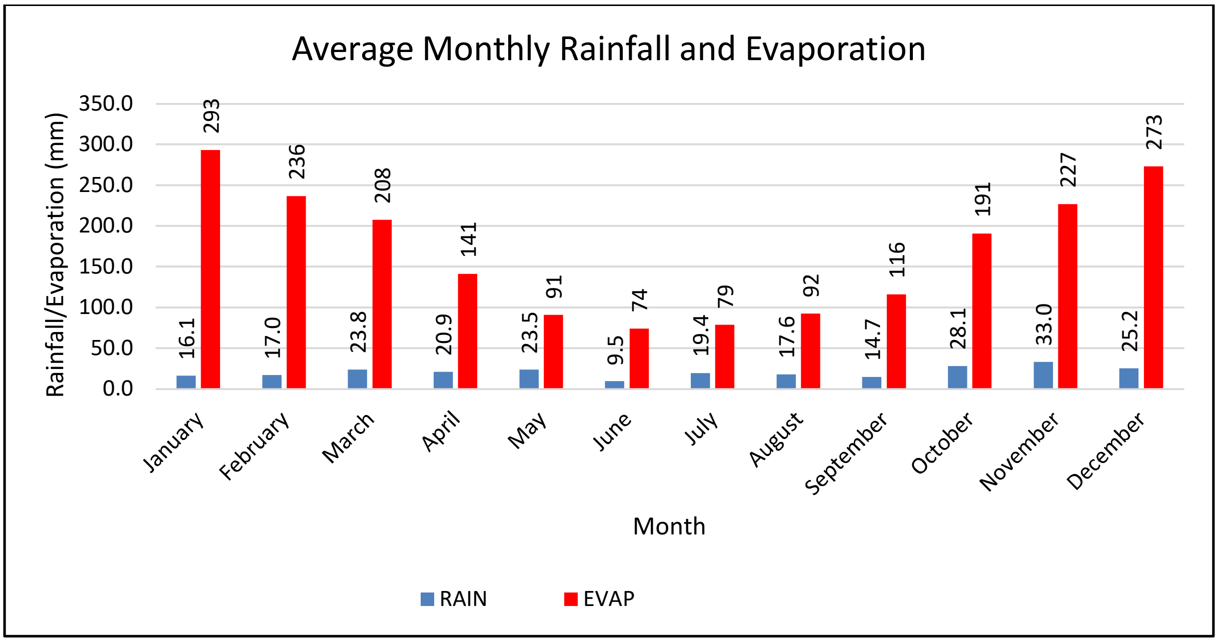


**Figure 3: Average monthly rainfall and evaporation for the Oudtshoorn area (DWA, 2015)**

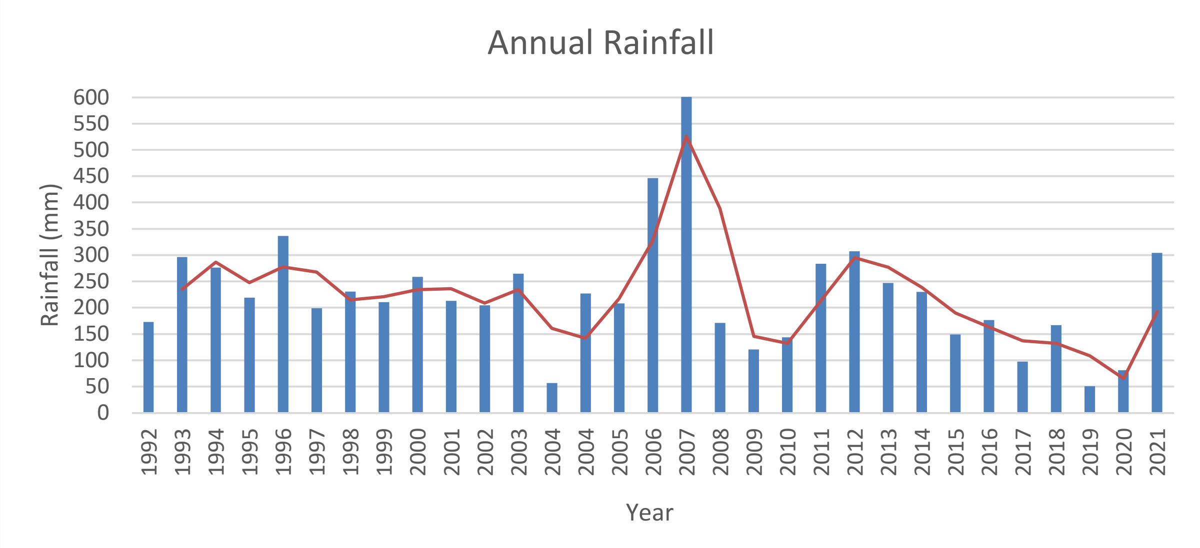


**Figure 4: Average rainfall between 1992 and 2021 with 2-year moving average**

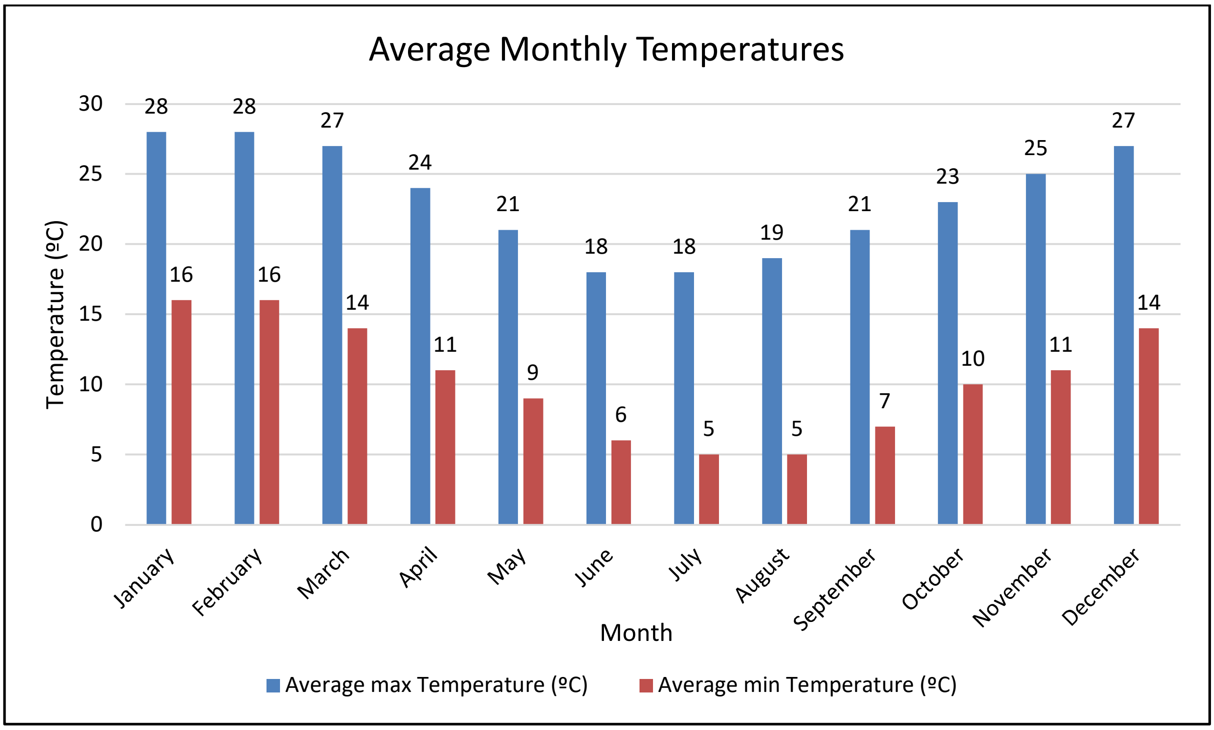


**Figure 5: Average monthly temperatures for the Oudtshoorn area (worldweatheronline.com, 2020)**

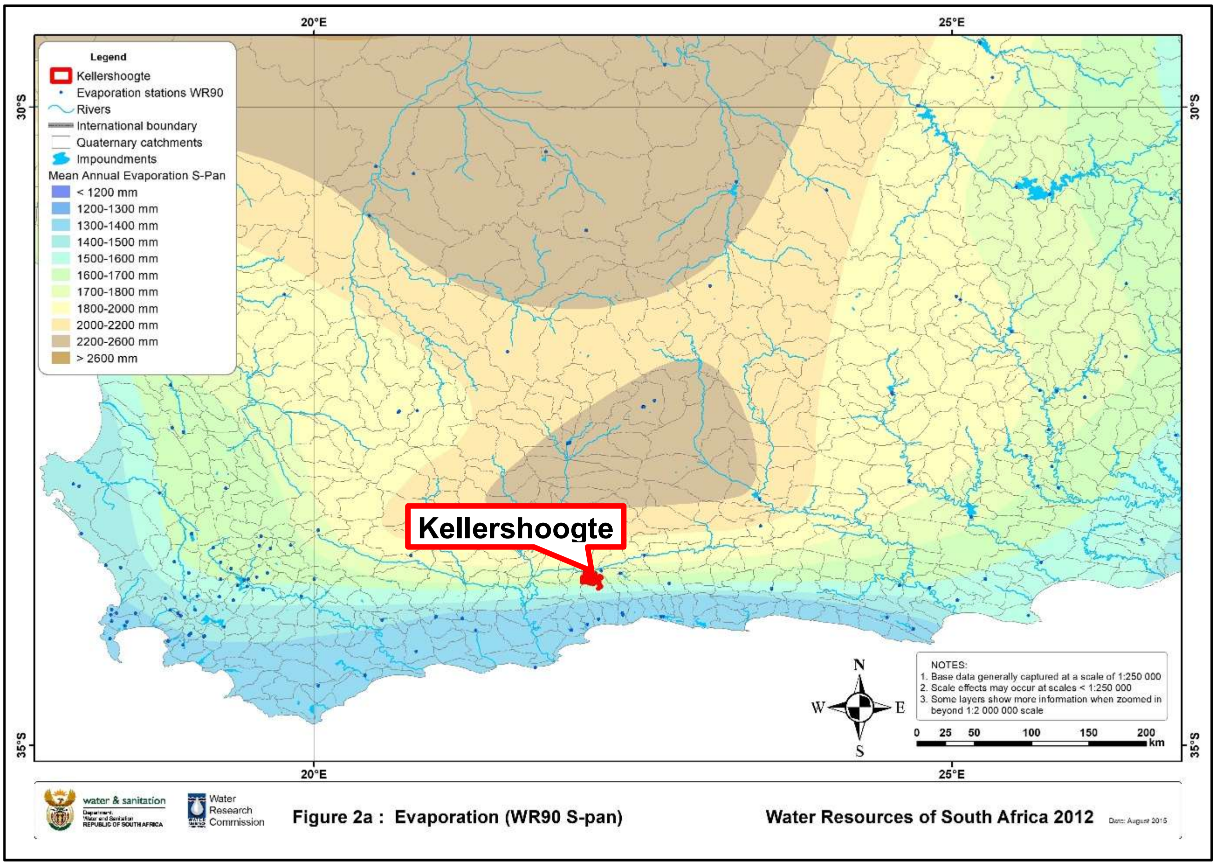


**Figure 6: Mean annual evaporation for the project area (Lynch, 2004)**

# 3 STUDY METHODOLOGY

## 3.1 DESK STUDY

All groundwater and related studies that could be located, topographical and geological maps as well as satellite images and associated information were assessed and used accordingly throughout the groundwater investigation where applicable. Groundwater information was also obtained from various open sources as well as dedicated information gathering.

Kellershoogte is located approximately 10-15 km west of the area being developed as the Blossoms Wellfield. Various studies were conducted for the Blossoms Project to evaluate the water supply potential of the deep artesian aquifer as a dependable water supply for the semi-arid Klein Karoo region. The main studies for the Blossoms Project are titled *Strategy For Groundwater Testing And Management In A Confined Artesian Basin: Oudtshoorn Area (Hartnady, et al., 2017), Groundwater Reserve Determination for Current and Potential Wellfield Development of TMG Aquifers (Riemann, et al., 2010).*

Existing 1:250 000 geological and 1:500 000 hydrogeological maps were also applied during the assessment **(Figure 11)**.

## 3.2 BASELINE STUDY

A hydrocensus/groundwater user survey was conducted within the project area by Groundwater Complete in May 2021. The main objectives of a hydrocensus field survey can be summarised as follow:

- To locate all interested and affected persons (I&APs) with respect to groundwater and surface water – most notably water users,
- To collect all relevant information from the I&APs (i.e. name, telephone number, address, etc.),
- Accurately record/log boreholes on the I&APs properties, and
- To collect all available information regarding the logged boreholes (i.e. yield, age, depth, water level etc.) but especially the use of groundwater from the borehole.

## 3.3 GEOPHYSICAL SURVEY AND RESULTS

No geophysical survey was conducted as a part of the study. Boreholes earmarked for production boreholes were already drilled and equipped.

## 3.4 SITING AND DRILLING OF BOREHOLES

All pumping boreholes were already drilled before the commencement of the study and the drilling was not included in the scope of this study. A single borehole was however drilled with the dual purposes of (1) observing the interaction between the shallow- and deep aquifers and (2) the interaction of the surface water (Kandelaars River) and groundwater. The location of the observation/monitoring borehole (KBH07) relative to the other boreholes and to the river is indicated in **Figure 7**.

## 3.5 AQUIFER TESTING

An aquifer test (also referred to as a pump test) is performed to determine aquifer parameters, especially transmissivity or hydraulic conductivity and also, in this case, the influence and interconnectedness the boreholes experience with each other. Aquifer parameters play an important role in the conceptualization of the project area (i.e. conceptual model), which in turn plays a large role in the understanding and interpretation of the aquifer characteristics and behaviour.

The pump test basically involves the abstraction of groundwater from a borehole by means of a pump (e.g. a submersible- or mono pump) at a known rate. Measurements of the decreasing water level within the borehole are taken at predetermined intervals, which are generally short at the start of the test and increase as the test progresses. After the test has been completed and the pump is shut down, measurements are again taken of the water level at set time intervals as it starts to recover/rise in the borehole (i.e. recovery test) to its original static or rest water level.

Boreholes KBH02, KBH03 and KBH04 were tested in the abovementioned manner and the pump test data was analysed with the Fracture Characterisation (FC) Method and AQTESOLV Professional software package, which offer a wide range of mathematical equations/solutions for the calculation of aquifer parameters. The time-water level data collected during the constant rate pump test is plotted on a log-linear graph. A straight line or curve (depending on equation used) can then be fitted to the different flow stages on the graph (process known as curve matching) and the aquifer transmissivity and storativity are calculated in accordance with the preselected analytical equation. Aquifer parameters provided in this report were calculated with the *Cooper-Jacob (1946)* equation while taking aquifer boundaries into account as per the FC Method.

It is important to note that the abovementioned equation for pump test analysis was designed for pump test interpretation in a primary porosity aquifer environment with the following assumptions:

- The aquifer is a homogeneous medium,
- Of infinite extent,
- No recharge is considered, and
- An observation borehole is used for water level recording at a distance from the pumped borehole.

Although few of these assumptions apply to the project area, the methods/equations could still be used as long as the assumptions and 'shortcomings' are recognized and taken into account. The most important among these is the fact that no actual aquifer exits that is of infinite extent. It is especially important to consider the finite extent in the secondary, fractured rock aquifers at Kellershoogte and was done so with the aid of the FC Method software.

### 3.6 GROUNDWATER RECHARGE ESTIMATIONS

According to the Vechter recharge map in **Figure 8** the mean annual recharge to the aquifer underlying the project area should be in the order of 1-3 mm, which based on an average rainfall of approximately 220mm/a **(Figure 3)** translates to a recharge percentage of ± 0.4-1.3%.

Another recharge estimation was proposed by Van Tonder and Xu (2001), based on the geology of the aquifer **(Table 1)**. The abovementioned method estimates the recharge in the Kellershoogte area around 2-5% of the annual precipitation, which is more in the range of 4.4-11 mm/a.

The recharge was also calculated using the chloride method and the values measured in the hydrocensus boreholes. According to the chloride method the recharge for the Kellershoogte area is in the order of 0.2 %, putting it in the same range as the Vegter estimates. The chloride method may not be very applicable in this specific case since the Bokkeveld Group of predominantly shales occurring at Kellershoogte is known for high groundwater salinity – specifically in terms of sodium-chloride salinity. The high salt content in this case is considered to be derived rather from the shales being deposited in a marine environment with some of the sea water salinity ‘captured’ within the aquifer rock matrix. The chloride salinity in groundwater is thus considered to rather originate from dissolution of salt from the rock matrix rather than stagnation and long-term ion exchange through a lack of active recharge. If the chloride salinity profile in shale aquifers of the Karoo Supergroup with similar climate and rainfall is compared, for example, the Karoo rocks will indicate much lower relative chloride content and a higher recharge estimation with the chloride method.

**Table 1: Typical recharge to different aquifer host rocks *(Van Tonder & Xu, 2001)***

| Geology | % Recharge (soil cover <5m) | % Recharge (soil cover >5 m) |
|---|---|---|
| Sandstone, mudstone, siltstone | 5 | 2 |
| Hard Rock (granite, gneiss etc.) | 7 | 4 |
| Dolomite | 12 | 8 |
| Calcrete | 9 | 5 |
| Alluvial sand | 20 | 15 |
| Coastal sand | 30 | 20 |
| Alluvium | 12 | 8 |

**Table 2: Chloride method recharge calculation**

| Name | Value | Unit |
|---|---|---|
| Cl-rain | 0.8 | mg/l |
| Rain per Annum | 220 | mm/a |
| Pear tree | 1510 | mg/l |
| Lusernstoor | 187 | mg/l |
| berg | 133 | mg/l |
| VoerKraal | 1460 | mg/l |
| KBH02 | 650 | mg/l |
| KBH03 | 650 | mg/l |
| Harmonic mean | 347.0 | mg/l |
| Recharge | 0.69 | (mm/a) |
| **Percentage** | **0.2** | **%** |

Given the dramatic water level response after good rainfall in October-December 2021, it is our opinion that the actual effective recharge at Kellershoogte is more in the order of 2 to 3% of rainfall such as estimated in Table 1.

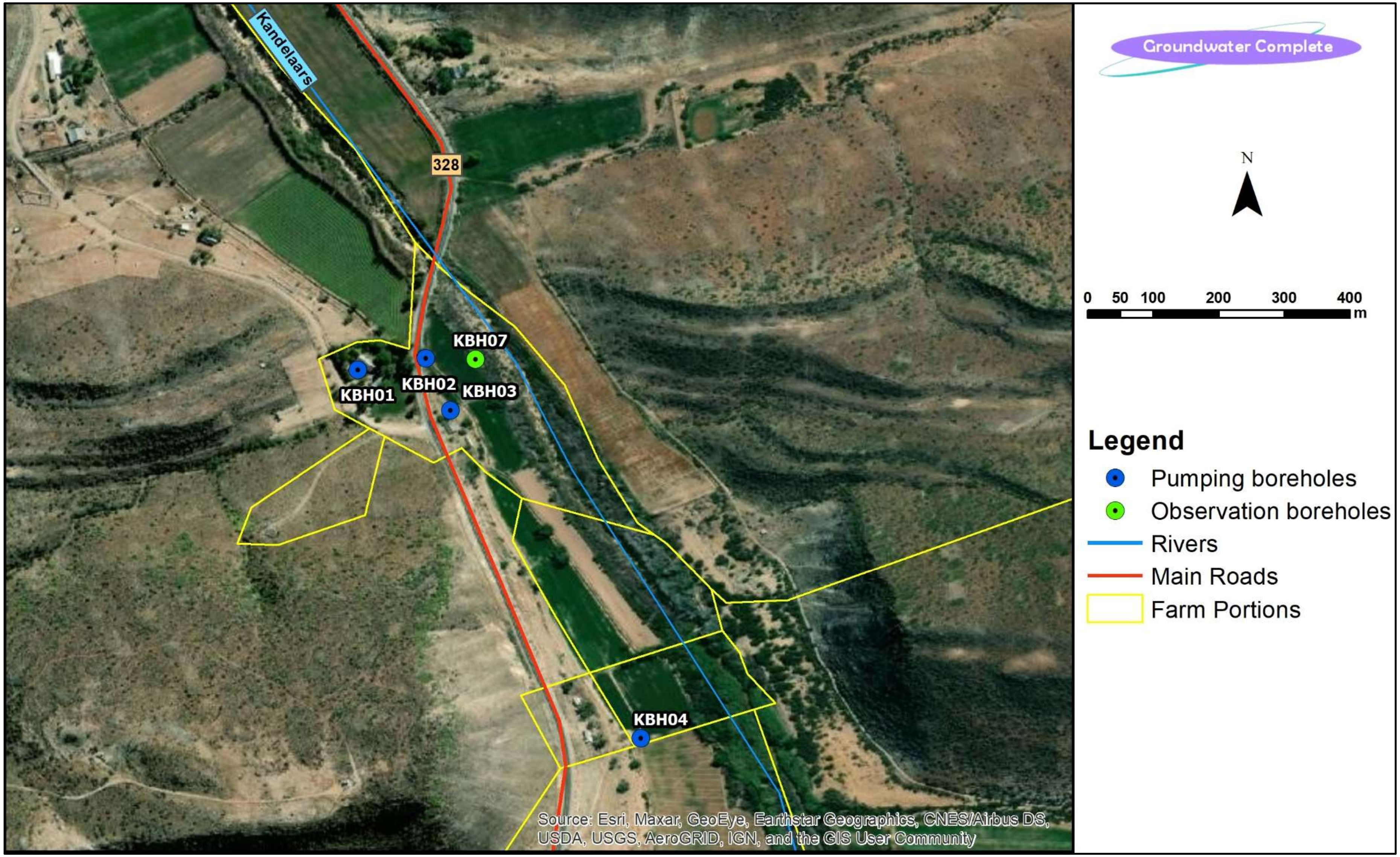


**Figure 7: Location of the observation borehole**

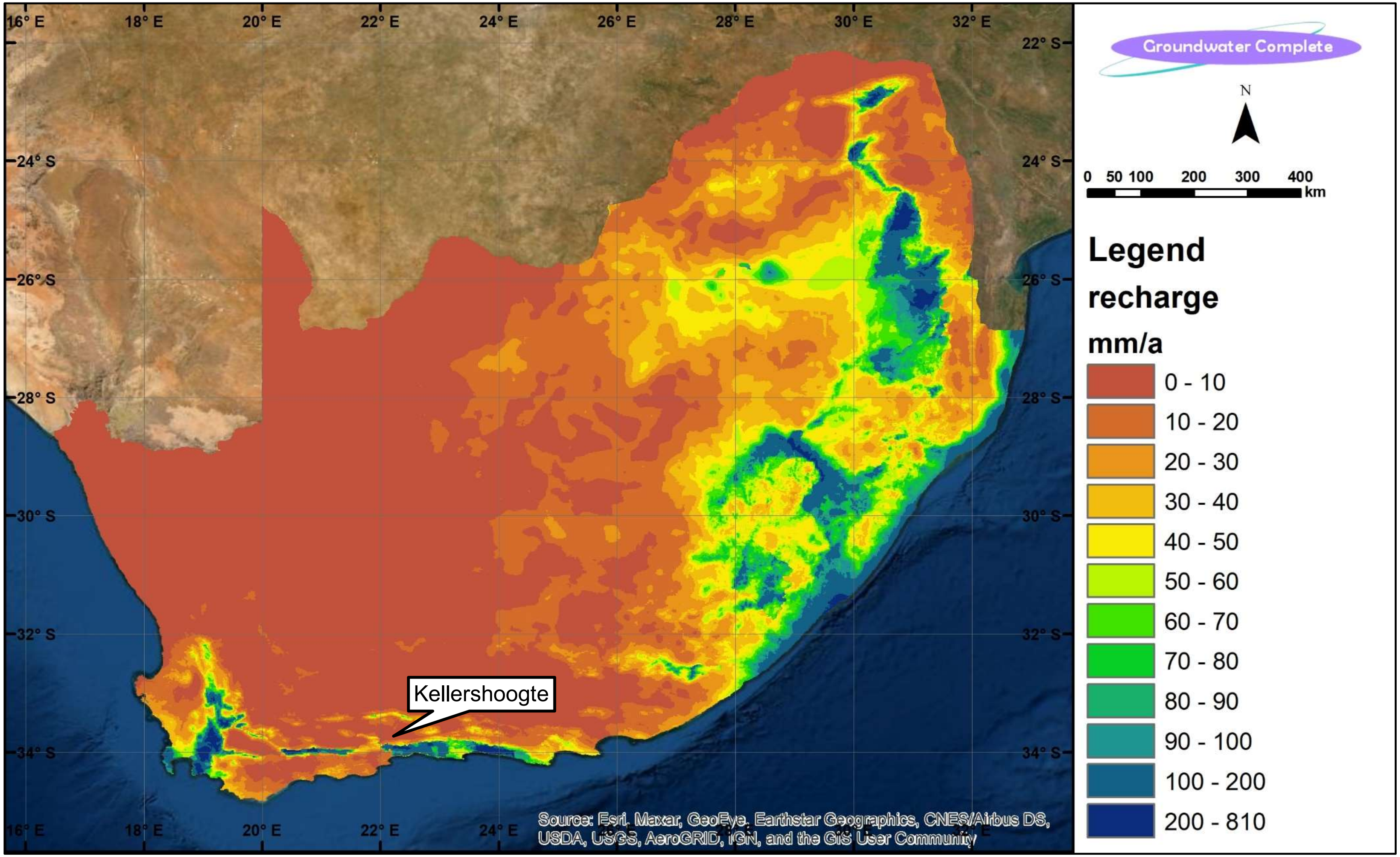


**Figure 8: Mean annual aquifer recharge for South Africa (Vegter, 1995)**

### 3.7 GROUNDWATER AVAILABILITY ASSESSMENT

A rapid (groundwater) reserve determination for Kellershoogte is conducted in this section. The following assumptions were made in terms of groundwater use and surface area:

- By far the most significant use of groundwater at Kellershoogte will be the water pumped from the boreholes for irrigation purposes.
- There will be some seepage water returning to the groundwater, however because of the depth of the borehole, the water is more likely to return to another aquifer and were not taken into account in these calculations.

The farm boundaries fall within quaternary catchment J35B which has a surface area of 651 km$^2$. The Kellershoogte farm area where extraction and irrigation will take place has a total area of 4.72 km$^2$. The study area falls within in the Olifants River catchment. The general authorised groundwater use in the catchment is in the order of 45 m$^3$/ha/year.

The Department of Water and Sanitation (DWS) categorises the water use in three categories based on the amount of recharge that is used by the applicant in relation to the specified property:

- Category A: Small scale abstractions (<60% recharge on property);
- Category B: Medium scale abstractions (60-100% recharge on property); and
- Category C: Large scale abstractions (>100% recharge on property).

**Table 3: Most salient parameters relevant to Catchment H90B**

| **Description** | ***Unit*** | **Value** | **Comment** |
|---|---|---|---|
| **Catchment Area** | *km$^2$* | 651 | J35B |
| **Farm Boundary** | *km$^2$* | 4.72 | 0.7% of catchment |
| **General Authorised Use (GA)** | *m$^3$/ha/a* | 45 | Sourced from, "*Government Gazette, No. 40243"* |
| **General Authorised Use** | *m$^3$/a* | 21 240 | (45 m$^3$/ha/a * 472 ha) |
| **Mean Annual Rainfall** | *mm/a* | 320 | Figure 3 |
| **Effective Annual Recharge** | *mm/a* | 5.6 | Section 3.5 |
| **Annual Recharge Volume** | *m$^3$/a* | 26 432 | Recharge over surface property area |
| **Groundwater use applied for** | ***m$^3$/a*** | **422 750** | **Annual rate of extraction** |
| **Groundwater use as % GA** | *%* | 1036 | (Planned use/GA use) *100 |
| **Groundwater use as % recharge** | *%* | 832 | Percentage of aquifer recharge |
| **Current Use in Catchment** | *m$^3$/a* | 1 990 000 | Total use for quaternary catchment area *(WR90)* |
| **Exploitation Potential** | *m$^3$/a* | 18 000 000 | Total for quaternary catchment area *(WR90)* |
| **Proposed abstraction as % of exploitation potential** | *%* | 2.3 | Limited percentage of exploitation potential |

A number of other groundwater users occur near the Kellershoogte boreholes as discussed in **Section 4.1**, due to the scarcity of surface water in the region. The aquifer structure in the area is highly heterogenous with alternating layers of aquifer and aquitards and the proposed abstraction at Kellershoogte is unlikely to significantly affect surrounding boreholes due to the fact that the aquifers are not generally hydraulically interconnected and recharge takes place away from the borehole location. Please refer to Section 4.2 and 6 for more detailed discussion on this subject.

Based on the DWS classification, the total sustainable yield (i.e. applicant use) estimated for the proposed sustainable groundwater abstraction **(Table 3)** can be classified as **Category C or large scale with respect to the property size**.

The applied-for use is, however, still supported on the basis that:

- unexploited groundwater will be used instead of over-stressed surface water resources;
- extensive testing showed that other groundwater users will not be significantly affected; and
- the applied-for groundwater use represents a mere 2.3% of the exploitable potential in the catchment.

# 4 PREVAILING GROUNDWATER CONDITIONS: THE BASELINE

## 4.1 RESULTS OF THE HYDROCENSUS/USER SURVEY

Seven boreholes were located around Kellershoogte during the survey, the positions of the neighbouring water users are indicated in **Figure 7**. The boreholes are located on two properties to the south of Kellershoogte. Groundwater Complete was refused access to the properties to the north of Kellershoogte by the owners, thus there is no hydrocensus information available for the properties to the immediate north. Hydrocensus information is summarized in **Table 4**.

The national groundwater archive (NGA) was consulted for groundwater information around the project area and the result is presented in **Figure 10**. The data from NGA is outdated, as most of the boreholes were last measured in the 1970's. The data does, however, serve the purpose of highlighting three important characteristics about the earlier groundwater environment:

- Firstly, the boreholes in the area are generally very shallow – none had water levels deeper than 30m below surface.
- Secondly, it confirms the highly heterogenous nature of the fractured rock aquifer environment, as the boreholes are on nearly the same elevations, but have greatly varying static groundwater levels.
- Finally, the effect of the extreme drought of the past few years is highlighted with some historical (NGA) water levels as shallow as 4 mbs recorded near the river – the shallowest during the May 2021 survey was around 9 mbs. The historical water levels in other NGA boreholes with water levels around 15 mbs have now decreased to 30 mbs.

***Notes:***

- *Groundwater in the project area is used for domestic and livestock water supply as well as irrigation.*
- *Access was denied for the hydrocensus and user survey on all the properties to the north of Kellershoogte.*
- *Known borehole depths around (south of) Kellershoogte are generally less than 70 meters deep.*
- *Static water levels in these boreholes vary between 9 and 35 mbs, which are similar to the levels in the Kellershoogte shallow borehole.*

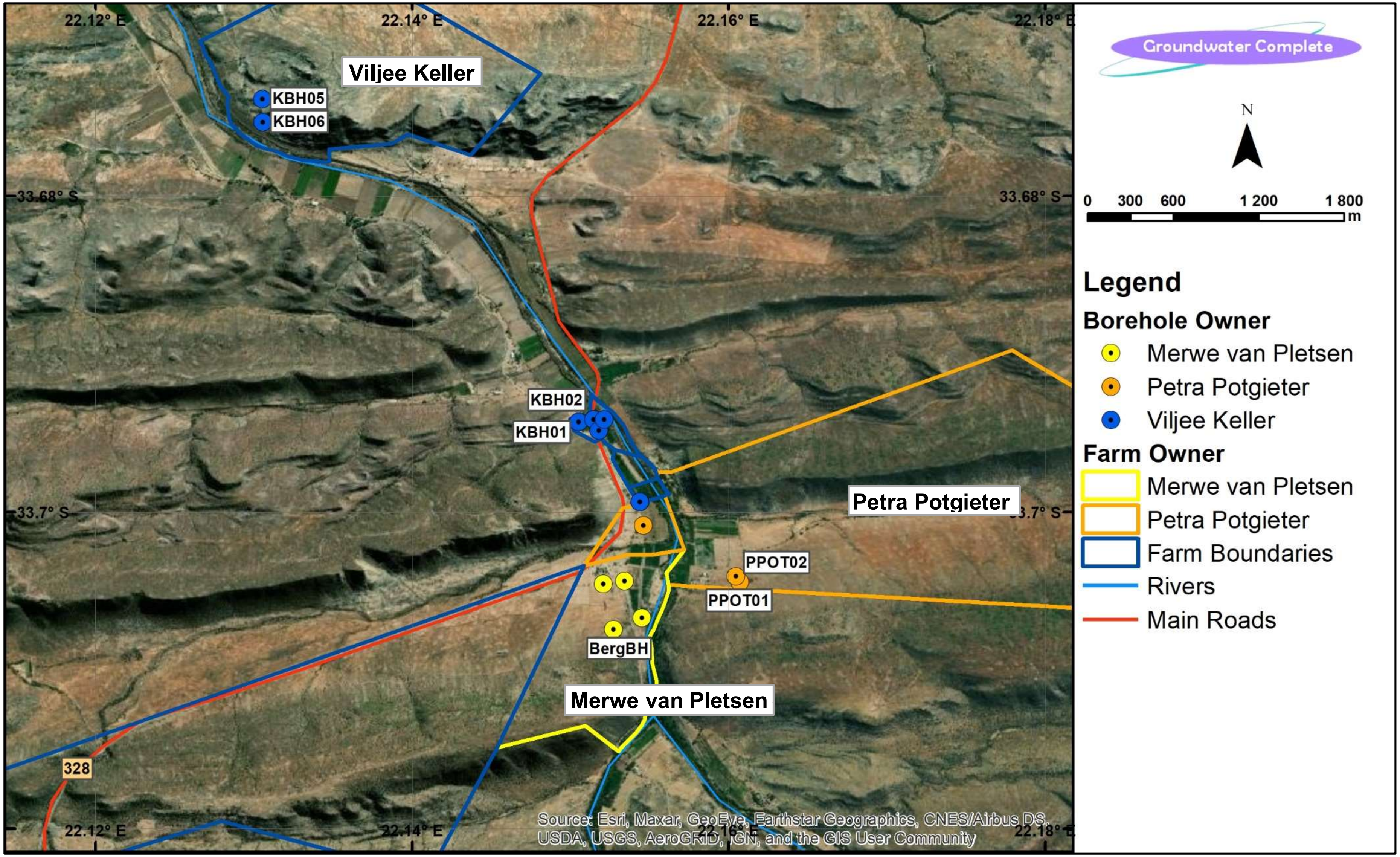


**Figure 9: Positions of the hydrocensus/user survey boreholes**

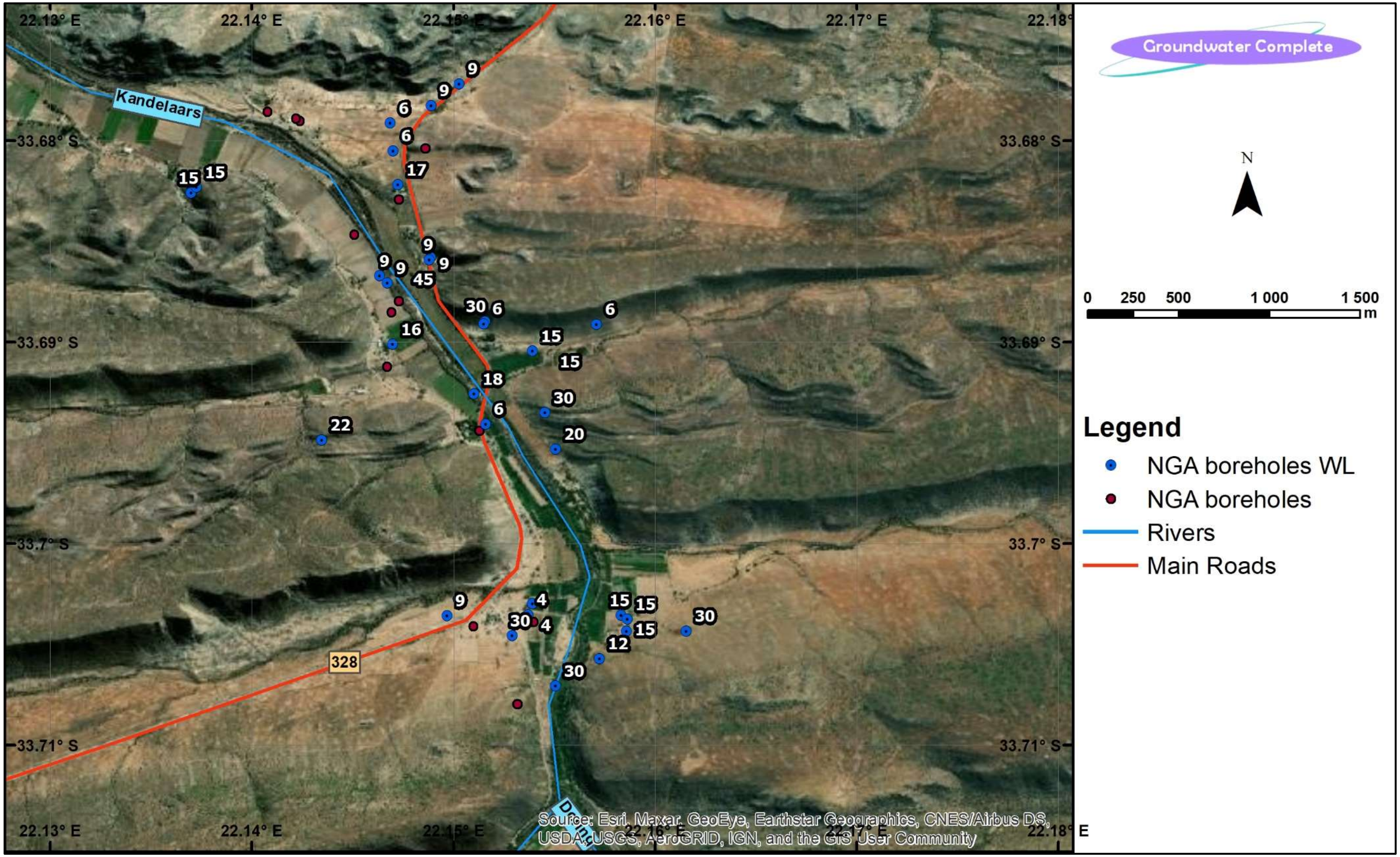


**Figure 10: Static groundwater levels in National Groundwater Archive (NGA) boreholes located around the Kellershoogte area**

**Table 4: Summarized results of hydrocensus/user survey**

| Owner Name | Locality Name | Y-coord | X-coord | Z-coord | Distance from Kellershoogte | Borehole Depth | Pump Type | Use | Estimated Yield (L/H) | Static Water Level | EC (mS/m) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Petra Potgieter | PPOT01 | -33.7044 | 22.1607 | 317 | 800 m | Unknown | Electric sub. | Unknown | Unknown | 28.97 | 360 |
| | PPOT02 | -33.7041 | 22.1605 | 315 | 750 m | Unknown | Electric sub. | Unknown | Unknown | 26.12 | 195 |
| | PPOT03 | -33.7008 | 22.1546 | 297 | 160 m | Unknown | N/A | Unknown | Unknown | 10.47 | 195 |
| Merwe van Pletsen | BergBH | -33.7074 | 22.1527 | 314 | 900 m | 59 | Solar | Irrigation | 667 | 34.56 | 142 |
| | VoerkraalBH | -33.7045 | 22.1520 | 307 | 610 m | 66.8 | Solar | Livestock & Domestic | 667 | 25.07 | 116 |
| | PeartreeBH | -33.7043 | 22.1534 | 300 | 550 m | 56 | Electric sub. | Irrigation | 22500 | 15.09 | 540 |
| | LusernstoorBH | -33.7067 | 22.1545 | 300 | 810 m | 54 | Solar | Irrigation | 667 | 7.95 | 138 |
| Viljee Keller | KBH01 | -33.6943 | 22.1505 | 298 | N/A | 52 | N/A | N/A | Dry | Dry | N/A |
| | KBH02 | -33.6941 | 22.1515 | 293 | N/A | 310 | Electric sub. | Irrigation | Unknown | 51.4 | N/A |
| | KBH03 | -33.6948 | 22.1518 | 296 | N/A | 200 | Electric sub. | Irrigation | Unknown | 50.14 | N/A |
| | KBH04 | -33.6993 | 22.1544 | 298 | N/A | 50 | Electric sub. | Irrigation | Unknown | 7.4 | 324 |
| | KBH05 | -33.6738 | 22.1306 | 292 | N/A | Unknown | Electric sub. | Irrigation | Unknown | 48.5 | 680 |
| | KBH06 | -33.6753 | 22.1306 | 284 | N/A | Unknown | Electric sub. | Irrigation | Unknown | 48.3 | 473 |
| | KBH07 | -33.6943 | 22.1520 | 297 | N/A | 30 | N/A | Monitor | Dry | Dry | N/A |

## 4.2 GEOLOGY

The geology in the area plays a crucial role in the characteristics and behaviours of the different groundwater systems. The groundwater quality, yield, storage properties and recharge rate all depend – at least to some degree – on the type of host rock of the aquifer.

An aquifer can be defined as a groundwater source that can provide an economically viable source of water. An aquiclude or aquitard is defined a rock layer with no, or very low, permeability and does not readily allow movement of water through it.

The region in which Kellershoogte is located is underlain by rocks from the Cape Supergroup. The Cape Supergroup outcrops along the southern coast of South Africa from the Cape peninsula in the west to Uitenhage in the east. It was formed by many different layers of sediment which were cemented and formed layers of sedimentary rock. Due to tectonic movement the layers of sedimentary rock were subjected to immense pressure and deformed (folded) to form the so-called Cape Fold Belt or mountain ranges. Most of the hills were weathered away over time and eroded to a more flat and habitable landscape that exists as present. When the geology is viewed from above (in plan view) it appears in east-west bands of alternating mountains and valleys **(Figure 11)**. The predominantly sandstone formations are very hard and weathering-resistant and formed the mountains while the shale, silt and mudstone layers weathered more readily and formed the valleys between the mountains.

The constituents of the different geological formations display significant variance in a vertical sense, i.e. between argillitic sediments such as shale, mudstone, siltstone layers (which mostly act as aquicludes) and arenitic sediments sandstone, greywackes, arenite layers (which form the main aquifers). Due to these geological variations, aquifers are often isolated from each other vertically in a hydraulic sense since they are separated by impervious layers. Shaly or silty aquicludes alternate with fractured sandstone. This results in very little to sometimes no interaction whatsoever between boreholes situated close together o surface but drilled to various depths. This concept is explained further in this section and illustrated in **Figure 22**.

**Figures 12** is a cross-section of the Cape supergroup geology produced for the Blossom Wellfield research report (Riemann & Blake,2010), which was conducted approximately 10-15 km east of the Kellershoogte project (Figure 12) in the same geological succession. The aim with the drilling the two deeper Kellershoogte boreholes (KBH02 and 03) was to target the same sandstone aquifer as targeted by the Blossoms Project. The advantages of the Blossoms aquifer are:

- Recharge is significant (at least an order of magnitude higher than at Kellershoogte) on the TMS where it outcrops to the form the Outeniqua Mountains to the south.
- The Bokkeveld Shale formations overlying the TMS generally form an aquiclude and where aquifers do form in the shale, the groundwater is often very saline.
- The shales above the TMS cause confinement of the TMS aquifer and when penetrated with a borehole from surface (through the shale) the TMS form artesian boreholes due to its piezometric pressure head based in the higher elevated outcrop to the south (Figure 12).

- The folded nature of the Cape Supergroup rocks results in the TMS occurring at various depths below surface. At the Blossoms Project, and also along the same strike in the Kellershoogte area, the TMS is relatively shallow due to the presence of the Wikliprug Anticline as indicated in Figure 12 and 13.

The constituents of the different geological formations display significant variance in a vertical sense, i.e. between argillitic sediments such as shale, mudstone, siltstone layers (which mostly act as aquicludes) and arenitic sediments sandstone, greywackes, arenite layers (which form the main aquifers). Due to these geological variations, aquifers are often isolated from each other in a hydraulic sense since they are separated by impervious layers.

As mentioned previously, the Blossoms Wellfield project is located about 16km due east of the Kellershoogte project area. The project targeted the deep Table Mountain Sandstone (TMS) formations in hope of finding a strong, reliable source of fresh groundwater for the arid area. The project is referenced in Section 9 of this report. The two deeper boreholes at Kellershoogte (KBH02 and 03) were drilled with the same principle in mind as they are located on the same regional anticline structure as the Blossoms Project **(Figure 13 and 14)**. The TMS layers at Kellershoogte are, however, situated significantly deeper below surface than the current depths (KBH02 = 300m and KBH03 = 210m) of two deeper Kellershoogte boreholes. The Kellershoogte boreholes did, however, succeed in intersecting other aquifers with acceptable salinity at deeper elevations than the other, traditionally shallower boreholes in the vicinity and deeper than the boreholes of the existing groundwater users.

The TMG sediments in the Kellershoogte (and Blossoms Project) area dip towards the north on the northern leg of the east-west trending Witkliprug Anticline structure. The oldest layers thus outcrops toward the south and the younger the layers are, the further north they outcrop **(Figure 11 and 12)**. The 1:250 000 scale geological map extract in **Figure 12** also shows the dip angles (inclinations) of the layers to the north, varying from near-horizontal in the Gamka Formation in the south to 4° northwards in the Hex River formation, increasing to 15° in the Boplaas Formation and 27° in the Traka Formation in the north.

As with its yield, the geological formations of the TMG also have a strong influence on the groundwater quality. The salinity of groundwater from the TMS aquifers is generally very low and suitable for human consumption with the Peninsula Sandstone Formation probably having the best water quality of all. The argillitic formations (shales/siltstones) often produce groundwater with higher salinity. In fact, the Bokkeveld Group of formations – predominantly shales with some interlayered feldspathic sandstone and greywacke – is known for groundwater of such salinity that it is often unsuitable for consumption or even irrigation. The salinity in some of the sandstone in the Bokkeveld Group is, however, acceptable and can be used as a source of water supply, which is the case at Kellershoogte.

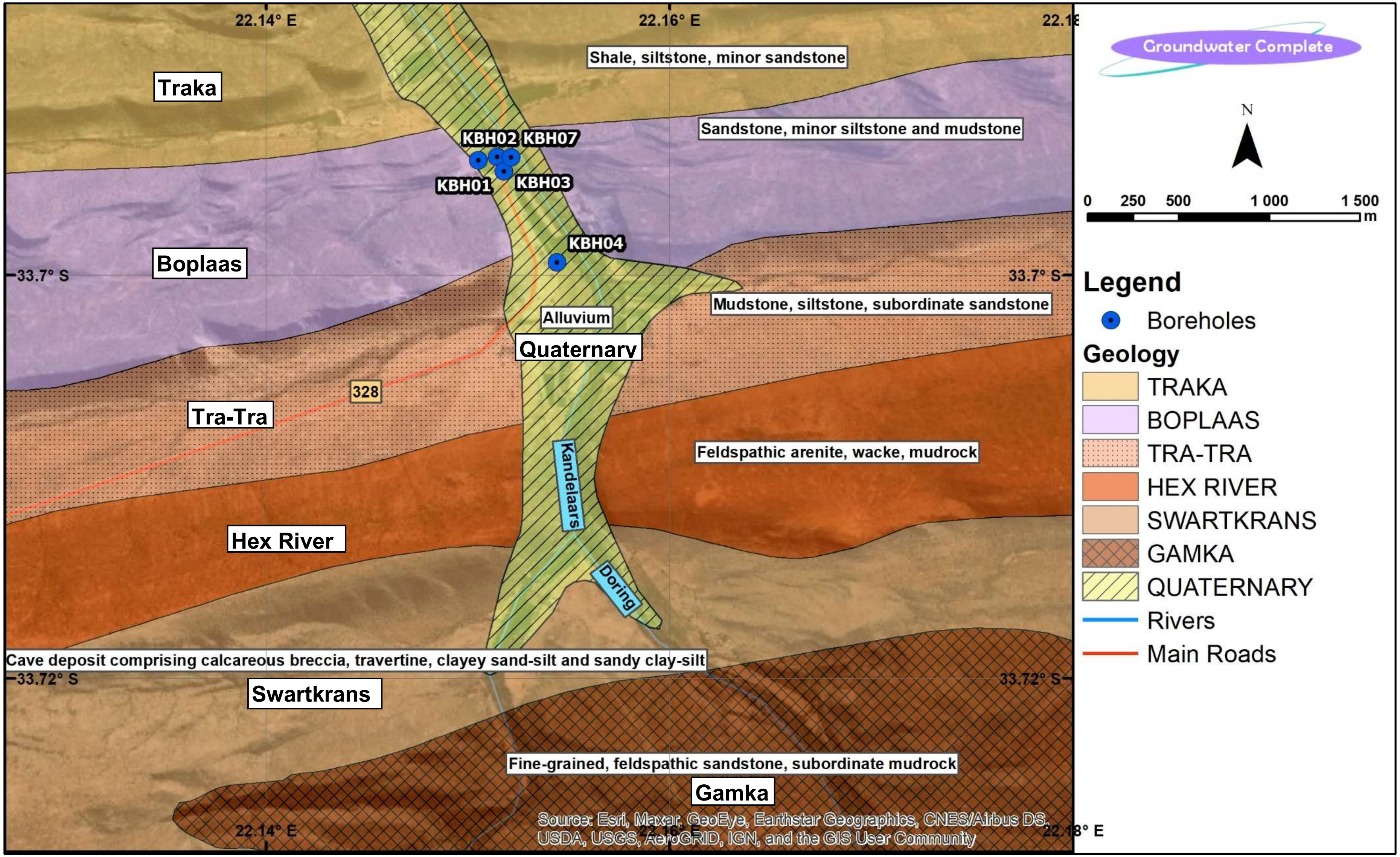


**Figure 11: Geological map indicating the descriptions of the different stratigraphic layers**

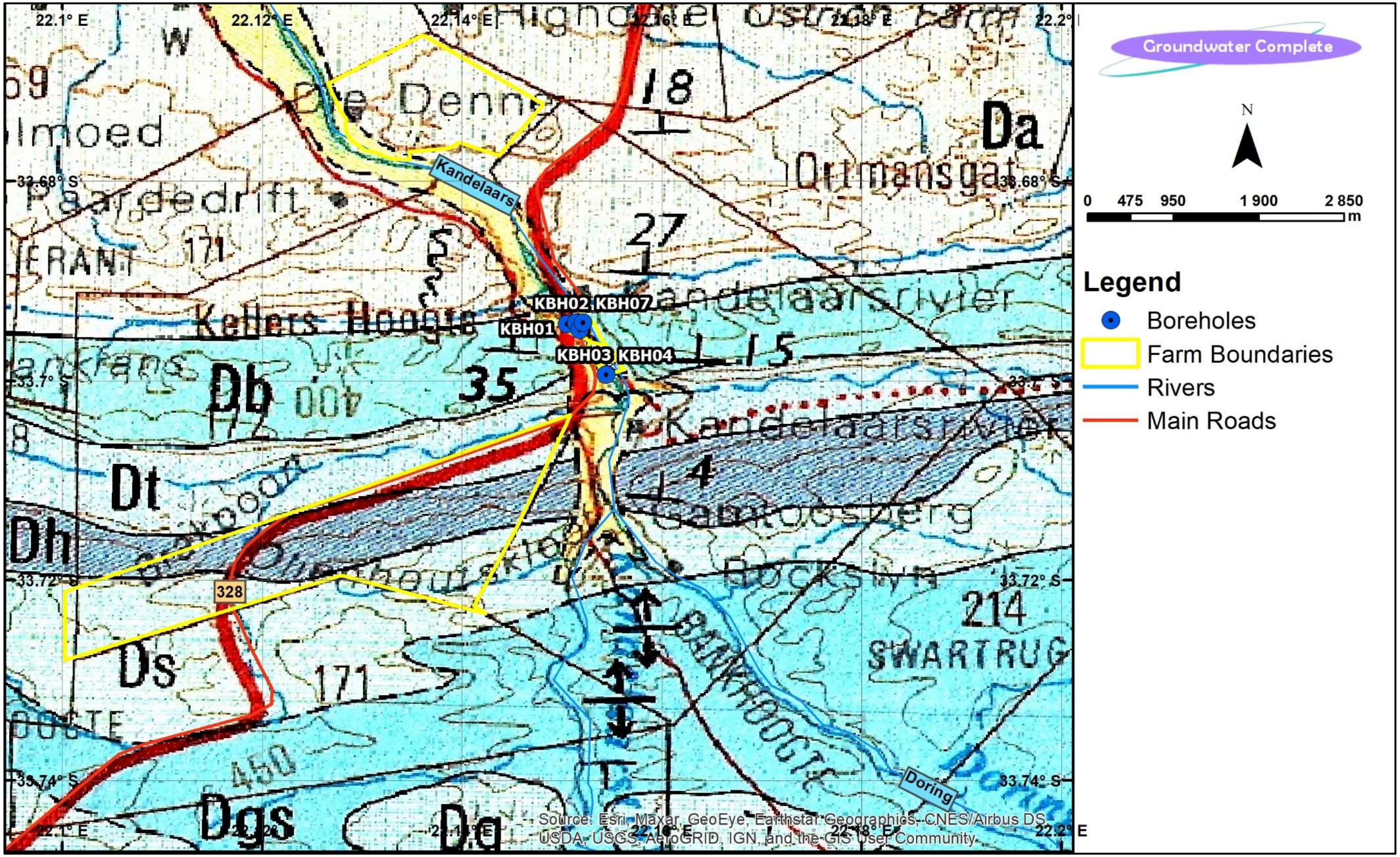


**Figure 12: 1:250 000 scale geological map of the project area**

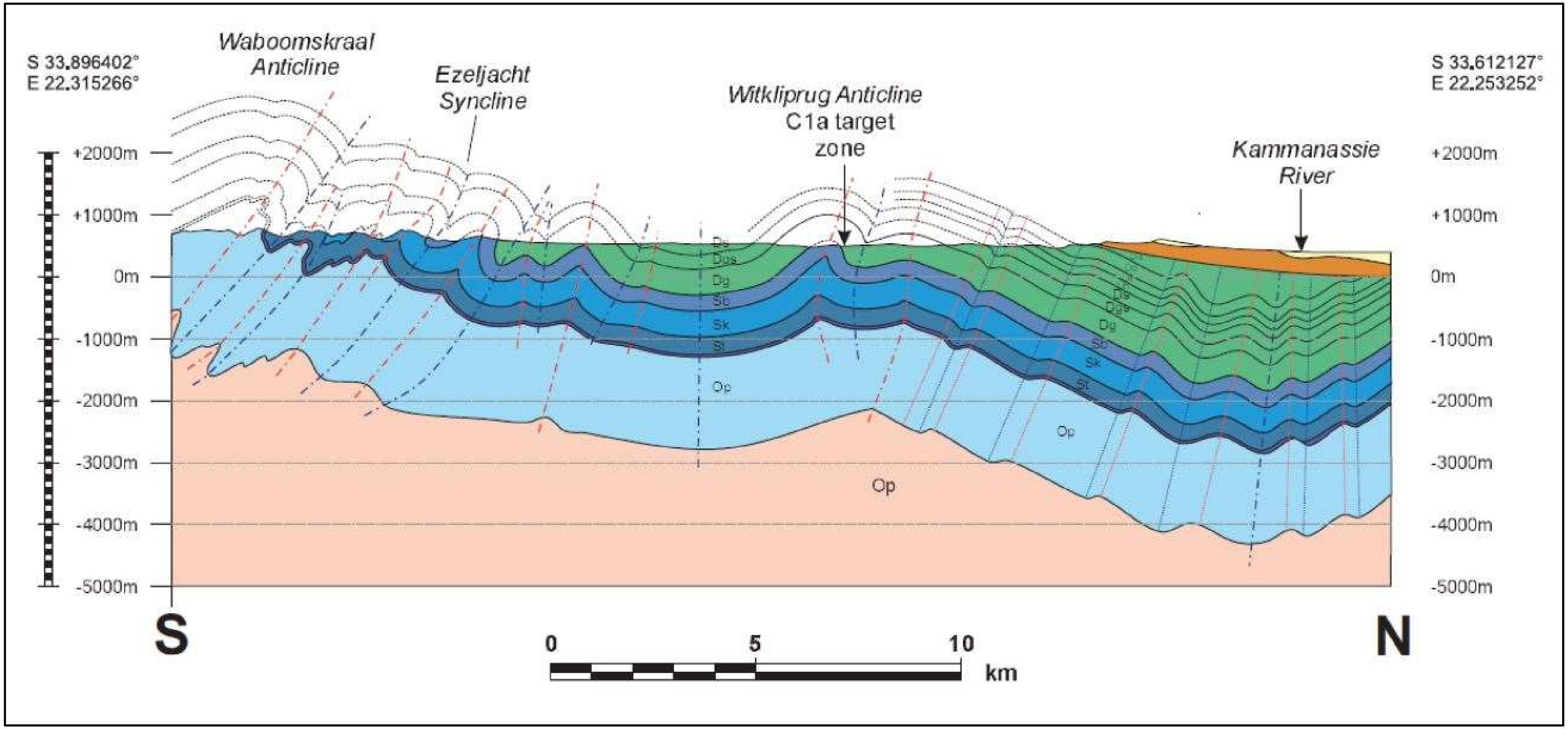


**Figure 13: Cross-section of the geological formations of the Cape Supergroup (Riemann&Blake, 2010)**

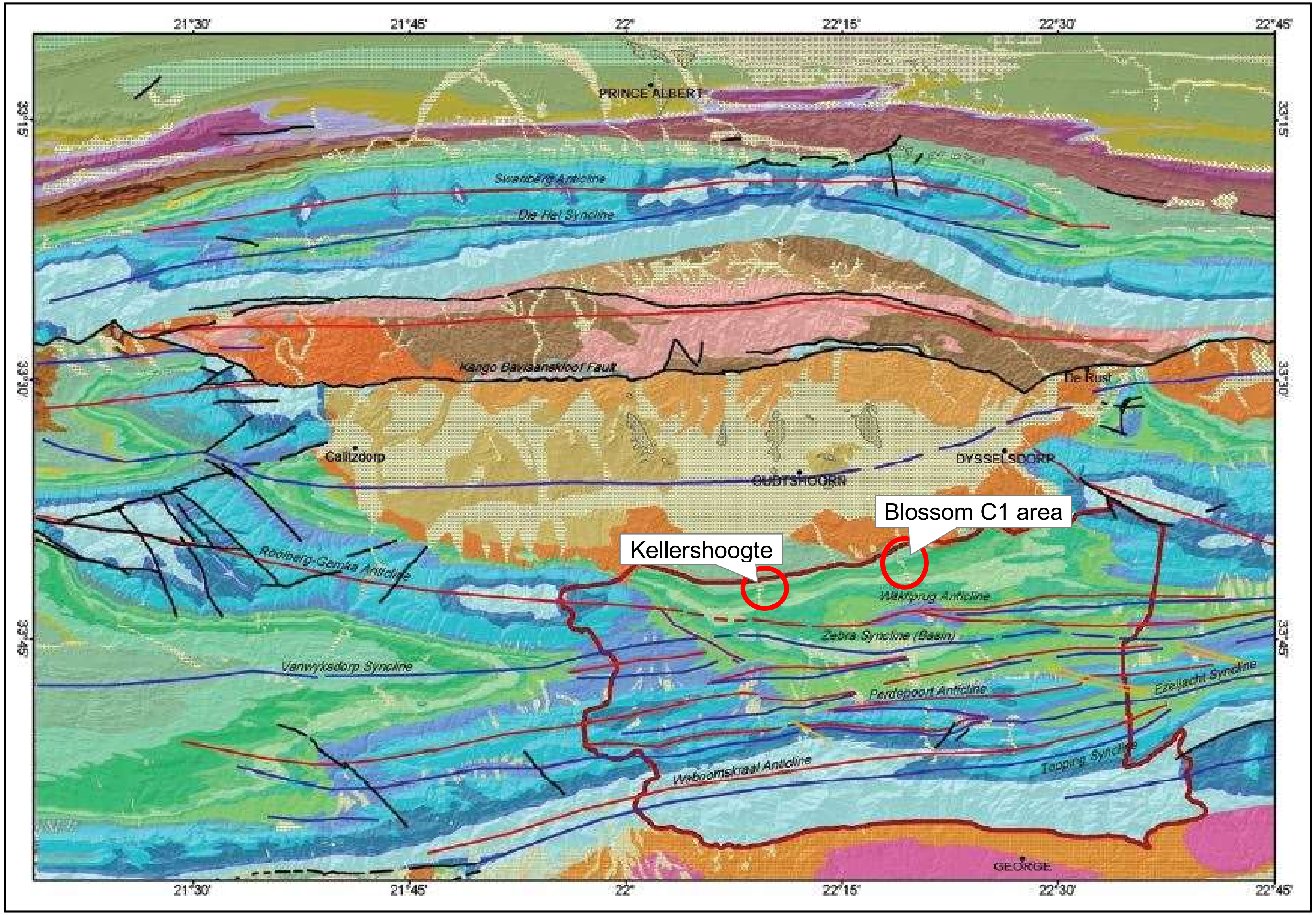


**Figure 14: Geological map of the Blossoms Wellfield project region (Riemann&Blake, 2010)**

## 4.3 GROUNDWATER QUALITY

Groundwater quality in the Kellershoogte areas varies significantly. Even within the same geological formation the salinity can vary greatly and over short distances. These variances are interpreted as typical of the heterogeneity in secondary aquifers. Every major fracture system intersects a certain geological composition and has its own recharge area, which results in its unique water quality – including the temporal variation thereof. The electrical conductivity (which is a representative indicator of the overall salinity) of groundwater was measured in boreholes during the hydrocensus and is displayed as a thematic map in **Figure 15** on a backdrop of the geological formations as they outcrop in the area. It follows from the figure that the electrical conductivity (EC) varies between 119 and 680 mS/m in the area with the lowest EC values measured in boreholes Berg and Lusernstoor. Interestingly, both the highest and the lowest salinities are measured in the shallow aquifer.

The general tendency of groundwater salinity is to increase with depth below surface due to increasingly stagnant conditions. The longer the residence time of groundwater in the aquifer, the longer the time for natural ion exchange reactions to occur and the groundwater salinity to increase. The salinity of the groundwater in the two deep boreholes is, however, moderate, if compared to the shallow aquifer salinities. The reason assumingly lies in the fact that a more sandstone-dominated aquifer is intersected by the two deep boreholes that do not cause the same extent of groundwater salinity as the shales intersected by the shallow aquifer boreholes.

More comprehensive analyses are shown in **Table 5** with exceedances of recommended SANS limits for domestic also indicated. The inorganic parameter concentrations show that the macro element content of groundwater is dominated by sodium on the cation side with chloride dominating the anion content. The plot positions of the groundwater qualities in the expanded Durov diagram in **Figure 16** confirm the relative dominance by sodium and chloride. The expanded Durov diagram further reveal that:

- The macro element composition of KBH02 and KBH03 are the same and similarly, the relative composition of Voerkraal and Peartree groundwater is also exactly the same, albeit with a higher calcium-magnesium over sodium ratio than the deep boreholes.
- The Berg an Lusernstoor boreholes with lowest overall salinity plot as a more even ratio (mixture) of the major ions, especially anions – chloride, sulphate and bicarbonate alkalinity.

**Table 5: Inorganic groundwater quality analyses of boreholes on and around Kellershoogte**

| Site Name | KBH02 | KBH03 | Berg | Voerkraal | Peartree | Lusern stoor | SANS 241:2015 |
|---|---|---|---|---|---|---|---|
| pH | 7.48 | 7.5 | 7.3 | 7.3 | 6.9 | 6.6 | ≥ 5 to ≤ 9.7 |
| EC (mS/m) | 303 | 289.0 | 119.4 | 597.0 | 653.0 | 123.1 | ≤ 170 |
| TDS | 1939 | 1850.0 | 764.0 | 3821.0 | 4179.0 | 788.0 | ≤ 1200 |
| Ca | 140.44 | 142.5 | 76.1 | 352.7 | 382.3 | 137.0 | N/A |
| Mg | 87.73 | 75.2 | 30.0 | 190.8 | 219.7 | 31.4 | N/A |
| Na | 425.04 | 404.3 | 142.2 | 718.1 | 787.8 | 147.1 | ≤ 200 |
| K | -5.0 | -5.0 | -5.0 | 9.0 | 12.8 | -5.0 | N/A |
| Alkalinity | 355.12 | 279.9 | 241.0 | 449.4 | 483.5 | 137.0 | N/A |
| Cl | 650 | 650.0 | 133.0 | 1460.0 | 1510.0 | 187.0 | ≤ 300 |
| SO4 | 310 | 330.0 | 123.0 | 270.0 | 290.0 | 132.0 | ≤ 500 |
| NO3-N | N/A | N/A | -1.0 | -1.0 | -1.0 | -1.0 | ≤ 11 |
| F | N/A | N/A | -0.1 | 0.2 | 0.2 | -0.1 | ≤ 1.5 |
| Fe | -0.1 | -0.1 | 0.3 | -0.1 | -0.1 | -0.1 | ≤ 2 |
| Mn | 0.6 | 0.44 | -0.1 | -0.1 | 0.6 | -0.1 | ≤ 0.4 |

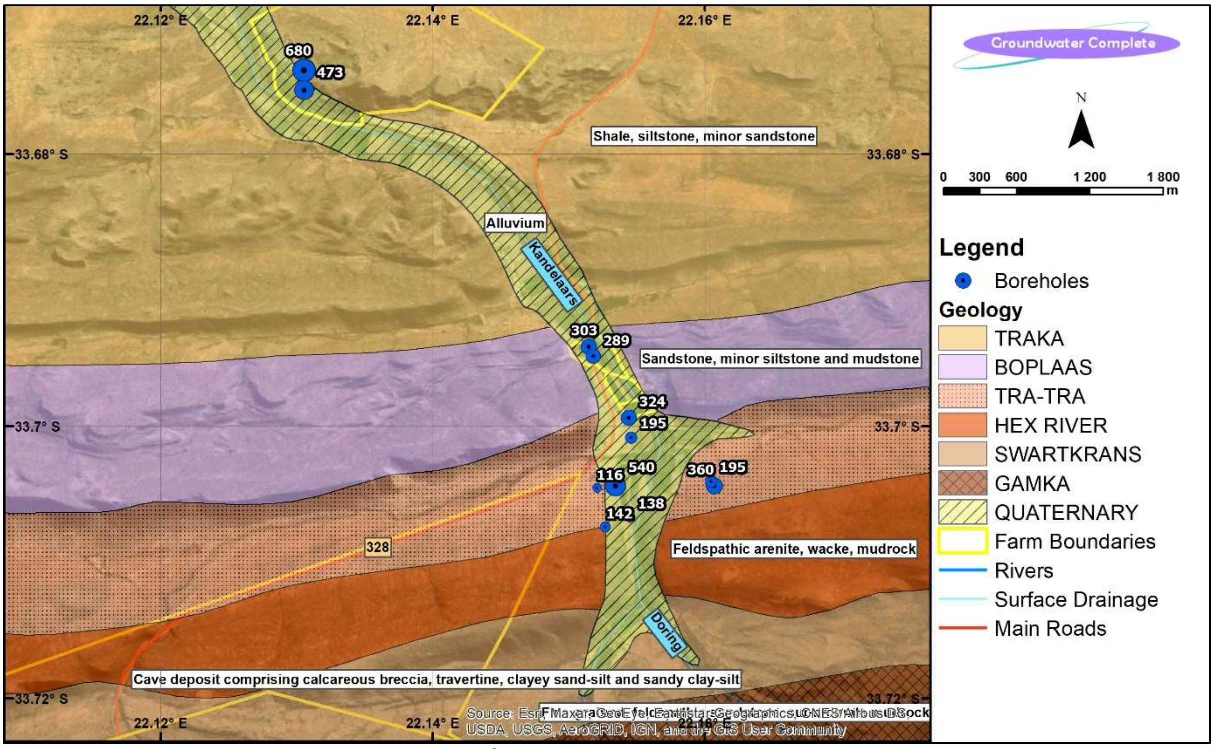


**Figure 15: Electrical conductivity of groundwater in the project area**

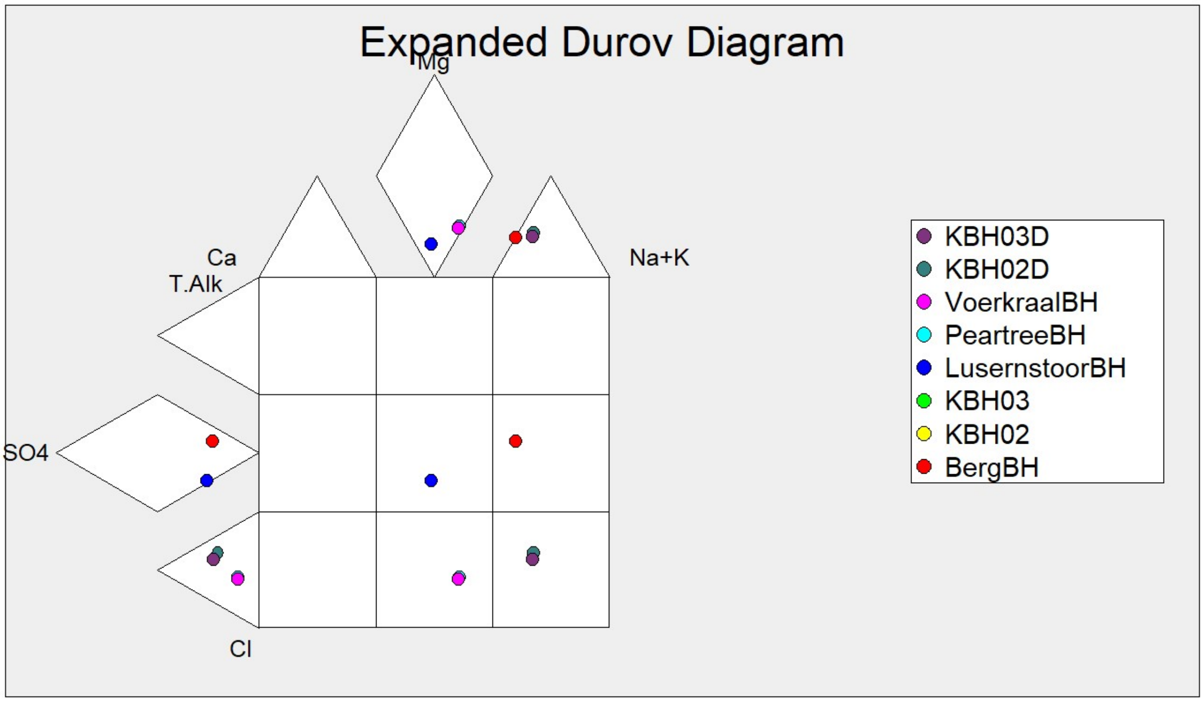


**Figure 16: Expanded Durov diagram of groundwater qualities in boreholes on and around Kellershoogte**

## 4.4 HYDROGEOLOGY

### 4.4.1 UNSATURATED ZONE

The unsaturated zone refers to the portion of the geological/soil profile that is located above the static groundwater elevation or water table. Based on the drilling results of the boreholes, the unsaturated zone is predominantly composed of soil on top followed by clay, sandstone and shale. In areas where weathering is less intense and/or water levels are deeper, the unsaturated zone may also extend into the fresh bedrock.

In the case of Kellershoogte, where there are multiple aquifers and aquicludes and where a high degree of structural deformation has occurred, the thickness of the unsaturated zone can fluctuate greatly. From water level measurements on and around Kellershoogte it was shown to vary between approximately 9 and 50 meters below surface, depending on the underlying geology, i.e. the aquifer and associated fracture system it penetrated.

### 4.4.2 SATURATED ZONE

The saturated zone, as the name suggests, is the portion of the geological/soil profile that is located below the static groundwater elevation or water table and is therefore saturated with water. Before the two deeper boreholes (KBH02 and 03) were drilled, the saturated zone at Kellershoogte was generally penetrated to less than 100 meters below surface (mbs). The deepest borehole (KBH02) provided information on the saturated zone down to 300 mbs. At the Blossoms Project, the saturated zone was penetrated and assessed down to a depth of 715 mbs.

The saturated zone is important as it forms the groundwater zone or system on which groundwater users rely for their water supply. It was thus also the focus of this groundwater study.

#### 4.4.3 HYDRAULIC CONDUCTIVITY

Constant rate pumping tests were performed on boreholes KBH02, KBH03 and KBH04 for the purpose of calculating representative aquifer parameters such as transmissivity or hydraulic conductivity **(Section 4.5)**.

Due to a highly varying and heterogenic geological system the hydraulic conductivities calculated for each borehole differs from the next and are only representative of the specific aquifer it penetrated. Monitoring of nearby boreholes during pump testing showed that aquifer hydraulic parameters of one borehole cannot be extrapolated to other boreholes. Transmissivities and hydraulic conductivities calculated during the pumping tests are provided in **Table 7**.

## 4.5 SUSTAINABLE YIELD ESTIMATION

The initial test program over five months during 2021 entailed multiple pumping tests on each of the three boreholes earmarked for groundwater supply with test durations ranging from 24 to 120 hours. During the constant rate pumping tests, water levels in the other boreholes were also measured to determine:

- the degree of interconnectivity between boreholes;
- the degree of connectivity with or recharge from the Kandelaars River to the tested boreholes, and
- the potential interference or overlapping of drawdown cones should the boreholes be used simultaneously in a well field setup.

The water level reaction in observation boreholes while pumping each individual borehole was very limited. This confirmed that there was very little – in some cases negligible – interaction between the different aquifers into which the boreholes were drilled. Please refer to Section 6 for a more expansive discussion and interpretation of the observed pump rates and water level reactions during the pump tests.

The constant rate pumping tests conducted on each of the proposed production boreholes were as follows:

- Three pumping tests were conducted on borehole KBH02, including two 72-hour tests and a 24-hour test.
- Borehole KBH3 was tested three times, namely for 24, 72 and 120 hours at a time.

- Two pump tests were conducted on borehole KBH04 – for 24 hours and 72 hours.

The final testing was completed in September and the draft report in October 2021. At nearly the exact time of submitting the draft report, the severe drought in the region around Kellershoogte was broken with three months (October, November and December of 2021) of above-average rainfall. In January 2022 the water levels in the deep boreholes have recovered and the sustainable yields improved/increased to such an extent that the applicant requested Groundwater Complete to repeat the tests and incorporate the results in this report.

Five months later (in February 2022), the two deep boreholes (KBH02 and KBH03) were re-tested for a period of 48 hours each. In the pump test results discussion in the following sections both the post-dry period and post-wet period test results will be discussed for each of the two deep boreholes where all the results will be considered to determine an appropriate sustainable yield for each borehole. The rest water level and yield of KBH04 in the shallower aquifer remained very similar in the dry and wet period and separate results will not be discussed.

### 4.5.1 KBH02

#### 4.5.1.1 POST-DRY PERIOD TESTING

The longest aquifer test on borehole KBH02 was performed in July 2021. The pumping test was conducted for a 72-hour period. The data obtained from the pump tests is displayed in **Figures 17 and 18**.

The pumping test determined that the matrix transmissivity of KBH02 is approximately 2 $m^2/s$. The storage coefficient cannot be determined with a high degree of accuracy from pump testing in a secondary, fractured rock aquifer and a conservative value of 0.005 were used for the aquifer matrix of all the boreholes.

The available drawdown in a fractured rock aquifer represents the distance between the static water level and the main or deepest water strike depth in the borehole. The relationship between sustainable yield and available drawdown is linear, meaning that if two boreholes were to occur with exactly the same transmissivity and storage coefficient values, but one had double the available drawdown, then the sustainable yield of such a borehole would be double the other. Borehole KBH2 has an available drawdown of about 150m and its main water strikes were at 100m-120m, 170m and some minor ones between 250m and 300m.

If this data is then entered into the FC pump test analysis program, an average sustainable yield of about 3 l/s is calculated when the borehole is pumped for 24-hours a day, 365 days a year. If the operational cycle is 12 hours a day, the borehole can be pumped at a rate of 6 l/s.

Due to the extremely heterogeneous nature of the fractured rock aquifer system, sustainable yields were calculated for four main aquifer scenarios/systems, namely:

- An open aquifer system that is not restricted by any boundaries (never found in practice),
- An aquifer bounded by a single no-flow boundary e.g. an impervious dolerite dyke or aquiclude occurring,
- An aquifer restricted by two no-flow boundaries – typically the impervious shale layers that form aquitards interlayered between the sandstone aquifers and , and
- A closed aquifer system (absolute worst-case scenario).

After completing the pumping test analyses, the recovery of the borehole was also measured. Analysis of the recovery data is another way to estimate the hydraulic parameters of the borehole. The recovery test data can be viewed in **Figure 18.** A transmissivity of 4.7 $m^2$/d for KBH02 was calculated from the recovery data. This correlates well with the pumping test and supports the sustainable pumping rate that was recommended the borehole.

While the pump test was being conducted, the nearest surrounding boreholes' (KBH03, KBH04 and PP03) water levels were measured to determine the effect KBH02 has on their water levels. **Table 6** contains the results of the response measurements and clearly indicate that none of the neighbouring boreholes were affected by the pumping test whatsoever.

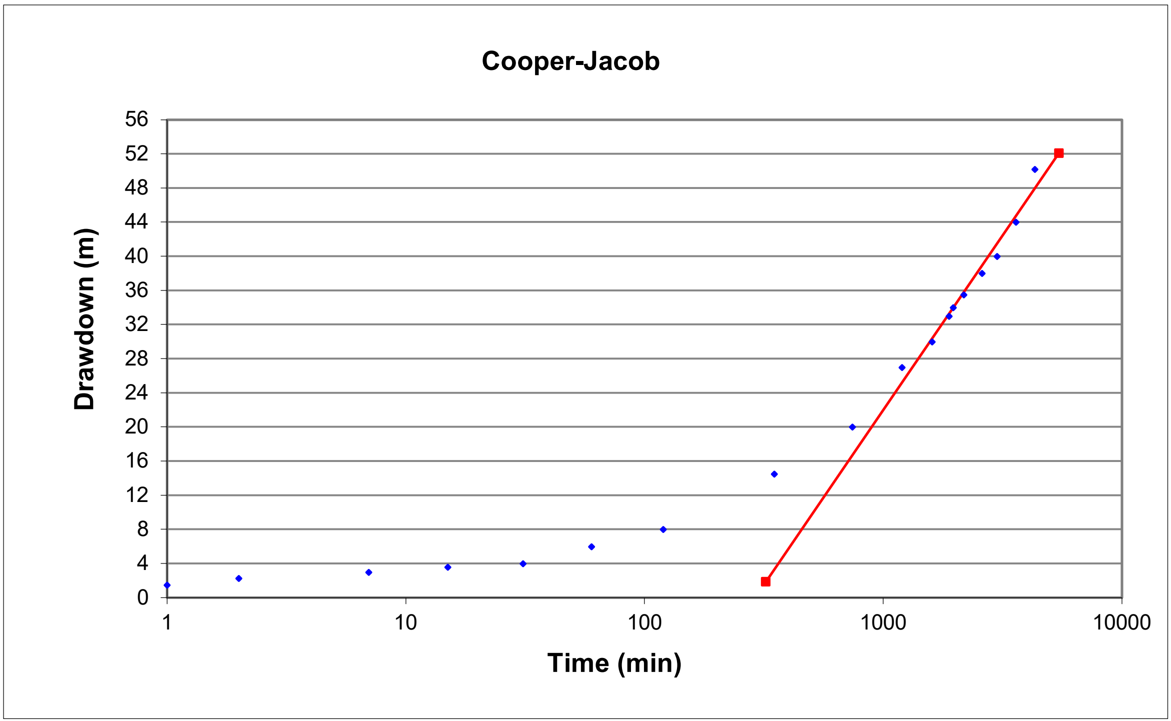


**Figure 17: Cooper-Jacob plot for analysis of drawdown data for borehole KBH02 at 5.12 l/s (September 2021)**

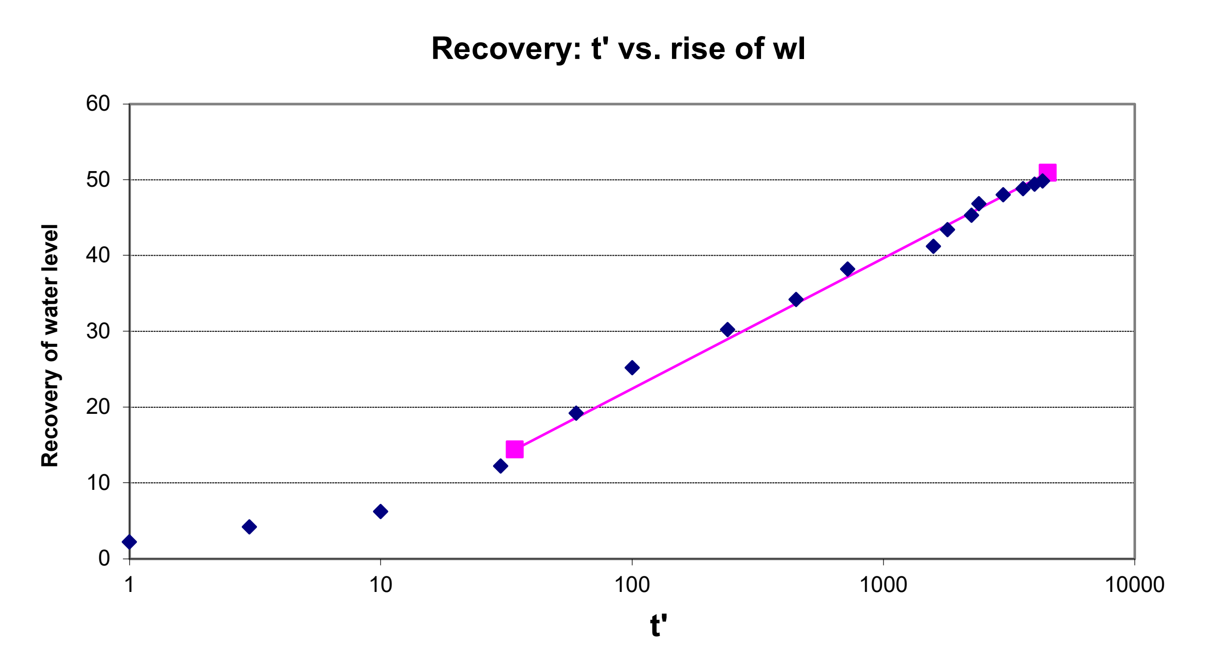


**Figure 18: Recovery curve plotted with the Theis formula for KBH02**

**Table 6: Response measured in surrounding boreholes during KBH02 pumping test (July 2021)**

| Real time | Time (minutes) | KBH2 | KBH3 | KBH4 | PP03 |
|---|---|---|---|---|---|
| 2021/07/29 09:13 | 0 (Static WL) | 45.00 | 44.00 | 8.00 | 10.00 |
| 2021/07/29 09:44 | 31 | 49.00 | | | |
| 2021/07/29 21:37 | 744 | 65.00 | | 8.00 | 10.00 |
| 2021/07/30 11:59 | 1606 | 75.00 | 44.01 | 8.01 | |
| 2021/07/30 16:44 | 1891 | 78.50 | | | |
| 2021/07/30 18:00 | 1967 | 79.20 | | | |
| 2021/07/30 21:30 | 2177 | 80.50 | | | |
| 2021/07/31 07:45 | 2792 | 83.20 | | | |
| 2021/07/31 11:13 | 3000 | 85.70 | 44.06 | 8.02 | 10.01 |
| 2021/07/31 16:42 | 3329 | 88.50 | 44.08 | | |
| 2021/08/01 09:15 | 4322 | 95.20 | 44.10 | 8.03 | 10.01 |
| **2021/08/01 09:15 Switch off pump** | | | | | |

### 4.5.1.2 POST-WET PERIOD TESTING:

The pump test conducted in February 2022 indicated that the abovementioned tests were representative of the absolute worst-case scenario caused by extreme draught conditions. The February 2022 test was conducted at a much higher pumping rate and resulted in a much less significant drawdown as evidenced in **Figure 19**. The pumping test determined that the matrix transmissivity of KBH02 is approximately 38 $m^2/s$. The FC pump test analysis program recommended an average sustainable yield of 20 l/s sustainable with an available drawdown of 100 m.

The final sustainable yields for borehole KBH02 was estimated based on an **average of the four types of boundaries** listed above. **This method is considered to provide a conservative estimate of the long-term sustainable yield and was applied during the sustainable yield estimation of all three boreholes**. The sustainable yield recommendation is around 20 l/s for a 24 hour pump cycle. This calculates to an annual volume of approximately 630 000$m^3$/a.

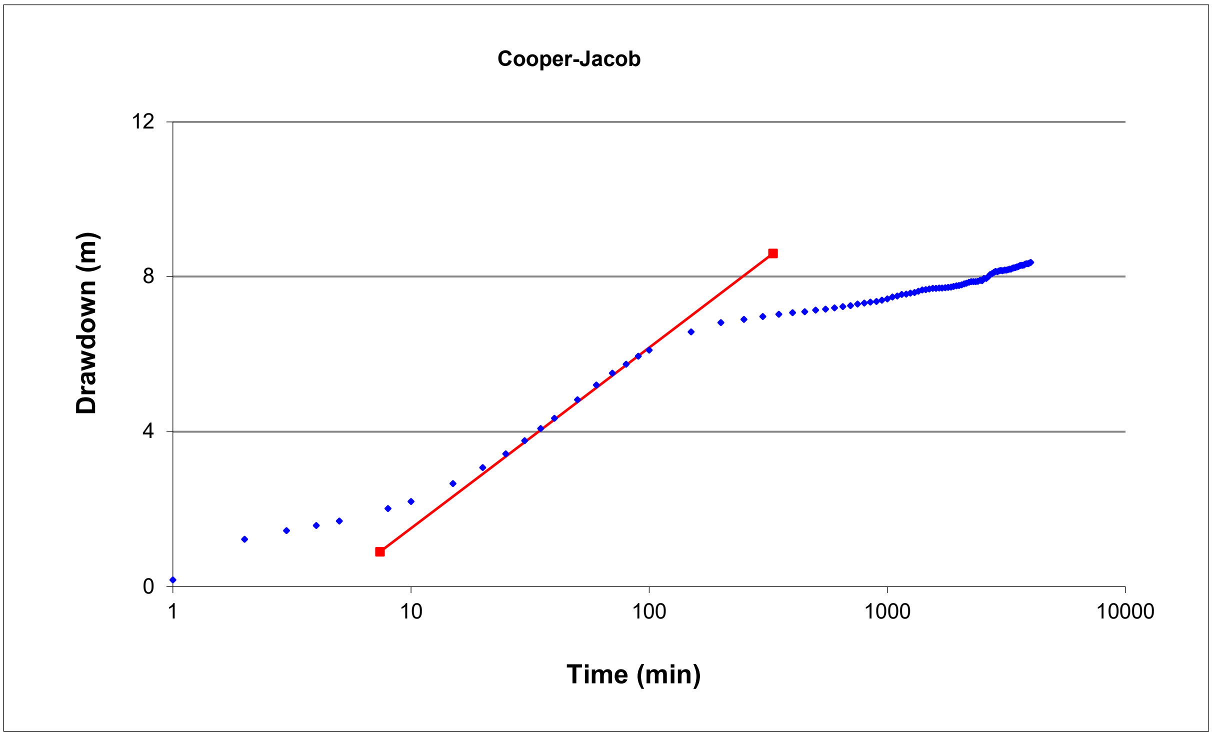


**Figure 19: Cooper-Jacob plot for analysis of drawdown data for borehole KBH02 at 11.11 l/s (February 2022)**

### 4.5.2 KBH03

#### 4.5.2.1 POST-DRY PERIOD TESTING

A 127-hour aquifer test was performed on borehole KBH03 in September 2021. The data obtained from the pump tests is displayed in **Figures 20 and 21**.

Analysis of the data indicated that the transmissivity for the borehole is about 2.1 $m^2$/d for KBH03, while the storativity is in the vicinity of 0.05. Borehole KBH3 has an available drawdown of around 80m. Initial water strikes were at 65 mbs but main water strikes were recorded between 120 and 185 mbs.

The FC borehole analysis program, while considering the influence of boundaries, determined an average sustainable yield of about 2.4 l/s for KBH03, when the borehole is pumped for 24-hours a day, 365 days a year. If the borehole is pumped for only 12 hours a day, the borehole can sustain a rate of 4.8 l/s.

The recovery of the borehole was also measured and can be viewed in **Figure 21.** A matrix transmissivity of 3.7 $m^2$/d was calculated from the KBH04 recovery data. This correlates well with the pumping test and supports the pumping rate that has been ascribed to the borehole.

While the pump test was being conducted, the nearest surrounding boreholes' (KBH02, KBH04 and PP03) water levels were measured to determine the effect KBH03 has on their water levels. **Table 11** contains the results of the response measurements and clearly indicate that none of the neighbouring boreholes were affected by the pumping test. In fact, KBH02's water level increased slightly during the pumping test.

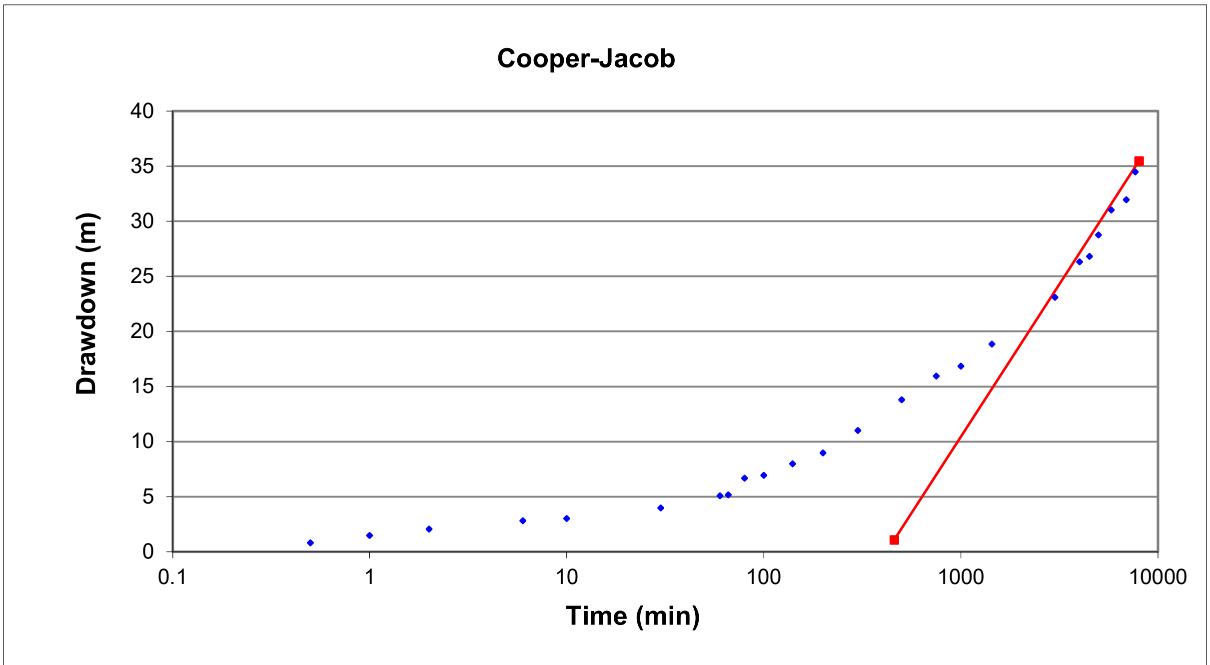


**Figure 20:Cooper-Jacob plot for analysis of pump test data for borehole KBH03 @ 3.6 l/s (September 2021)**

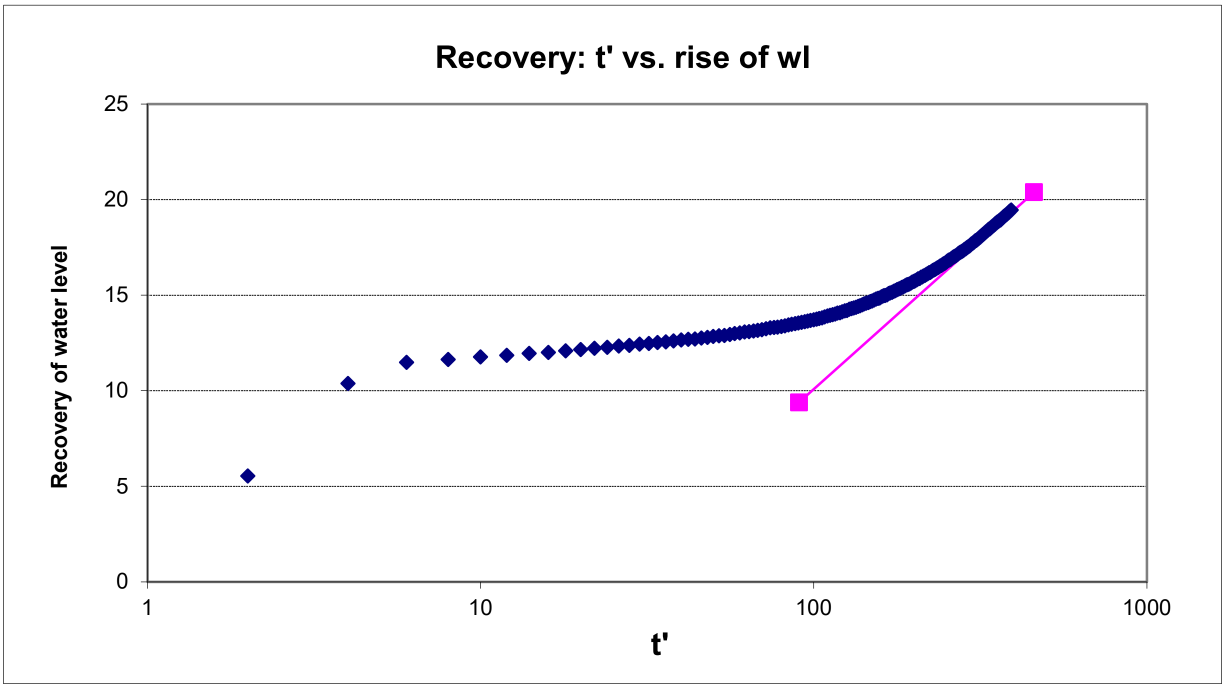


**Figure 21: Recovery curve plotted with the Theis formula for KBH03**

**Table 7: Response measured in surrounding boreholes during KBH03 pumping test**

| Real time | Time (minutes) | KBH3 | KBH2 | KBH4 | Petro Potgieter |
|---|---|---|---|---|---|
| 2021/08/04 09:30 | 0 | 43m | 45m | 8.64m | 10m |
| 2021/08/04 13:00 | 210 | 53.4m | 45m | | |
| 2021/08/05 09:00 | 1410 | 55.2m | 45m | 8.67m | |
| 2021/08/05 17:30 | 1920 | 65.9m | 44.5m | | |
| 2021/08/05 18:00 | 1950 | 66.0m | 44m | | |
| 2021/08/07 09:00 | 4290 | 69.4m | 45m | 8.78m | |
| 2021/08/07 18:00 | 4830 | 70.9m | 45m | | |
| 2021/08/08 08:00 | 5670 | 74.0m | 45m | 8.83m | 10.1m |
| **08:00 Switch off pump** | | | | | |

#### 4.5.2.2 POST-WET PERIOD TESTING:

The pump test in February 2022 was conducted at a much higher pumping rate of around 9.1 l/s and resulted in a much less significant drawdown as evidenced in **Figure 22**. The pumping test determined that the matrix transmissivity of KBH03 is approximately 27 $m^2/d$. The FC pump test analysis program, recommended an average sustainable yield of up to 30 l/s could be sustainable with an available drawdown of 100 m.

A sustainable yield of **21 l/s** is recommended from the February 2022 data for a 24 hour pump cycle, which calculates to 662 000 $m^3/a$.

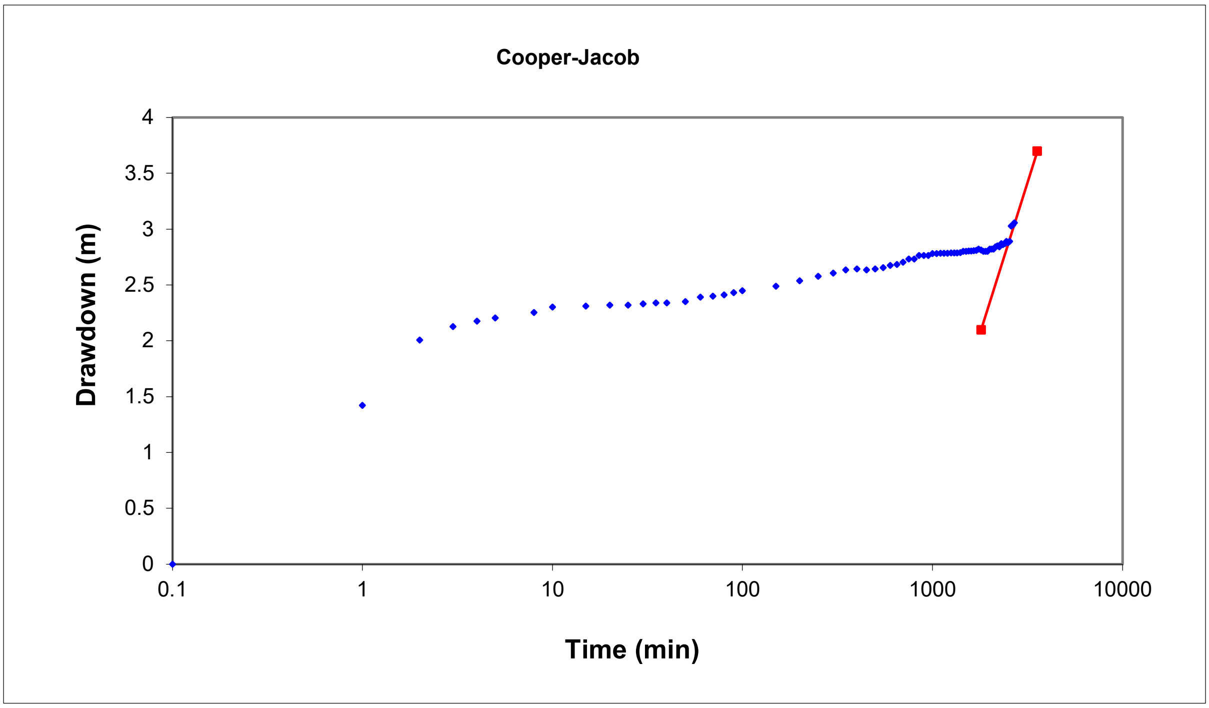


**Figure 22: Cooper-Jacob plot for analysis of pump test data for borehole KBH03 @ 9.1 l/s (February 2022)**

### 4.5.3 KBH04

The aquifer test was performed on borehole KBH04 in May 2021. The test was conducted over a 76-hour period. The data obtained from the pump tests is displayed in **Figures 23 and 24**.

The pumping test determined that the matrix transmissivity for the aquifer is 4.3 $m^2/s$. The straight-line fit was not done on the las part of the drawdown curve due to increased pump rates at late test times that caused a higher rate of drawdown. The storativity is in the vicinity of 0.05. If this data is then entered into the FC borehole analysis program, an average sustainable yield of about 1.6 l/s is calculated, when the borehole is pumped for 24-hours a day, 365 days a year. If the borehole is pumped for only 12 hours a day, the borehole can be pumped at a rate of 3.2 l/s.

Borehole KBH4 has an available drawdown of approximately 40m. The borehole is much older than the others and its water strike info is not known.

After finishing the pumping test, the recovery of the borehole was also measured. The recovery test data can be viewed in **Figure 24.** A matrix transmissivity of about 4 $m^2/d$ for KBH04 was calculated from the recovery data. This correlates well with the pumping test and supports the pumping rate that has been subscribed to the borehole.

While the pump test was being conducted in KBH04, the nearest surrounding boreholes' (KBH03 and PP03) water levels were measured to determine the effect KBH04 abstraction has on their water levels. The observation measurements indicated the following:

- PP03 showed no measurable decrease in water level during the pump testing of KBH04.
- The water level in KBH03 was measured with a water level logger and displayed a **continuous increase during both the pump and recovery test cycles of KBH04**. This increase is interpreted as being the result of two phenomena:
  - Firstly, the fact that there is no drawdown in KBH03 during the pump test on KBH04 confirms that the two boreholes are developed in two different aquifers separated by aquitards.
  - Secondly, it provides information on the recharge mechanism to the aquifer intersected by KBH03, namely that it receives recharge from a distance away and the recharge takes a few months to reach the water table through the unsaturated zone. By far the most significant rainfall event prior to the pump testing occurred in February 2021. The thunderstorm also caused runoff in the Kandelaars River for a few hours. The continuous increasing water level in KBH03 is interpreted as being a response to this rainfall event that had a lag time of approximately 2 months in recharge to the deeper aquifer intersected by KBH03.

The pump- and recovery drawdowns (decreases or increases from static levels) of pumped borehole KBH04 and observation borehole KBH03 are shown in **Figure 25**.

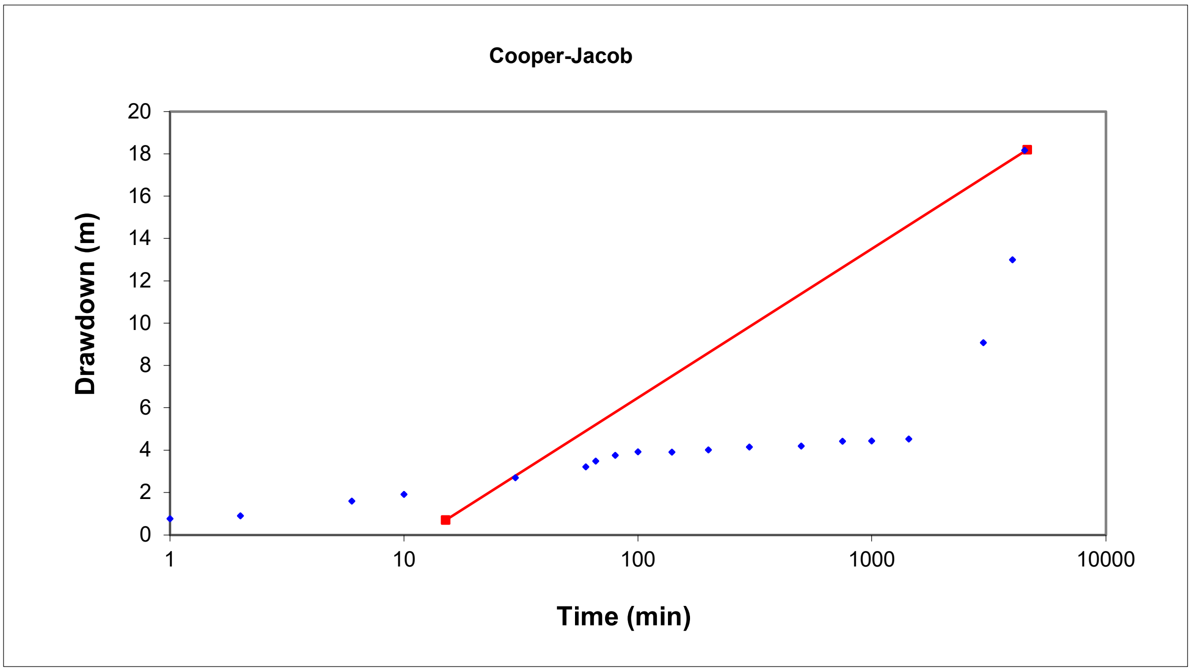


**Figure 23: Cooper-Jacob plot for analysis of pump test data for borehole KBH04**

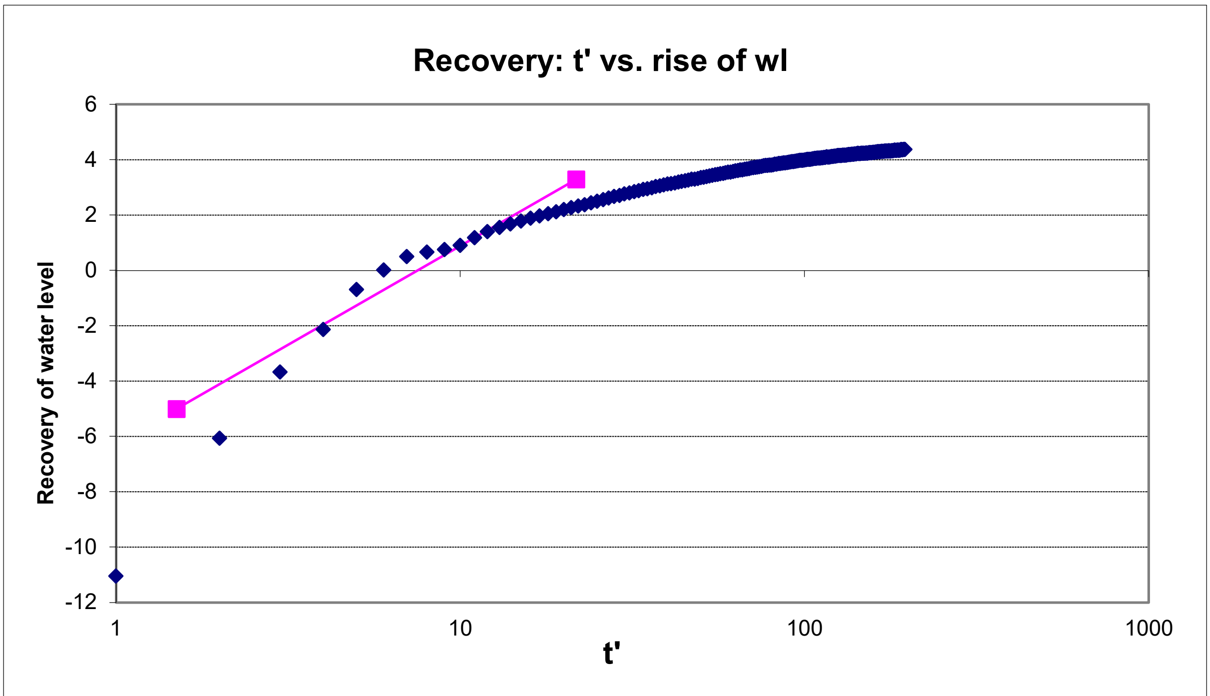


**Figure 24: Recovery data measured after the pump test for KBH04**

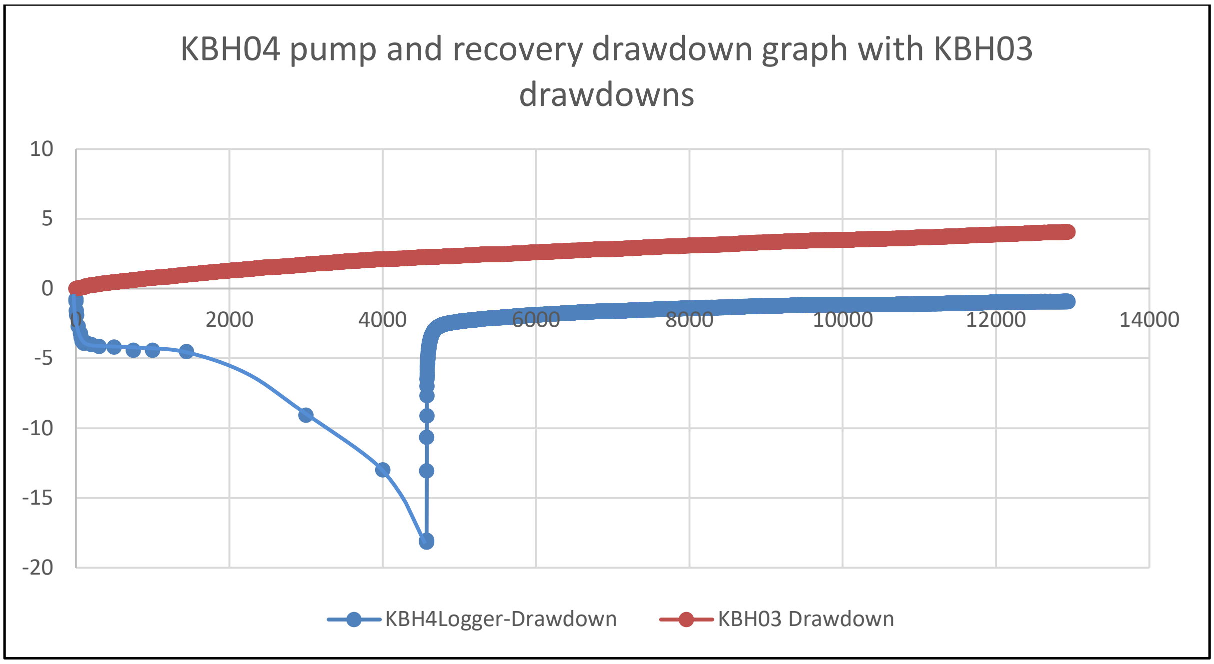


**Figure 25: KBH04 pump and recovery drawdown with KBH03 as observation borehole**

The major effect of rainfall recharge – even after a single good rainfall event – on the deep aquifer is evident from Figure 25, is is the lack of interconnectivity between the shallow (KBH04) and deeper (KBH03) aquifers.

### 4.5.4 SUMMARY DISCUSSION OF RESULTS

#### 4.5.4.1 POST-DRY PERIOD TESTING:

The total sustainable yield of the three boreholes available for pumping in the Kellershoogte area amounted to a total of **604 m³/d** or **220 752 m³/a** following the post-dry period tests. A summary of the pumping test results and recommended sustainable yields are provided in **Table 8**.

**Table 8: Summary of parameters determined by the pumping tests**

| BH Name | Test type | Transmissivity (matrix) | Available Drawdown | Recommended Q | | |
|---|---|---|---|---|---|---|
| | | | | 24h/day | 12h/day | 12h/day |
| | *Unit* | *m²/d* | *m* | *l/s* | *l/s* | ***l/h*** |
| KBH02 | Pump | 2 | 150 | 3 | 6 | **21600** |
| | Recover | 4.7 | | | | |
| KBH03 | Pump | 2.1 | 110 | 2.4 | 4.8 | **17280** |
| | Recover | 3.7 | | | | |
| KBH04 | Pump | 4.3 | 40 | 1.6 | 3.2 | **11520** |
| | Recover | 4 | | | | |

The abstraction in each of the three pump-tested boreholes had very little influence on other boreholes observed during the testing as shown in **Table 9**.

**Table 9: Summary of drawdown influence of pumped boreholes on observation boreholes**

| Pumped BH – drawdown (date) | Maximum Drawdown | Test duration | Observation BH | Distance from pumped BH | Max. drawdown in observ. BH |
|---|---|---|---|---|---|
| **KBH02 (July 2021)** | 50.2 | 72 hours | KBH03 | 85 | **0.1** |
| | | | KBH04 | 640 | **0.03** |
| | | | PPOT03 | 800 | **0.01** |
| **KBH03 (September 2021)** | 34.5 | 127 hours | KBH02 | 85 | **0** |
| | | | KBH04 | 557 | **0.19** |
| | | | PPOT03 | 716 | **0.10** |
| **KBH04 (May 2021)** | 18 | 76 hours | KBH02 | 640 | **N/A** |
| | | | KBH03 | 557 | **-4.04 (rise)** |
| | | | PPOT03 | 165 | **0** |

The following observations were made from **Table 9**:

- Hydraulic interconnectivity between all the boreholes is very limited given the duration of pumping and the drawdown achieved in the abstraction boreholes.
- Interconnectivity between the deep boreholes (KBH02 and KBH03) is also surprisingly limited considering their relative close proximity.
- Interconnectivity between KBH02 and KBH04 is significantly less than the connectivity between KBH03 and KBH04.
- The time of test – due to the difference in effective recharge – had a major influence on the test results. The pump test on KBH04 in May 2021 occurred just more than 2 months after the most significant rainfall event in the region in a long time. The Kandelaars River flowed after the storm and it is evident from water levels in the deep boreholes that recharge was taking place at a significant rate at the time. Before the rainfall event in February, water levels in the deep boreholes were around 80 mbs and during the pump test in May they increased to about 45 mbs. (A four meter increase was measured over 72 hours in KBH03 while the pump test was conducted in KBH04!) The September pump test in KBH03 occurred after five months of no meaningful (so that it would cause measurable recharge) rainfall event and apart from slightly deeper static water levels, it is clear from the water level reaction that recovery is somewhat slower.
- No water level formed in KBH07 drilled 30m deep and nearer to the Kandelaars river, showing that no shallow alluvial-type aquifer occurs.

It is concluded from the data that:

- Abstraction during >72-hour constant rate pump tests had very little impacts on nearby boreholes. Although long-term abstraction will undoubtedly cause wider effects, the impact is expected to remain very limited given the distance from surrounding users and the poor interconnectivity of the aquifers – or the fracture systems within the fractured rock aquifers.
- Recharge play a major role and the sustainable yields can be expected to increase significantly in seasons with average or higher rainfall. Once time-series data is available over a season or two it is recommended that the data be reviewed, and the applied-for volumes amended if the yields recommended from these tests prove to be overly conservative due to the test period after a few years of severe drought.
- Groundwater abstraction at Kellershoogte will not affect flow or water availability in the Kandelaars River.

#### 4.5.4.2 POST-WET PERIOD RESULTS SUMMARY:

The total (theoretical) sustainable yield of the three proposed production boreholes at Kellershoogte amounted to a total of 3 680 m$^3$/d or 1 340 000 m$^3$/a. A summary of the pumping test results and recommended sustainable yields are provided in **Table 10**.

**Table 10: Summary of parameters determined by the pumping tests**

| BH Name | Test type | Transmissivity (matrix) | Available Drawdown | Recommended Q | | |
|---|---|---|---|---|---|---|
| | | | | 24h/day | 12h/day | 12h/day |
| | *Unit* | *m$^2$/d* | *m* | *l/s* | *l/s* | ***l/h*** |
| KBH02 | Pump | 38 | 100 | 20 | 40 | **144 000** |
| | Recover | N/A | | | | |
| KBH03 | Pump | 27 | 100 | 21 | 42 | **151 200** |
| | Recover | N/A | | | | |
| KBH04 | Pump | 4.3 | 40 | 1.6 | 3.2 | **11520** |
| | Recover | 4 | | | | |

Please note that the maximum drawdown for boreholes KBH02 and KBH03 was taken at 100m (drawdown from rest water level). This is a precaution against the recharge-dependant nature of the aquifer.

#### 4.5.4.3 POST-DRY AND POST-WET RESULTS COMPARISON AND DISCUSSION

Results of the pump test program at different times (at the end of the drought and after good rains) and sustainable yield estimation from the tests are summarised in **Table 11** below.

**Table 11: Comparison of pump test data, aquifer parameters and sustainable yield of tests during drought and tests after good rainfall**

| **Description** | **Pump testing during 2021 drought** | | | **Pump testing in 2022 after good rainfall** | | |
|---|---|---|---|---|---|---|
| **Borehole** | **KBH02** | **KBH03** | **KBH04** | **KBH02** | **KBH03** | **KBH04** |
| Matrix Transmissivity ($m^2$/d) | 2 | 2.1 | 4.3 | 39 | 95 | 4.3 |
| Storage Coefficient | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 |
| Available drawdown | 100 | 100 | 40 | 100 | 100 | 40 |
| Test Duration | 72 | 127 | 76 | 48 | 48 | N/A |
| Sustainable Yield (l/h for 12 h/d) | 21600 | 17280 | 11520 | 90 000 | 165 000 | 11 520 |
| Yield ($m^3$/a) | 94 600 | 75 700 | 50 450 | 788 000 | 1 450 000 | 50 450 |
| **Total ($m^3$/a)** | **220 750 $m^3$/a** | | | **2 288 000$m^3$/a** | | |

The following conclusions were reached, and recommendations are made from these results:

- The aquifer parameters (transmissivities) and recommended sustainable yields at the end of the drought and after good rainfall using the same methodology, equipment and algorithms yielded results that differed by an order of magnitude.
- It therefore seems impossible to recommend a single long term sustainable yield for every borehole from pup test data alone.
- The effective recharge to the deep aquifer plays by far the most important role in borehole yield.
- It is therefore recommended that one of two approaches are used to determine the safe sustainable yield of the deep boreholes, namely recharge-based or drawdown-based and these approaches are briefly outlined below.

**Recharge-based sustainable yield:**

The first alternative is to base the annual sustainable yield of the deep boreholes on rainfall (recharge) during the season. The water level reaction even after one good rainfall event early in 2021 showed that the effect of recharge is significant, while tests on the same boreholes in September – when storage was depleted after 6 dry months – yielded much poorer yield results.

If the effective recharge rate and area can be accurately determined, then the sustainable yield can be adapted annually based on the rainfall during the foregoing season. This approach would be very similar than for surface water use from a catchment storage dam.

A prerequisite for the recharge-based yield approach is that at least two to three years of detailed monitoring of daily rainfall data, borehole water levels and pump rates from the aquifer(s) are gathered during a ‘trial period’. An in-depth assessment of the data then needs to be done to determine a ‘formula’ according to which the annual allowable yield is calculated. As the water use continues, the aquifer performance must be closely monitored on a continuous basis to refine, review and adapt the abstraction rates if necessary.

**Drawdown-based sustainable yield**

It is general accepted practice in sustainable yield estimation in fractured rock aquifers to not have the water level reach – or go below – the level of the main water-yielding fracture or fracture zone discussed in Blossoms document *(Hartnady, et al., 2017)*. If this happens, the aquifer host rock slowly but surely loses its elasticity which cause the water-yielding fractures to not open up again after pumping. The fracture apertures around the borehole keep on reducing and the borehole yield reduces concurrently.

In KBH02 the main water strikes occurred at between 100 and 120 mbs and at 170 mbs with minor strikes between 250 and 300 mbs. In KBH03 there were minor strikes at 76 mbs but the major strike occurred between 120 and 185 mbs.

If the water level in KBH02 is thus prevented from being drawn down below 100 mbs, it would remain above all major water strike zones and the effect on the aquifer elasticity would be minimal.

Similarly, if the water level in KBH03 does not go below 110-120 mbs it should not have a degenerating effect on the aquifer.

The pumps in both boreholes KBH02 and KBH03 have been installed at 100 mbs, which falls precisely within the safe operating depth of the water level in the boreholes.

Since the water use license only allows for a single maximum allowable annual abstraction rate the proposed sustainable rate for the two deep boreholes is situated between the extreme dry period test results and the tests conducted after the above-average rainfall received from October to December 2021.

**Table 12: The following maximum sustainable abstraction rates are recommended - at least as a point of departure while longer term information is gathered:**

| **Borehole** | **KBH02** | **KBH03** | **KBH04** |
|---|---|---|---|
| Sustainable Yield (l/h for 12 h/d) | 40 000 | 45 000 | 11 520 |
| Yield ($m^3/a$) | 175 200 | 197 100 | 50 450 |
| **Total ($m^3/a$)** | **422 750 $m^3/a$** | | |

# 5 AQUIFER CHARACTERISATION

## 5.1 GROUNDWATER VULNERABILITY

The *Groundwater Vulnerability Classification System* used in this investigation was developed as a first order assessment tool to aid in the determination of an aquifer's vulnerability/susceptibility to groundwater contamination. This system incorporates the well-known and widely used *Parsons Aquifer Classification System* as well as drinking water quality guidelines as stated by the *Department of Water Affairs and Forestry*. This system is especially useful in situations where limited groundwater related information is available and is explained in **Table 14** and **Table 15**. The project area achieved a score of **5 (Table 13)** and the underlying aquifer can therefore be regarded as having a medium vulnerability.

**Table 13: Groundwater vulnerability rating for project area**

| | Rating |
|---|---|
| Depth to groundwater level | 1 |
| Groundwater quality | 2 |
| Aquifer type | 2 |
| **Total score:** | **5** |

**Table 14: Groundwater vulnerability classification system**

| ***Rating*** | ***4*** | ***3*** | ***2*** | ***1*** |
|---|---|---|---|---|
| Depth to groundwater level | 0 – 3 m | 3 – 6 m | 6 – 10 m | >10 m |
| Groundwater quality *(Domestic WQG*)* | Excellent (TDS < 450 mg/l) | Good (TDS > 450 < 1 000 mg/l) | Marginal (TDS > 1 000 < 2 400 mg/l) | Poor (TDS > 2 400 mg/l) |
| Aquifer type *(Parsons Aquifer Classification)* | Sole aquifer system | Major aquifer system | Minor aquifer system | Non-aquifer system |

** WQG = Water Quality Guideline.*

**Table 15: Groundwater vulnerability rating**

| Vulnerability | Rating |
|---|---|
| Low vulnerability | ≤ 4 |
| Medium vulnerability | > 4 ≤ 8 |
| High vulnerability | ≥ 9 |

## 5.2 AQUIFER CLASSIFICATION

Geological maps, pumping test results and experience gained from numerous studies conducted in similar geohydrological environments suggest that the possible aquifer type present in the project area is a double porosity aquifer. For the purpose of this study an aquifer is defined as a geological formation or group of formations that can yield groundwater in economically useable quantities. Aquifer classification according to the Parsons Classification system is summarised in **Table 16**.

There are many different aquifer system systems in the Kellershoogte, but it is likely that the vast majority are **double porosity aquifers** that are hosted within the sedimentary rocks of the Cape Supergroup (i.e. **fractured rock aquifer**). Groundwater yields can be quite heterogeneous but can range up to high flow rates. This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often significantly higher than the water-bearing fracture position. Fractures may occur in any of the co-existing host rocks due to different tectonic, structural and genetic processes. **According to the Parsons Classification system, the aquifer could be regarded as a minor aquifer system, but also a sole aquifer system in some cases where groundwater is the only source of domestic water.**

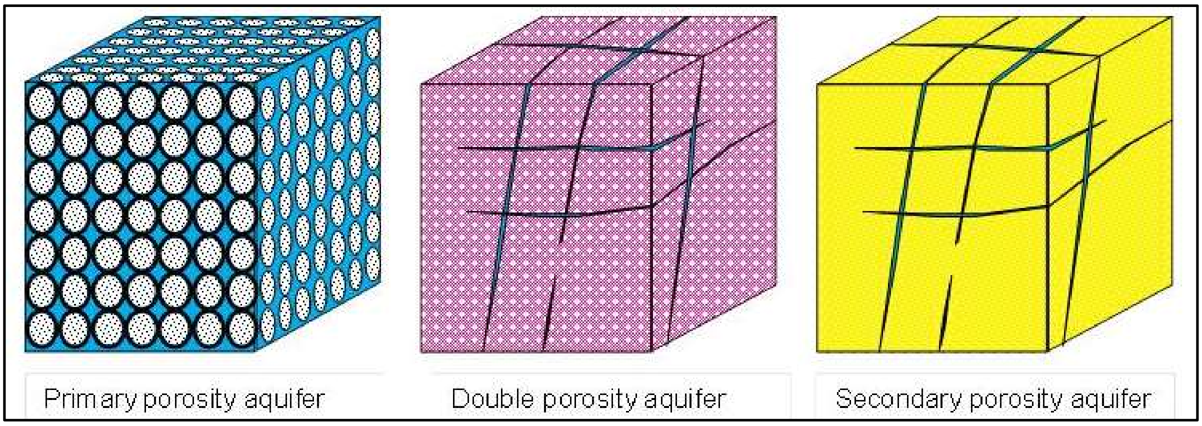


**Figure 26: Types of aquifers based on porosity**

**Table 16: Parsons Aquifer Classification *(Parsons, 1995)***

| | |
|---|---|
| **Sole Aquifer System** | An aquifer that is used to supply 50% or more of domestic water for a given area, and for which there is no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial. |
| **Major Aquifer System** | Highly permeable formation, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (less than 150 mS/m). |
| **Minor Aquifer System** | These can be fractured or potentially fractured rocks that do not have a primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large volumes of water, they are important both for local suppliers and in supplying base flow for rivers. |
| **Non-Aquifer System** | These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer unusable. However, groundwater flow |

| | |
|---|---|
| | through such rocks, although impermeable, does take place, and needs to be considered when assessing the risk associated with persistent pollutants. |
| **Special Aquifer System** | An aquifer designated as such by the Minister of Water Affairs, after due process. |

## 5.3 AQUIFER PROTECTION CLASSIFICATION

The combination of Aquifer Vulnerability Classification rating and Aquifer System management Classification provides a protection level referred to as Groundwater Quality Management Classification (GQM).

**Table 17: GQM = Aquifer System Management (ASM) x Aquifer Vulnerability (AV)**

| **ASM Classification** | | **AV Classification** | | **GQM** | | **Kellers-hoogte GQM** |
|---|---|---|---|---|---|---|
| **Class** | **Points** | **Class** | **Points** | **Index** | **Level of protection** | |
| Sole Source Aquifer System | 6 | High | 3 | <1 | Limited | |
| Major Aquifer System | 4 | | | 1 - 3 | Low | |
| Minor Aquifer System | 2 | Medium | 2 | 3 – 6 | Medium | 4 |
| Non-aquifer System | 0 | | | 6 – 10 | High | |
| Special Aquifer System | 0 - 6 | Low | 1 | >10 | Strictly non-degradation | |

The GQM for Kellershoogte to 4, which indicates a medium level of protection. Therefore, it is recommended that the monitoring system outlined in **Section 7** be in place for the proposed project.

# 6 CONCEPTUAL MODEL

A conceptual model is formed from the available data to better understand and analyse the area of study. The conceptual model also plays a key role in explaining the interactions between different boreholes. From all the geological information, other reports, pump tests and climate data available for the Kellershoogte area, the following model is formed:

- The geology is made up of many alternating layers of shale, siltstone, mudstone, sandstone, wacke and arenite.
- The study area where water supply boreholes are situated is located on the northern leg of a more-or-less east-to-west anticline that dips towards the north beneath the project area.
- The sandstone, wacke and arenite layers generally act as aquifers, yielding a serviceable amount of water.
- The shale, siltstone and mudstone layers act as aquicludes or groundwater barriers, that do not allow movement between upper and lower layers.
- Due to the dipping/sloping nature of the geology the groundwater recharge to the deeper aquifers does not take place around the borehole but to the south of the borehole where the aquifer outcrops.
- The level of confidence in the conceptual model and the abovementioned geological setting was increased by the fact that the production boreholes had a very limited influence on each other and no drawdown influence was measured on the accessible user boreholes further away from the Kellershoogte boreholes.
- Monitoring borehole KBH07 – specifically drilled as a borehole in the shallow aquifer to determine the interaction between the shallow and deep aquifer as well as the interaction between groundwater and surface water confirmed that:
    - There is no shallow aquifer – at least to a depth of 30 mbs - present in the study area;
    - There is no alluvial aquifer around the Kandelaars river in the study area: at the time of the site visit the shale bedrock was exposed in several areas among the alluvium as the run-off in the river has scoured the alluvium to expose the shale;
    - KBH07 was drilled on a terrace approximately 2 meters higher than the riverbed. The borehole only intersected 2 meters of sand before it drilled through shale for the remaining 28 meters until end-of-hole;
    - There is no base flow interaction between the groundwater and the Kandelaars River in the project area – the river acts as a losing stream and groundwater abstraction has no influence on the hydrology or fresh water ecology of the river.
- Shallower static groundwater levels such as those measured in KBH04 (at around 9 mbs) and the other shallow and deeper levels with high variance are simply piezometric pressure levels of the specific semi-confined fracture system intersected by each borehole.

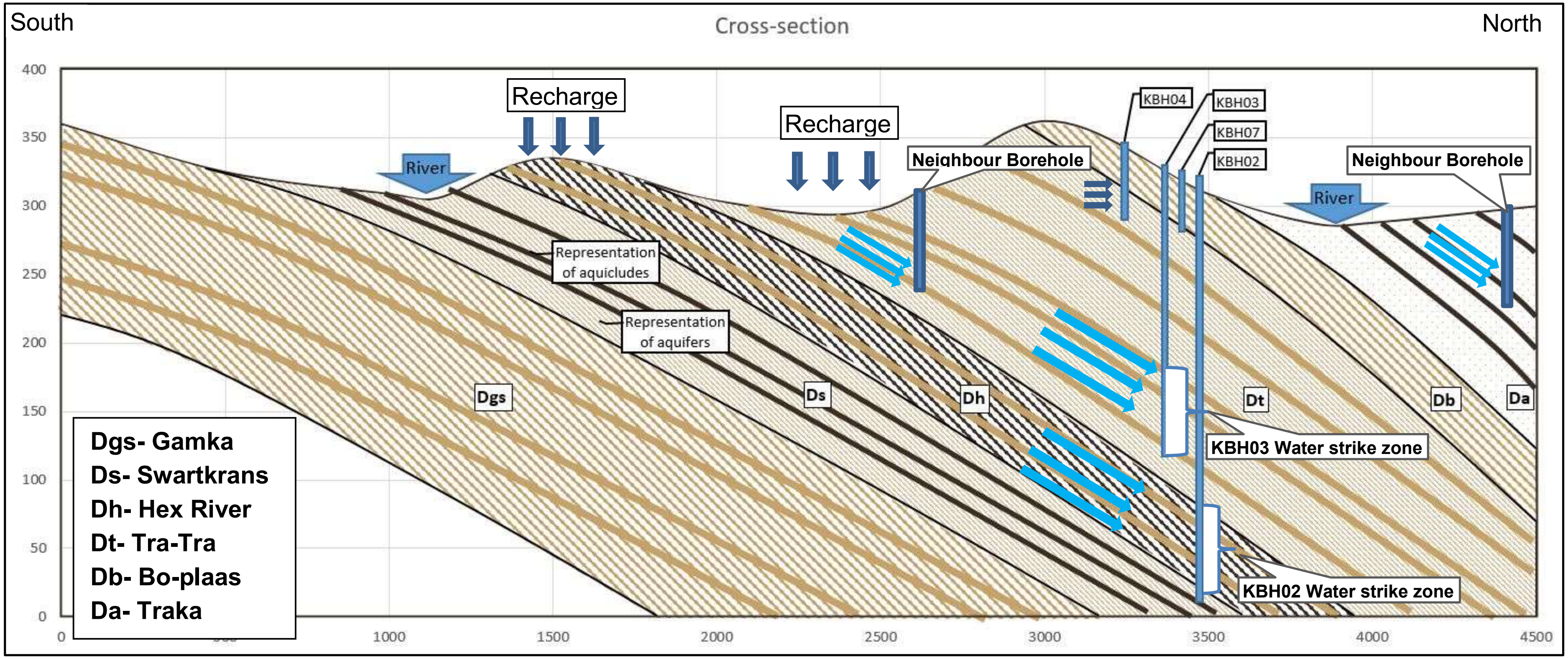


**Figure 27: Cross-section to explain geological and hydrogeological systems in the Kellershoogte area**

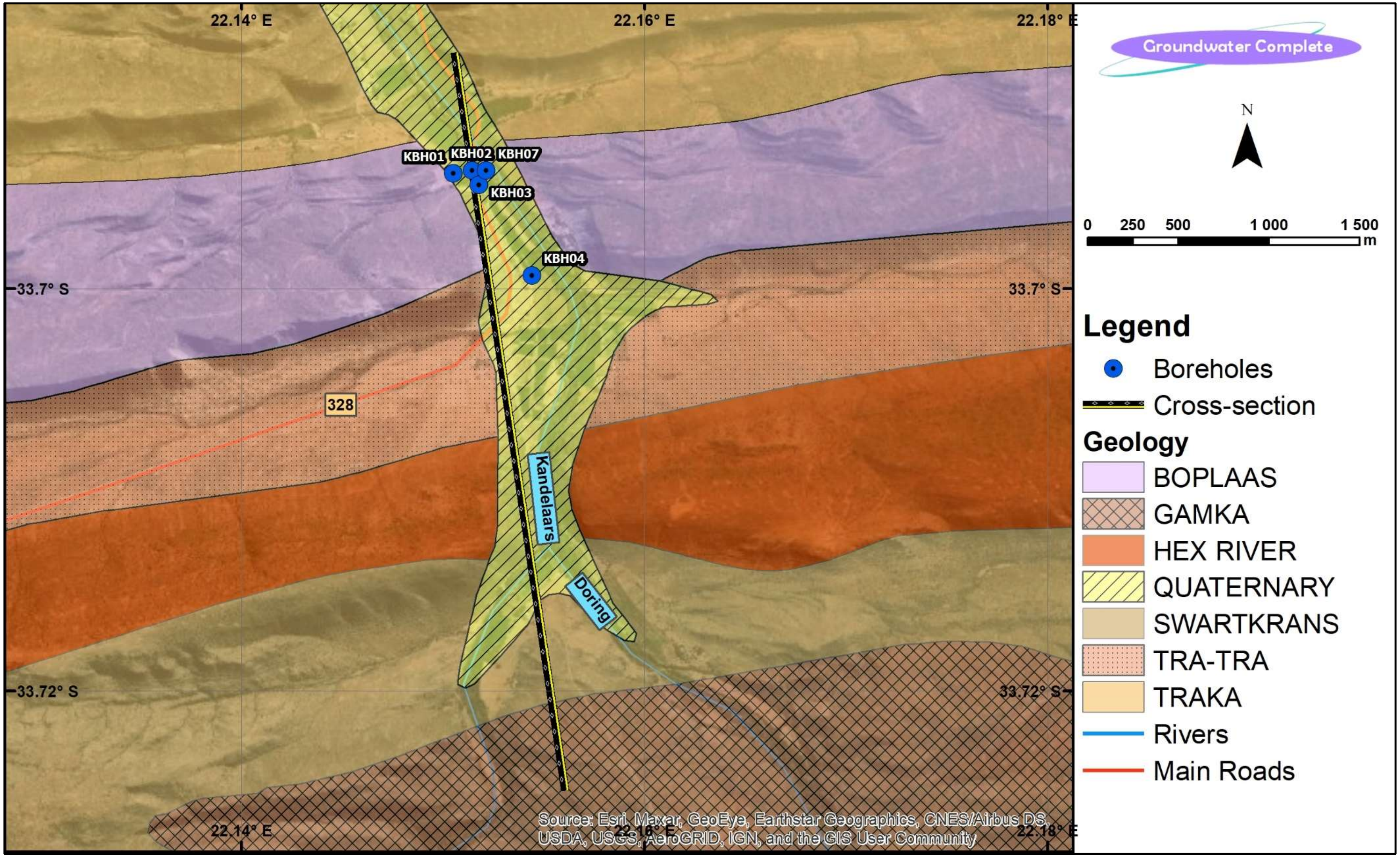


**Figure 28: Location of the Cross-section**

# 7 IMPACT ASSESSMENT

## 7.1 IMPACTS ON GROUNDWATER QUANTITY

Groundwater will regularly be extracted from the boreholes on Kellershoogte. The pumping tests provide a sustainable yield for the aquifer system. If the recommended sustainable yields per borehole are not exceeded the abstraction is not expected to have any significant immediate effects on groundwater availability of nearby groundwater users or lasting adverse impacts on the groundwater system.

The pumping tests have shown that after extensive pumping:

- The Kellershoogte boreholes have very little impact on each other.
- Nearly no interaction (water level response) could be measured between the shallow and the deeper aquifers in the Kellershoogte boreholes.
- There was even very little (a few centimetres) interaction between the two deep boreholes during the pump testing in the deep aquifer.
- No water level response was measured in the nearest neighbouring user borehole.

## 7.2 IMPACTS ON GROUNDWATER QUALITY

Kellershoogte will not discharge any waste/process water and thus will not alter the ambient quality of the groundwater. Thus, no adverse impact is foreseen on groundwater quality from Kellershoogtes's activities.

## 7.3 GROUNDWATER MANAGEMENT

The following guidelines can be followed to ensure that the aquifer is not overstressed or abused:

- Use groundwater only at the recommended sustainable yield as to not over-exploit the aquifer.
- When reservoir is full and the water is not being used, switch of pumps and let the boreholes recover.
- Follow diligent groundwater monitoring to confirm the long-term aquifer response and act on monitoring results if necessary.
- All pumps will be installed at 100m below the current static groundwater level. This will lessen the available drawdown and protect the integrity of the aquifers.

## 7.4 SUMMARY

Extensive pump testing showed that very limited – if any – impact is expected from the abstraction from the Kellershoogte boreholes on the groundwater availability of nearby lawful users. Although long-term abstraction will undoubtedly cause wider effects, the impact is expected to remain very limited given the distance from surrounding users and the poor interconnectivity of the aquifers.

# 8 GROUNDWATER MONITORING SYSTEM

The following recommendations regarding the monitoring of the WULA boreholes should be considered:

- Groundwater levels should be measured on a monthly basis to verify the results of the sustainable yield estimations. In doing so, timely adjustments can be made to the pumping rate and/or duration of a borehole that shows signs of an unacceptable decline in water level and its imminent failure (if any).
- The flow meters with which the boreholes have been equipped must be read at monthly intervals.
- The above data should be captured into an electronic database for easy access, interpretation and review.

Diligent monitoring and recording of data is especially important for future re-evaluation of data to determine if the recommended yields were under-estimations (after the severe drought) or over-estimations (due to limited fracture networks) and to then amend the report and yields based on long-term verified information.

# 9 CONCLUSIONS AND RECOMMENDATIONS

The geohydrological environment can be summarised as follows:

- The geology in the Kellershoogte area created a highly varying secondary, fractured rock aquifer system with multiple unconnected or poorly connected aquifers.
- The area is underlain by Cape Supergroup sedimentary rocks.
- The Cape Supergroup is known for deformation and creating the Cape Fold Belt mountain ranges. The deformation can also form high-yielding fractured aquifers.
- The static groundwater level depth varies greatly due to the poorly connected aquifers and ranges between 9 mbs and 50 mbs.
- Estimates with various methods of the effective aquifer recharge at Kellershoogte vary between 0.2-5% of the mean annual precipitation. Water level response during 2021 indicated a value closer to the high end, namely around 3% of rainfall.
- .

The baseline assessment, geology and aquifer test results led to the following conceptual model:

- The study area where water supply boreholes are situated is located on the northern leg of a more-or-less east-to-west anticline that dips towards the north beneath the project area.
- The sandstone, wacke and arenite layers generally act as aquifers, yielding a serviceable amount of water.
- The shale, siltstone and mudstone layers act as aquicludes or groundwater barriers, that do not allow movement between upper and lower layers.
- Due to the dipping/sloping nature of the geology the groundwater recharge to the deeper aquifers does not take place around the borehole but to the south of the borehole where the aquifer outcrops.
- Shallow static groundwater levels simply represent piezometric pressure levels of the specific semi-confined fracture system intersected by each borehole.
- Aquifer recharge to the deeper boreholes plays such a significant role in borehole yield that pump test results alone could not be used for the sustainable yield recommendation.

Conclusions and recommendations from the impact assessment are provided below:

If the recommended sustainable yields per borehole are not exceeded, the proposed groundwater abstraction is expected to neither have any significant immediate effects on groundwater availability of nearby groundwater users, nor would it have lasting adverse impacts on the groundwater system.

The pumping tests have shown that after extensive pumping:

- The Kellershoogte boreholes have very little water level impact on each other.
- Nearly no interaction (water level response) could be measured between the shallow and the deeper aquifers in the Kellershoogte boreholes.

- There was even very little (a few centimetres) interaction between the two deep boreholes during the pump testing in the deep aquifer.
- No water level response was measured in the nearest neighbouring user borehole.
- There is no shallow (primary or secondary) aquifer present in the study area;
- There is no alluvial aquifer present around the Kandelaars river in the study area.
- No base flow interaction occurs between the groundwater and the Kandelaars River in the project area – the river acts as a losing stream and groundwater abstraction has no influence on the hydrology or fresh water ecology of the river.
- At the end of an extreme drought the estimated sustainable yields of the two deep boreholes were less than 20% of the yield calculated after good rainfall occurred and the aquifer was adequately recharged.

Based on the DWS classification, the total sustainable yield (i.e. the applied-for volume) can be classified as Category C or large scale with respect to the property size and far exceeds the annual recharge on the property surface area. The applied-for use is, however, still supported on the basis that:

- unexploited groundwater will be used instead of over-stressed surface water resources in the area;
- the abstraction will mainly occur from deeper aquifers that are not currently used by any nearby user;
- extensive testing showed that other groundwater users will not be significantly affected; and
- the applied-for groundwater use represents a mere 2.3% of the exploitable groundwater potential in the catchment.

Results of pump test program at different times (at the end of the drought and after good rains) and sustainable yield estimation from the tests are summarised below:

| **Description** | **Pump testing during 2021 drought** | | | **Pump testing in 2022 after good rainfall** | | |
|---|---|---|---|---|---|---|
| Borehole | KBH02 | KBH03 | KBH04 | KBH02 | KBH03 | KBH04 |
| Sustainable Yield (l/h for 12 h/d) | 21600 | 17280 | 11520 | 144 000 | 151 000 | 11 520 |
| Yield ($m^3$/a) | 94 600 | 75 700 | 50 450 | 630 000 | 661 000 | 50 450 |
| **Total ($m^3$/a)** | **220 750 $m^3$/a** | | | **1 341 000$m^3$/a** | | |

The following conclusions were reached, and recommendations are made from these results:

- The aquifer parameters (transmissivities) and recommended sustainable yields at the end of the drought and after good rainfall using the same methodology, equipment and algorithms yielded results that differed by an order of magnitude.
- It is apparent that the availability of groundwater depends greatly on the climate conditions.
- The pump rates in the table below are thus put forward as sustainable yields considering all factors.

- It is however, suggested that the pumps be installed to provide an available drawdown of more-or-less 100m. This should limit the over stressing of the aquifer by providing a barrier to over pumping.

The final recommended sustainable yields of the different boreholes considering severe dry and above-normal wet conditions and maximum pump depth of 120 mbs are as follow:

| **Borehole** | **KBH02** | **KBH03** | **KBH04** |
|---|---|---|---|
| Sustainable Yield (l/h for 12 h/d) | 40 000 | 45 000 | 11 520 |
| Yield ($m^3/a$) | 175 200 | 197 100 | 50 450 |
| **Total ($m^3/a$)** | **422 750 $m^3/a$** | | |

# 10 REFERENCES

Bredenkamp D.B., Botha L.J., van Tonder G.J., van Rensburg H.J., 1995, *Manual on Quantative Estimation of Groundwater Recharge and Aquifer Storativity*, Water Research Commission.

DWA.gov.za/hydrology/verify

Fetter, C.W., 1994, *Applied Hydrogeology, 3rd Edition.*

South African National Standard for drinking water (SANS 241:2015) guidelines

SA Explorer, 2018.

Strumm, W. and Morgan, J.J., 1981. Aquatic Chemistry, First Edition.

v. Tonder & Xu, 2001. *Estimation of recharge using a revised CRD method.*

Vegter, JR, 1995. *An Explanation of a set of National Groundwater Maps.*