

REPORT

VAAL-GAMAGARA AUGMENTATION PROJECT - PHASE 2

Groundwater Basic Assessment Report and Resource Management Plan

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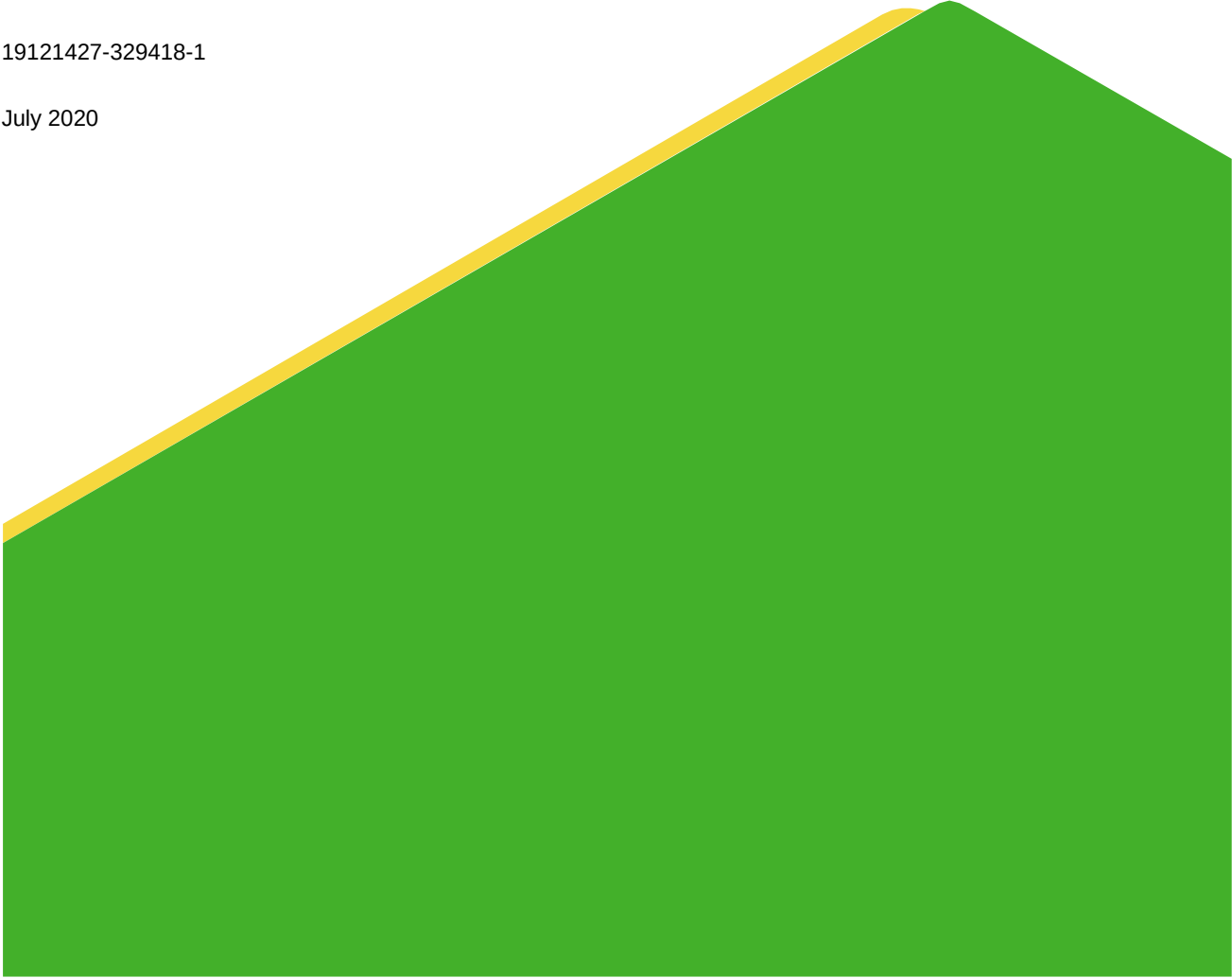
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APPENDICES**APPENDIX A**

SD1 Hydrocensus

APPENDIX B

SD1 Summarised Drilling Results

APPENDIX C

SD1 Summarised Test Pumping Programme

APPENDIX D

SD2 Summarised Hydrocensus Borehole Information

APPENDIX E

SD2 Summarised Drilling Results

APPENDIX F

SD2 Exploration Boreholes Pump Tested

APPENDIX G

Sinkhole Risk Assessment of Exploration Boreholes

APPENDIX H

Document Limitations

APPENDIX I

SD1 Static groundwater levels (2014 & 2019)

APPENDIX J

SD1 Predicted production borehole drawdown curves

APPENDIX K

SD1 Predicted monitoring borehole drawdown curve's

APPENDIX L

SD1- Predicted private borehole user drawdown curve's

APPENDIX M

SD2: Static groundwater levels (2019)

APPENDIX N

SD2: Predicted Wellfield borehole drawdown curve's

APPENDIX O

SD2: Private groundwater user drawdown curve's

1.0 INTRODUCTION

The Vaal Gamagara Water Supply Scheme (VGWSS) was completed in the late sixties with the purpose to supply Vaal River water to the arid areas of the Gamagara valley near Postmasburg and north thereof. This was done to enable large scale diamond mining at Lime Acres and the mining of iron ore and manganese at Beeshoek, Sishen, Mamatwan, Hotazel and Blackrock. Several local authorities receive water from the scheme of which the towns of Delporthoop, Postmasburg, Kathu and Hotazel are the largest.

Later the addition of the Kalahari East Board, a bulk consumer of the VGWS scheme, brought about further changes in water demand. The Kalahari East scheme was completed in 1992 to supply domestic and stock water to an area of approximately 1 412 000 ha that includes more than 250 farms.

The VGWS scheme consists of a purification works that can purify 13.27 million m³/a water, pumps, 11 reservoirs and 370 km of pipes that delivers water to users. The pipeline has the capacity to convey and import approximately 15 million m³/a into the D41J and D41K catchments. The 13.27 million m³/a water is augmented by dewatering activities of the Kolomela, Beeshoek and Sishen mines (to ensure safe mining conditions).

The current scheme is operating at capacity and is not able to supply the future water demand due to increased mining activities. The major driving force of the increased water demand is the iron ore and manganese mining operations. These mines of the Northern Cape produce 84% of South Africa's iron ore and 92% of the world's high-grade manganese deposits are in the Kalahari basin. Diamond and lime operations also contribute to the water demand but to a lesser degree.

Households in the area supplied by the VGWS scheme are anticipated to increase from 18 332 in 2010 to 31 367 in 2030 (71% increase) with a projected increase in population from 77 316 to 129 196 over the same period.

Secondary to the expected increased water demand are water supply interruptions that are amplified due to the aging infrastructure. The infrastructure, being more than 44 years old, is nearing its useful life.

Sedibeng Water and the Department of Water Affairs have initiated studies to assess the feasibility to augment and/or upgrade the Vaal Gamagara Water Supply (VGWS) scheme to meet increased water demands in the Northern Cape Province.

The Reconciliation Strategy and Water Master Plan study for Sedibeng Water's Vaal Gamagara Water Supply Scheme highlighted the potential for localized available groundwater resources to augment the bulk water supply scheme. Areas were identified as possessing enhanced groundwater development potential, these areas were designated Source Development Areas (SD's). Based on the resource potential of resource groupings and shortfalls in the VGG pipeline scheme, four groundwater source development areas (Figure 1) were identified: SD1 – Danielskuil, SD2 – Postmasburg, SD3 – Kathu and SD4 – Tsineng.

The pipeline feasibility study was completed in August 2011 and recommends the upgrade of the total VGWS scheme to supply the water demand of users for the planning horizon to 2030. The study indicated the current water demand of 13.7 million m³/a is to increase to approximately 40 million m³/a by the year 2030. It is projected that the mining sector will be the largest consumer; consuming approximately 63.5% of the water, whereas the local authorities and other water users will utilise 14.7% and 21.8% respectively by 2030.

Sedibeng Water has thus proposed the upgrading of the VGRWSS and appointed Proplan Engineering Consultants (Pty) Ltd (Proplan) to implement Phase II of the upgrade which consists of the following:

- Upgrading of the existing VGRWSS pipeline scheme, and
- Incorporate groundwater abstraction from Source Development Areas SD1 and SD2.

Proplan Engineering Consultants (Pty) Ltd appointed Golder Associates Africa (Pty) Ltd to render geohydrological technical inputs during the VGG Public Participation for the EIA and WULA Process.

The PP process relates to the planned exploitation of the groundwater resources for which landowners are against and have expressed concerns that their resources will be impacted on.

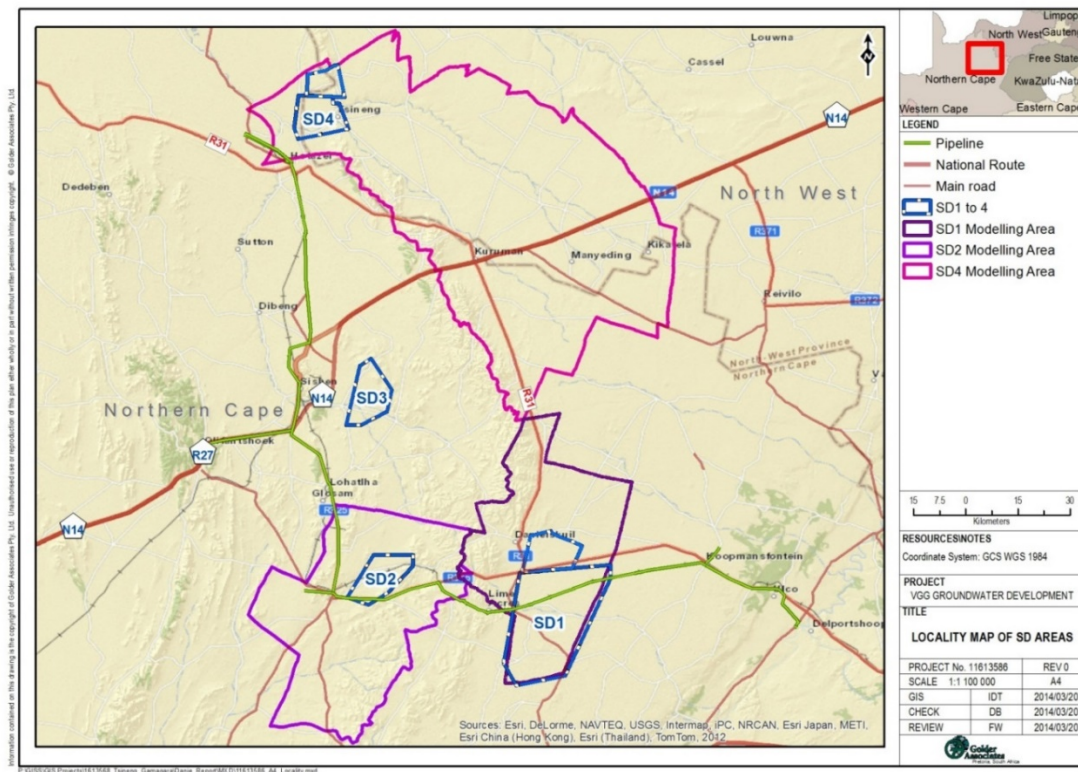


Figure 1: Locality Map of SD Areas

2.0 OVERVIEW OF SD1 AND SD2 HYDROGEOLOGICAL INVESTIGATIONS

2.1 Objectives and Scope of Work

The main objective of the groundwater feasibility study (2012 to 2014) was to:

- Determine whether there are sustainable groundwater resources to augment the existing VGG bulk water scheme and if confirmed develop the groundwater resources,
- Collect information of existing groundwater use, and
- Assess the exploitable supply potential of the identified source development areas to augment the anticipated 2030 water demand.

The following scope of work was followed:

- Detailed desktop study, including collation and updating of existing groundwater information,
 - Sourcing of current and historical water level monitoring data,
- Stake Holder Engagement process,
- Airborne geophysical surveys, which entailed high resolution airborne magnetic and advanced Time Domain Electromagnetic (TEM) surveys (SKYTEM – Denmark). The survey allowed for detailed mapping/delineation of:
 - geological structures with magnetic contrast – intrusive dykes, and

- high resolution mapping of resistivity changes in underlying geology/aquifers (accurate mapping from very near surface to depths of 200 to 250 metres),
- Extended ground geophysical surveys (using the gravity method) were conducted to optimize drilling targets in the dolomite and banded ironstone formations (BIF),
- Remote sensing and assessment of airborne geophysical data to identify:
 - areas of potentially enhanced groundwater occurrence, and
 - delineate intrusive dykes within the dolomite aquifer that may act as compartment/aquifer boundaries,
- Hydrocensus – identify existing boreholes and verification of existing groundwater use and selective water sampling to characterized quality of existing groundwater sources,
- Test pumping of existing boreholes consisting of Step Draw-down Tests (SDT) and 1 to 24hour Constant Discharge Test (CDT),
- Drilling of exploration boreholes using air percussion drilling method according to, but not limited to DWA minimum standards and requirements,
- Groundwater sampling on newly drilled exploration boreholes to confirm potable groundwater quality,
- Borehole and aquifer test pumping on newly drilled exploration boreholes:
 - Short term test pumping (SDT and 24 to 48hour CDT) to assess borehole yield capacity and aquifer sustainability
 - Long term test pumping (72hours CDT) to confirm aquifer sustainability and obtain aquifer hydraulic parameters for numerical modelling.
- Groundwater Resource Assessment
 - Groundwater use (boreholes and fountains)
 - Groundwater piezometric levels and groundwater flow
 - Identification of compartment boundaries and groundwater management units
 - Aquifer recharge estimates- using the Chloride Ratio Method,
 - Existing groundwater reserve assessment
 - Groundwater quality
 - Hydrogeological conceptualizing (hydrogeological cross sections)
- Develop 3D numerical groundwater model at quaternary catchment level:
 - Software code used for the numerical finite-element modelling was SPRING,
 - Model construction (domain, model layers, sources and sinks),
 - Model calibration (steady state and transient),
 - Determine water balance of model domain,
 - Predictive simulations of the numerical model to calculate the impact of the proposed well-field abstraction on:
 - groundwater flow,
 - aquifer recharge (apply rainfall variability) and discharge,

- lowering of the water table:
 - at production and identified long term monitoring boreholes,
 - at existing users (private boreholes) located within the long term predicted area of impact
 - change in aquifer storage
 - reduction in flows across outflow boundaries (downstream catchments) and groundwater contribution to drainages and pans
- Scenario modelling to ensure long term sustainability considering variable recharge and limit depth of water level drawdowns (8 to 10m) to mitigate risk of sinkhole formation
- Develop recommendations to address any shortcomings and data knowledge gaps that need to be addressed in order to:
 - improve on the future calibration of the groundwater model,
 - verify the long-term predictions made in terms of groundwater flow
- Delineate aquifer protection zones according to best national practice as outlined by DWS,
- Compile detailed management recommendations for production boreholes designed to ensure long term sustainability (limit risk of over abstraction by pump operators),
- Propose groundwater monitoring programme,
- Compile study report.

2.2 Review of SD1 Hydrogeological Assessment Study (2014)

2.2.1 SD1 Description of Study Area

2.2.1.1 Location

SD1 investigation area falls under the jurisdiction of Kgatelopele Local Municipality (LM), of the Siyanda District and located in the North Cape Province. The study area is approximately 145km north-west of Kimberley and 80km south of Kuruman.

The SD1 initial investigation area was extended north towards Danielskuil as indicated on Figure 2, in order to obtain more hydrogeological background information and maximize the exploitable potential of a major karstification zone.

SD1 groundwater modelling area includes portions of the C92A, C92C, C92B and C33C quaternary catchment areas, with the size of the modelling area at 1826km².

2.2.1.2 Topography

The SD1 investigation area is bounded to the west by a broken mountain ridge, namely the Asbestos Mountains. This mountain range forms the eastern margin of a regional north- south irregular highland, which resulted from positive erosion of resistant siliceous rock formations and regional tectonic events. Elevations range from 1750mamsl at the highlands to 1430mamsl at the south-east of the investigation area. The irregularities on the escarpment are caused mostly by extensive mechanical erosion of various geological structures, running from the Asbestos Mountains towards the Ghaap Plateau (Van Wyk, 1986).

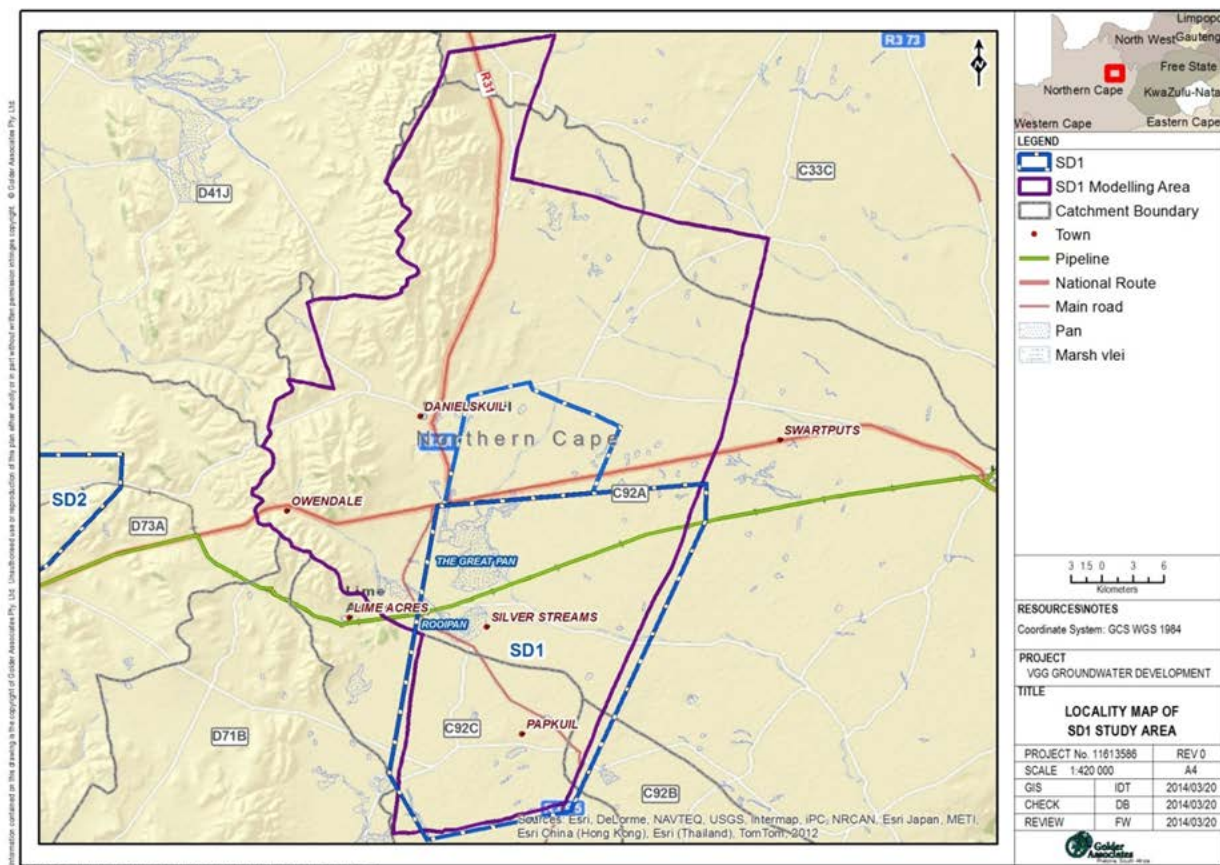


Figure 2: Locality Map of SD1 Study Area

The topography gradually declines towards the east through a definite but irregular escarpment. Three prominent depressions/pans namely the Danielskuil, Great and Rooipan are situated at the foot of the escarpment. These depressions are in the order of 5 to 10m lower than the surrounding area. Towards the east of the escarpment lies the featureless Ghaap Plateau, a virtually flat area at an elevation of approximately 1500mamsl. In its natural state the area is relatively featureless with calcrete ridges that form over dykes. The ridges vary in height from less than one metre to several metres, depending on the width and extent of dolerite dyke intrusions

2.2.1.3 Surface Drainage

The main surface drainage arteries from the plateau are the Vaal River in the south-east. Surface runoff from the escarpment towards the plateau is mainly restricted to a system of linear depressions resulting from leaching process of the carbonate rocks (Van Wyk, 1986).

There are no major drainage systems from the local pans (Danielskuil, Great and Rooipan) towards the Vaal River. It is likely that these pans form a series of interior drainage basins which overflow occasionally during extremely high rainfall seasons, like during 1974 to 1976 period. The major surface runoff is diverted by the drainage basins and eroded geological structures along the piedmont, to a subsurface system. This explanation is in line with the fact that Danielskuil was flooded in 1974 by groundwater and not surface water (Van Wyk, 1986).

No perennial rivers exist and run-off accumulation in surface depressions can persist for several weeks until water has evaporated or infiltrated into the ground. The Steenbok river and Kleinriet river represent non perennial surface drainage towards the east.

2.2.1.4 Vegetation

The Ghaap Plateau vegetation belongs mainly to the Vryburg Shrub Bushveld, a subdivision of the Khalahari Thornveld. This veld type occurs on rocky soil and hard rock formation and shows minor variations from north to south (Van Wyk, 1986).

The Vryburg Shrub Bushveld is again sub divided into four types of which the Tarchonanthus Veld of the Ghaap Plateau is found in the study area. Mostly this veld type is fairly dense Bushveld, compose of shrubs and scattered small trees. In the presence of topsoil the area is covered with grass.

In the southern part of the study area, covered with surface limestone trees of the species, *Olea Africana* (“Olienhoutboom”) (Figure 3), *Boscia Albitrunca* and *Acaia Karoo* is well presented in the study area.



Figure 3: *Olea Africana* - “Olienhoutboom”

A large *Olea Africana* (“Olienhoutboom”) forest is found on the farms Rooipan 507 and Carter Block 485. These trees have an average height of 18m, with a shallow root system (Figure 4). It is a hardened tree type, which needs little water and adjusts well in dry areas. These trees roots are well above the water table and their influence on the groundwater level can therefore be neglected (Van Wyk, 1986).

Towards Danielskuil the surface limestone cover and some of the larger trees disappear. This area is mainly covered with ordinary savannah type grassland, with *Themada Triandra* and *Cymbopogon Plurinodis* types dominate.

The most common shrubs found on the escarpment are the *Acaia Mellifera* subspecies *Detinens* and the *Rhus Ciliata*. These species however result from over grazing and is subsequent an invasion of the Karoo vegetation (Van Wyk, 1986).



Figure 4: Olea Africana – “Olienhoutboom” – Shallow Root System

2.2.1.5 Climate and Rainfall

The climate of SD1 is typical continental with large seasonal and diurnal variations in temperature. The mean maximum temp range between 24° C and 37° C, with the mean minimum temperature range varies between -4° C and 11° C. Maximum temperatures are experienced in January and minimum temperatures usually occur in July (Van Wyk, 1986).

The climate of the subcontinent is controlled by a low-pressure system, during the hot summer months, allowing moist air to flow from the Indian Ocean toward the interior land. In the Northern Cape the movement of air masses is characterised by a dry north to north-easterly wind with a low precipitation rate.

The area is semi-arid with the annual evaporation nearly five times the annual precipitation. The Average evaporation range between 2000 and 2100mm per year. Prevailing wind directions is north-west to west during the dry and dusty July to October period (Van Wyk, 1986).

The SD1 study area lies in a summer rainfall region, with an irregular rainfall pattern and occurs mostly in the form of thunderstorms during January, February and March when moist tropical air from the north reach the area due to frontal systems.

The annual precipitation is erratic with wet and dry cycles evident. An extreme wet cycle that peaked 1974 to 1976 (3 years) was followed by a dry cycle from 1978 to 1987 (9 years). This was followed by a wet cycle 1988 to 1991 (4 years) with an extreme dry year in 1992 with a dry period lasting till 1998 (6 years). From 1999 to 2002 (3 years) above average precipitation prevailed. From 2002 below average precipitation indicate a dry cycle.

The average rainfall for the SD1 area is portrayed by rainfall stations Danielskuil and Wonderwerk. The average monthly rainfall for Danielskuil rainfall station for the period 1952 to 2012 is indicated in Figure 5, with the MAP for the period as 346mm. The average monthly rainfall for Wonderwerk rainfall station for the period 1951 to 2012 is indicated in Figure 6. The MAP for the Wonderwerk rainfall station for the period is 448mm.

The amount of annual rainfall and rainfall intensity (monthly rainfall) are the major driving forces of groundwater recharge, and both stations are used in estimating groundwater recharge.

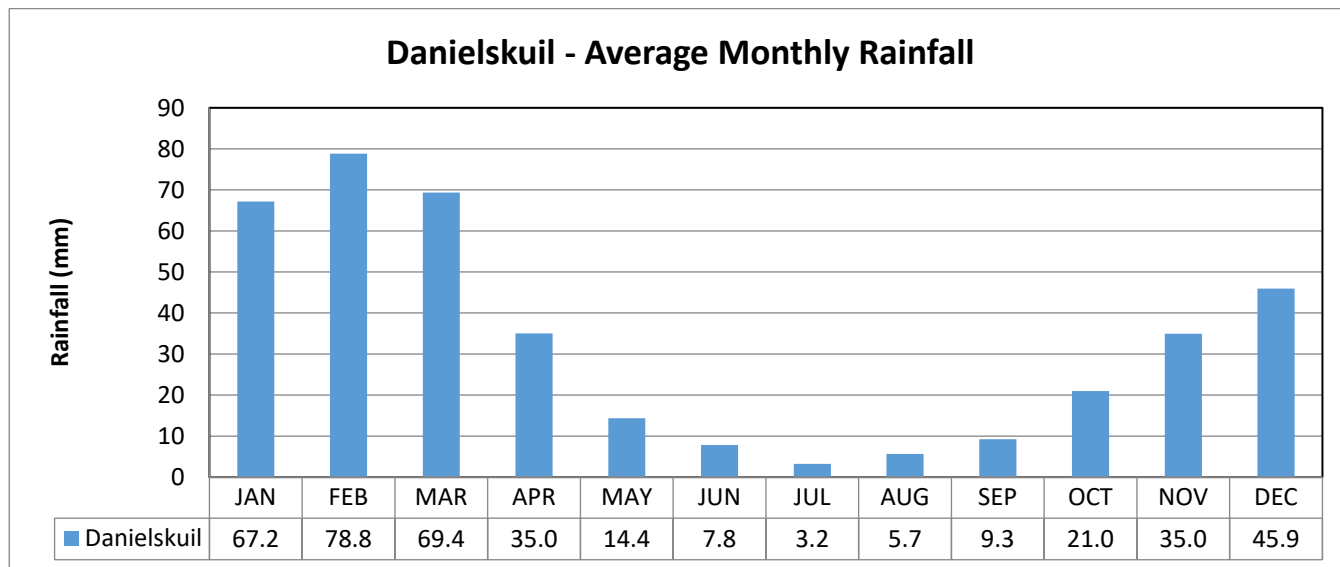


Figure 5: Danielskuil Average Monthly Rainfall

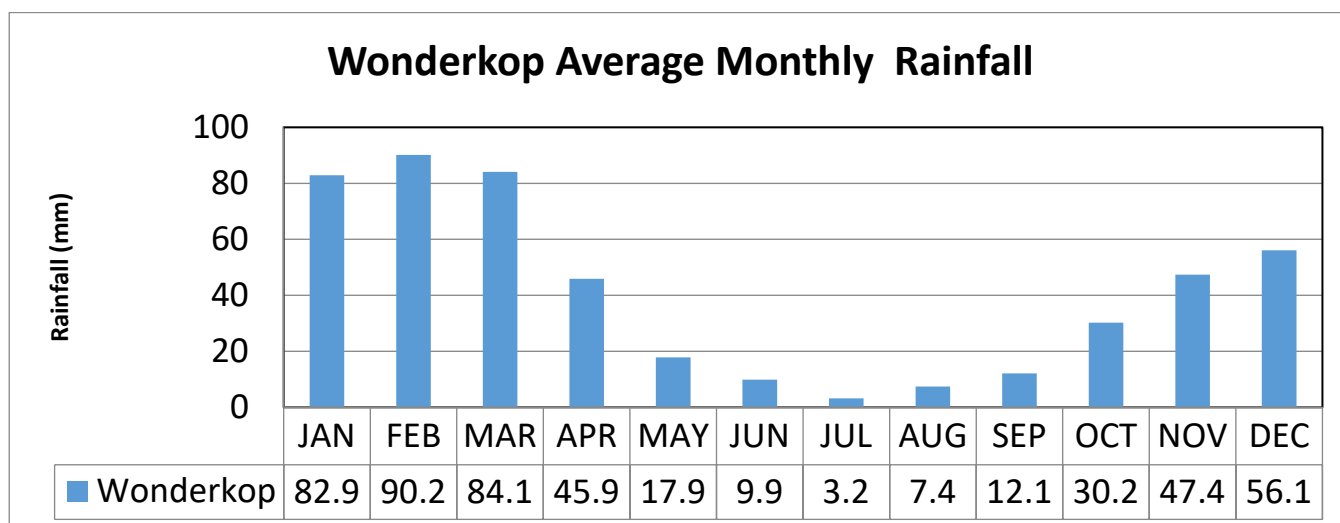


Figure 6: Wonderwerk Average Monthly Rainfall

2.2.1.6 Local Geology

SD1 fall onto the Council of Geoscience 1:250 000 scale Postmasburg geology map (2822 Map Reference) and is shown in Figure 7. The surface bedrock geology of SD 1 consists mainly out of dolomite of the Ghaap Plateau formation in the Campbell Group and Banded Ironstone Formation (BIF) of the Asbestos Hills Subgroup in the Griqualand Group.

The Campbell Rand Subgroup manifests itself in the Maremane Dome or anticline and consists of alternating layers of oolitic and stromatolitic dolomite with thin interbedded layers of shale and quartzite. The oolites are largely chertified. The shale becomes more prominent higher up in the succession with the result that the middle member consists mainly of ferruginous shale with siltstone and interbedded thin dolomite. The upper layer consists mainly of calcitic dolomite with few stromatolites and thin interbedded shale and siltstone

The Koegas and Asbestos hills Subgroups lie conformably on the Campbell Rand Subgroup. The subgroups contain the Kuruman and Danielskuil marker formations which are also magnetic markers. The uppermost

chert grades into banded iron stone of the Kuruman Formation which varies in thickness from 180 to 240m. It consists of a succession of thin alternating layers of light-colored chert and jasper and dark-colored ferruginous jaspilite. The Danielskuil Formation has an undulating structure and consists of brown jaspilite with thin magnetite layers and lenticular breccias and chert nodules. The overlying jaspilite attains a thickness of 150m and several marker layers.

Kalahari and Quaternary Deposits

The bedrock geology in the study area is partially concealed by semi consolidated sediments of the Kalahari group and Quaternary deposits. The Kalahari formation consists primarily of calcrete, gravel and clay beds.

Limestone or calcrete varies in thickness from a few mm to several metres covers most of the south eastern part of the study area. Relatively thick deposits of calcrete occur as cappings of the dolerite rocks and normally causes a higher relief due to the expansion mechanism present in the calcification process. These ridges of calcrete are easily distinguishable on satellite imagery and in the field.

Intrusive Structures

Intrusive dolerite dykes are a common feature in the study area but seldom outcrops. Dolerite dykes are usually observed as major linear structures and intersect the geological formations perpendicular. These dykes are subjective to both positive and negative weathering, depending on the specific hydrological environment.

Chemical weathering is responsible for the deposition of secondary calcite on top of the dykes, with the intensive materializing of clayey decomposed dolerite at depth. These dykes naturally appear as ridges with depressions formed by the solution of the country rocks within the contact zone alongside the dykes. Most of the surface water drainage channels are restricted to these features.

These dolerite dykes (mainly magnetic with some low to non-magnetic) generally intruded fault zones, are mostly impervious and compartmentalize the dolomite aquifer. Increased borehole yields are often associated with contact zones of dykes and faults.

2.2.1.7 Groundwater Occurrence

Groundwater resources occur throughout the study area. The major aquifers identified in the different geological formations comprise of:

- Kalahari Sediments - intergranular unconfined aquifer system - Sandstone, Gravel & Calcrete, with low permeability retards and restrict water movement and acts as storage unit,
- Banded Ironstone Formation (BIF) - weathered and fractured semi-confined aquifer system, and
- Dolomite karst aquifers - unconfined to semi confined aquifer system, compartmentalised by dolerite dykes.

The intergranular aquifers are presented by the upper (Eden Formation) as well as basal sand and gravel beds (Wessel Formation) of the Kalahari sediments. These aquifers are characterised by borehole yields generally less than 2 l/s, but with the ability to store large volumes of water. They are separated by the red clays of the Budin Formation acting as a confining layer. The basal sand and gravel formation and underlying bedrock can be regarded as one aquifer.

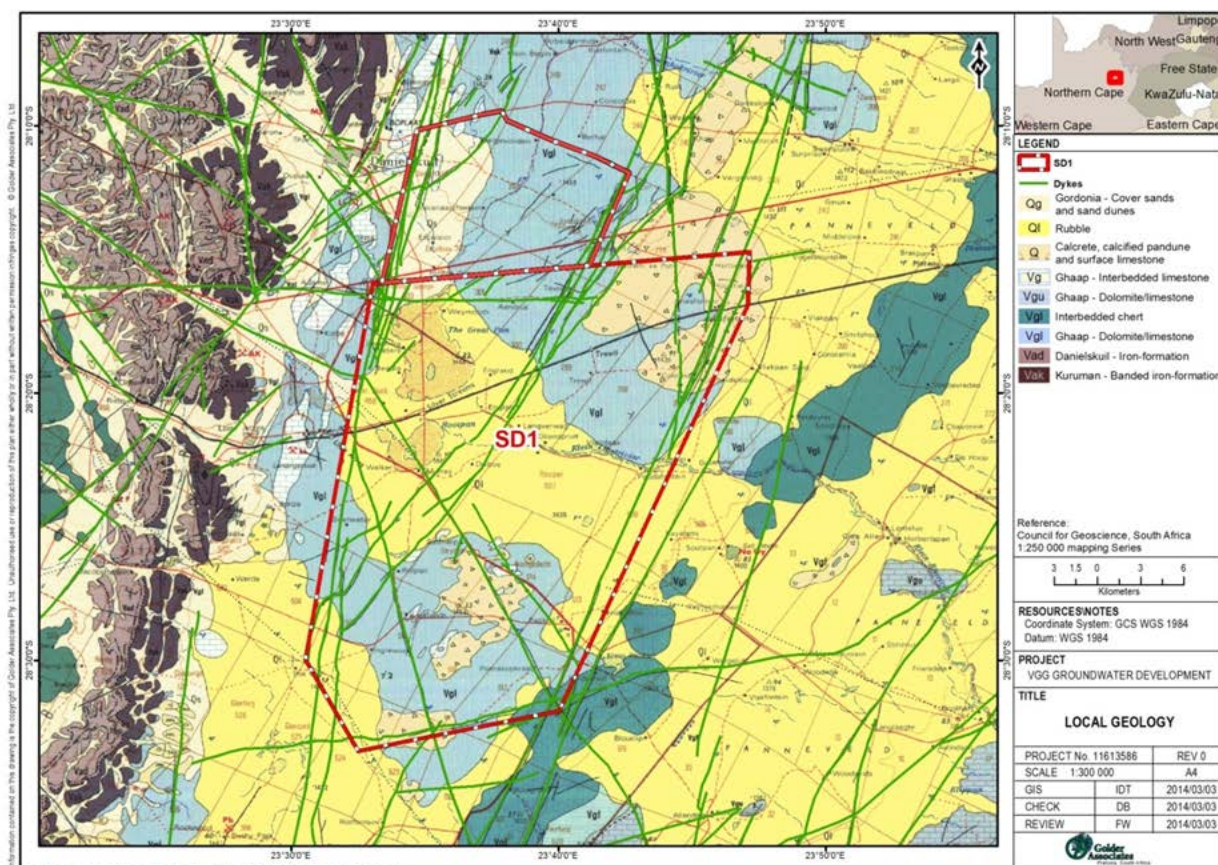


Figure 7: Local Geology

The BIF and karst aquifers associated with the Ghaap Plateau dolomite formations are quite productive and support borehole yields > 40 l/s, in use at Kuruman, Sishen, Kathu, and Beeshoek. Delineation of dykes that may compartmentalize dolomite aquifers and identification of leached dolomite is critical to:

- ensure sustainable use,
- reliably quantify resource potential.

2.2.2 SD1 Geophysical Survey

The geophysical survey at SD1 comprised of:

- A high resolution airborne magnetic survey (at 50m flight-line spacing and flight-height of 30m) was flown to allow detail mapping of intrusive dykes of the main groundwater exploration target area. The airborne magnetic survey included detail digital elevation and radiometric data along flight-lines.
- The magnetic survey identified a paleo-channel and it was decided to investigate this feature with targeted SkyTEM (TDEM) survey of selected flight-lines to obtain resistivity data at depth (from 2 to over 250m deep),
- Extended ground gravity surveys were conducted at 50 and 100m station intervals, along access routes and over selected geological targets as identified from the air borne geophysical survey.

The position of survey flight-lines for the extensive magnetic survey at SD1 is indicated on Figure 8.

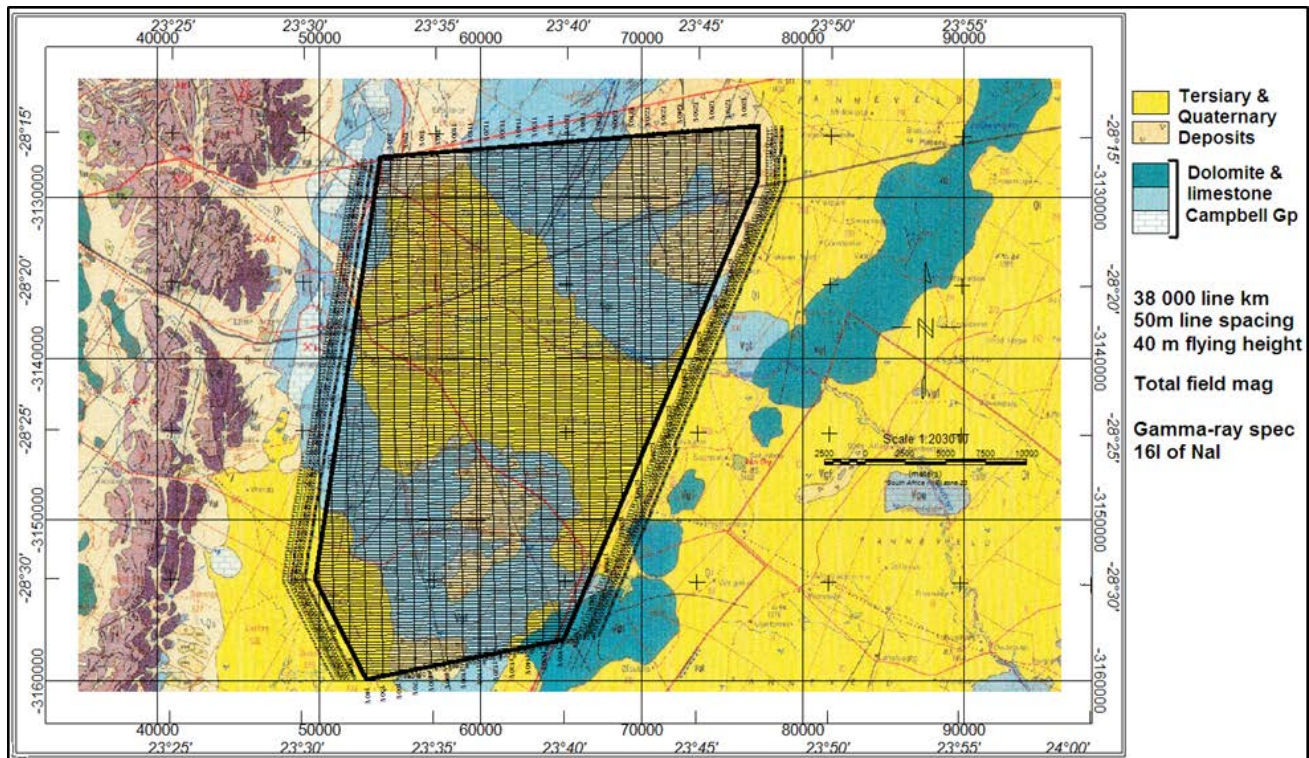


Figure 8: SD1 Airborne Survey Flight Lines

2.2.2.1 Digital Elevation Data

The topography was determined from subtracting the Laser height (altimeter) from the on-board GPS elevation, as is shown in Figure 9 .

The elevations over the Campbell Rand Subgroup dolomite are fairly flat, and of interest is the drainage pattern. There are 2 pans in the north western part of the map:

- the more northern one is fed from a stream entering on the northern apex of the pan and water drains again from the southeastern corner.

The second more southern pan is fed from a stream entering it from the NW and this stream drains the iron rich Kuruman and Danielskuil Formations to the west. This second pan has no visible exit on the topography, but water probably leaves it via underground passages in the dolomite.

2.2.2.2 Aeromagnetic data

The total magnetic field for SD1 is shown in Figure 10 as an artificially sun shaded color image and the warm colors indicate the magnetic highs. Increases in the magnetic field strength or 'magnetic highs' are portrayed as ridges or hills colored in a (warm), reddish hue and decreases in the field strength appear as valleys or troughs and are colored in a (cold) bluish hue.

Spectacular and most obvious is the broad broken-up pattern of magnetic highs (purple-red) and that start in the NW and WNW corner of the map, meet in the center of the map on a slightly curved NNE striking lineament (magnetic dyke) and then continuing to the ESE where it is slightly displaced by a NNE trending dyke before continuing to the ESE. This feature is due to a paleo-river filled with remnants of Kuruman and Danielskuil magnetic rock material.

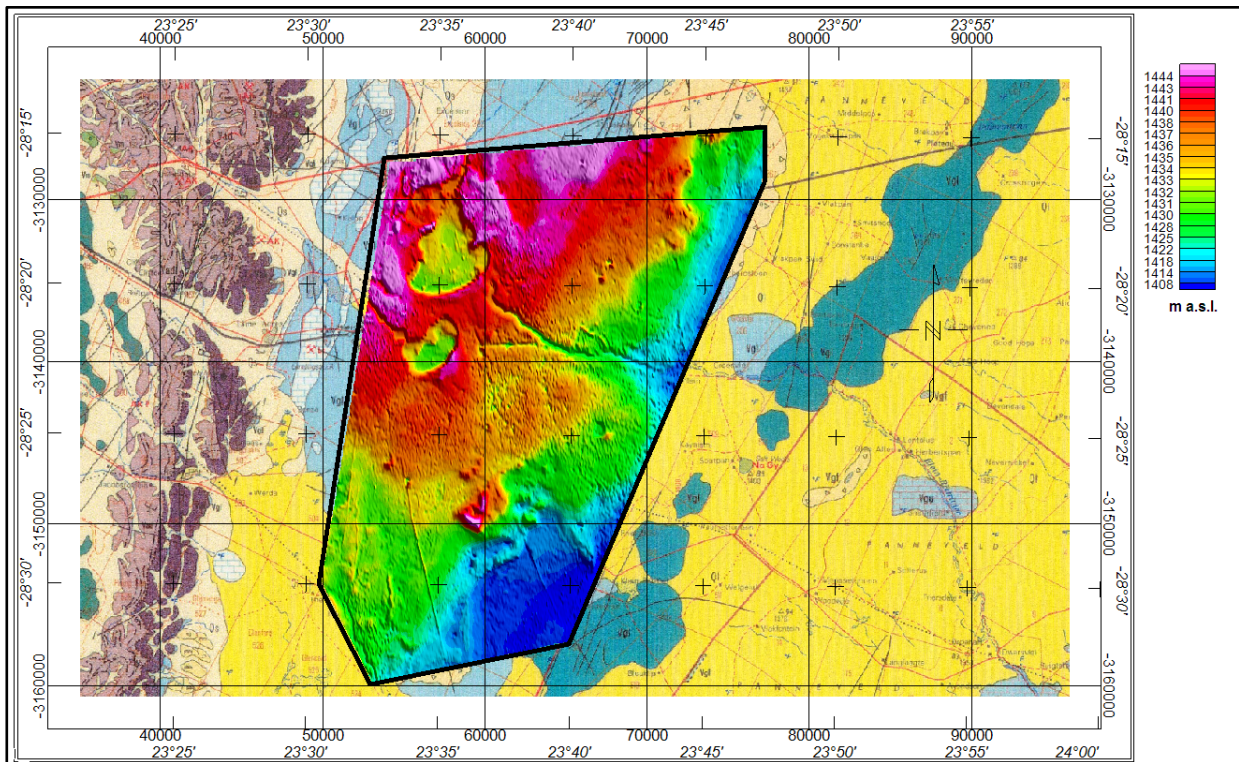


Figure 9: SD1 Digital Elevation Model

Several dykes occur and are defined by their magnetic anomaly highs. A sill is also visible in the SW corner of the map where it is connected to a dyke and forms a slightly oblate pattern connected to the dyke.

To highlight all possible features and lineaments a ternary color image is produced by using the Cyan, Magenta, Yellow (CMY) color scheme to combine the Analytical Signal, the $\partial M/\partial h$ derivative and the tilt-angle in one diagram as shown in Figure 11.

The ternary image shows the disturbed linear pattern caused by the Sishen-Saldanah railway line and the broader green mottled pattern coinciding with the two pans indicating them to be filled with alluvial magnetic sediments from the Kuruman and Danielskuil magnetic rocks. The many dykes with mostly NNE strike are also visible and a third drainage pattern flowing into the more southern pan can also be seen.

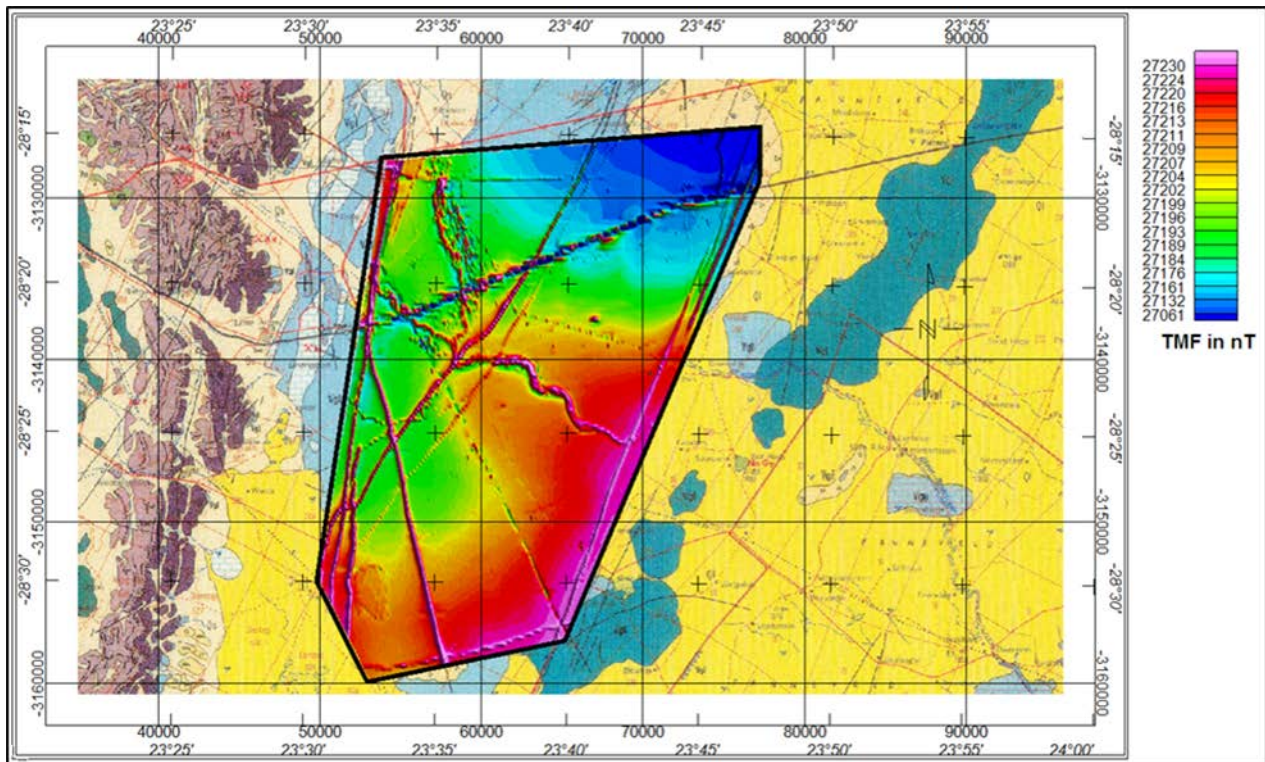


Figure 10: SD1 Total Magnetic Field

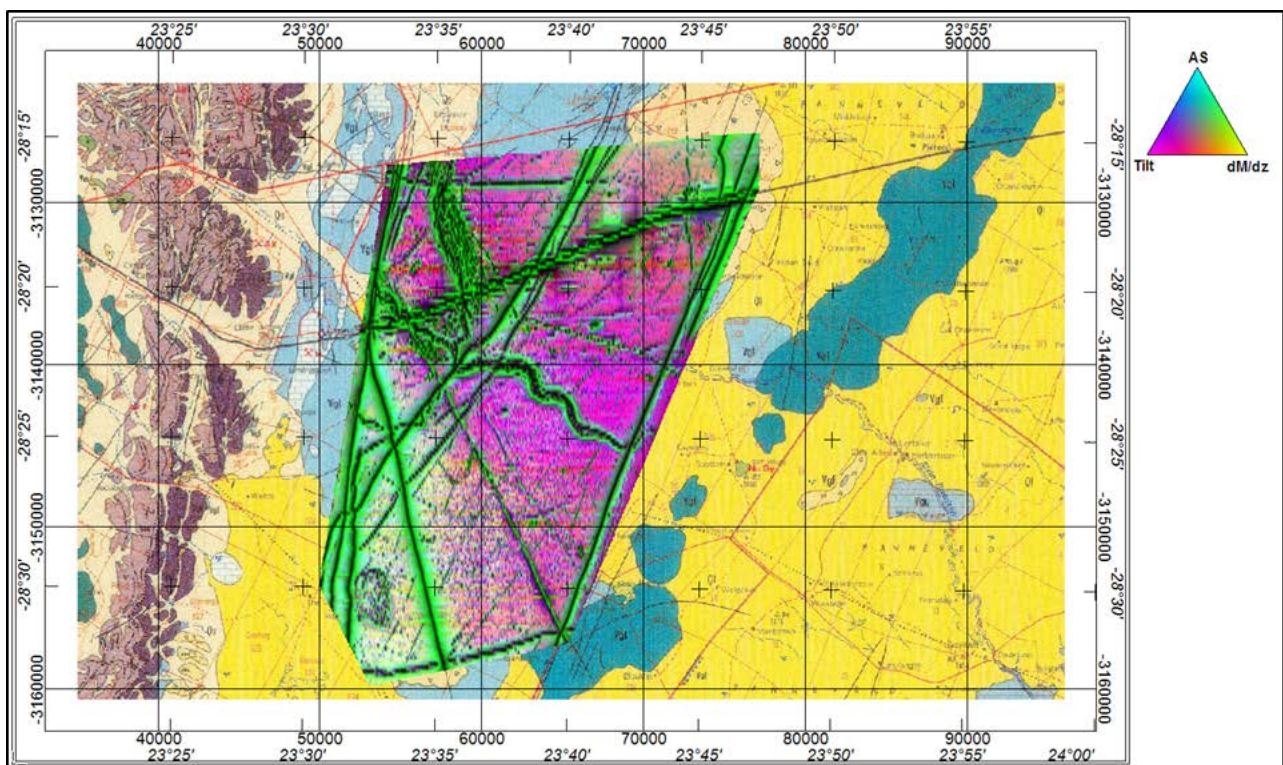


Figure 11: Ternary Plot of the Magnetic Data combining Analytical Signal, $\Delta M/\Delta h$ and Tilt Angle

Figure 12 gives a qualitative interpretation of the data, indicating fences, railway line, paleo-drainage channel, several dykes and one sill.

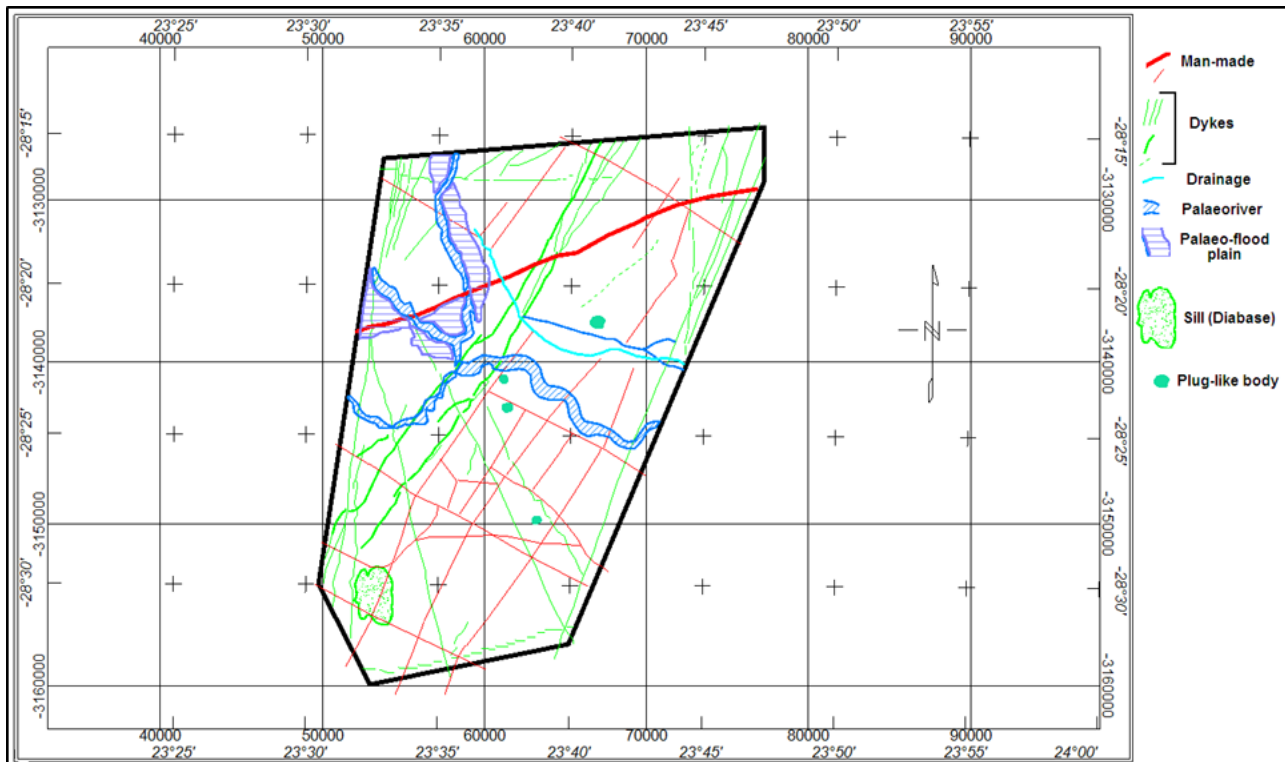


Figure 12: A Qualitative Interpretation of the Magnetic Data Set

2.2.2.3 Airborne Time Domain Electromagnetic Data

The transmitter coil has a high and low moment and data were provided for both moments as just the signal strength measured in the receiver coil or converted into an apparent resistivity as a function of time channels which were converted into an approximate depth below surface.

The survey area flown with the SkyTEM system is shown in Figure 13 and lines were flown both N-S and E-W with a line spacing of 300m in the central part of SD1 to sample all possible directions. A few additional lines at 1km line spacing were also flown to provide a wider coverage.

Numerous plots can be generated to show how the electrical resistivity changes as a function of depth and position. The Time Domain Electromagnetic (TDEM) result thus gives us a good indication of the internal make-up of the paleo-river sediments and the depth extent.

For example, the resistivity distribution near surface between 10 and 15 m below surface, the paleo-river does not show up clearly and this is probably due to the highly calcretized river sediments present near surface. In contrast Figure 13 clearly shows the paleo-river at a depth between 50 and 60m indicating permeable material whereas at the depth interval of 98 to 110 m the paleo-river disappeared. The TDEM results thus gives us a good indication of the internal make-up of the paleo-river sediments and the depth extent shows the paleo-river clearly at a depth between 50 and 50m indicating permeable material

Most dykes are slight conductors at surface, but all turn into electrical resistors at depth and are not clearly seen. Other conductors apart from the paleo-rivers, are present and are probably due to graphitic / carbonaceous films in the dolomite.

2.2.2.4 Ground Geophysics - Gravity Survey

The gravity method measures the gravitational field of the earth at different location over an area of interest, to associate variations in the gravitational field with differences in the distribution of densities of the formation. Such density variations in dolomite terrain are produced by varying thicknesses of unconsolidated

deposits over bedrock, and solution cavities in bedrock. The method is effectively applied for locating zones of karstification and infilling by residual debris in dolomite strata.

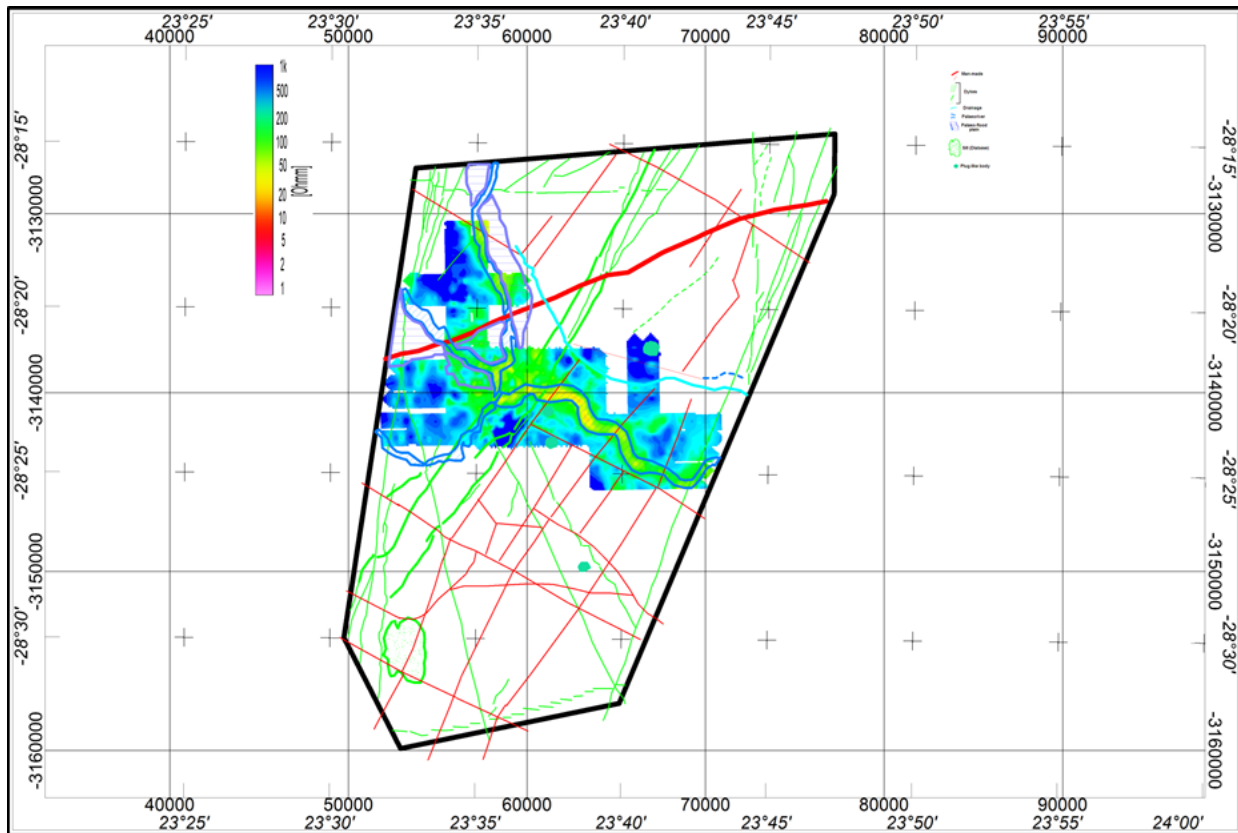


Figure 13: Resistivity Distribution at a Depth interval between 50 and 60m below Surface

The survey was conducted along easily accessible fences, tracks and roads as indicated by the fine dotted lines shown in Figure 14. The residual gravity map shows some deep gravity lows, indicating likely leached out water-filled cavernous zones in the dolomite. The magnetic dykes and lineaments do not correlate clearly with any of the residual gravity anomalies, but the residual gravity lows correlate very well with the paleo-river courses.

The advantage of the gravity data is that it indicates possible leached, permeable water-bearing zones and the central gravity lows (blue color) represent fill-in of an old karst area in the dolomite which were exploited by the paleo-rivers. The present-day drainage from the northern pan to the eastern boundary of the SD1 survey area follows the gravity low structure.

Exploration drill sites were mainly selected on the residual gravity data. Drilling sites were selected to investigate geological structure and lithology, determine aquifer characteristics, obtain groundwater levels, determine groundwater flow directions, and to establish potential production and monitoring boreholes.

2.2.3 SD1 Hydrogeological Investigation

2.2.3.1 Desk Study

The following information was reviewed during desk study:

- 1:250 000 geological map series, 1:8 500 000 Groundwater Harvest Potential map of RSA (DWA 1995);
- 1:2 500 000 Groundwater Resources map of RSA – Sheet 1 (WRC.DWA 1995),
- 1:4 000 000 Groundwater Resources map of RSA – Sheet 2 (WRC.DWA 1995),

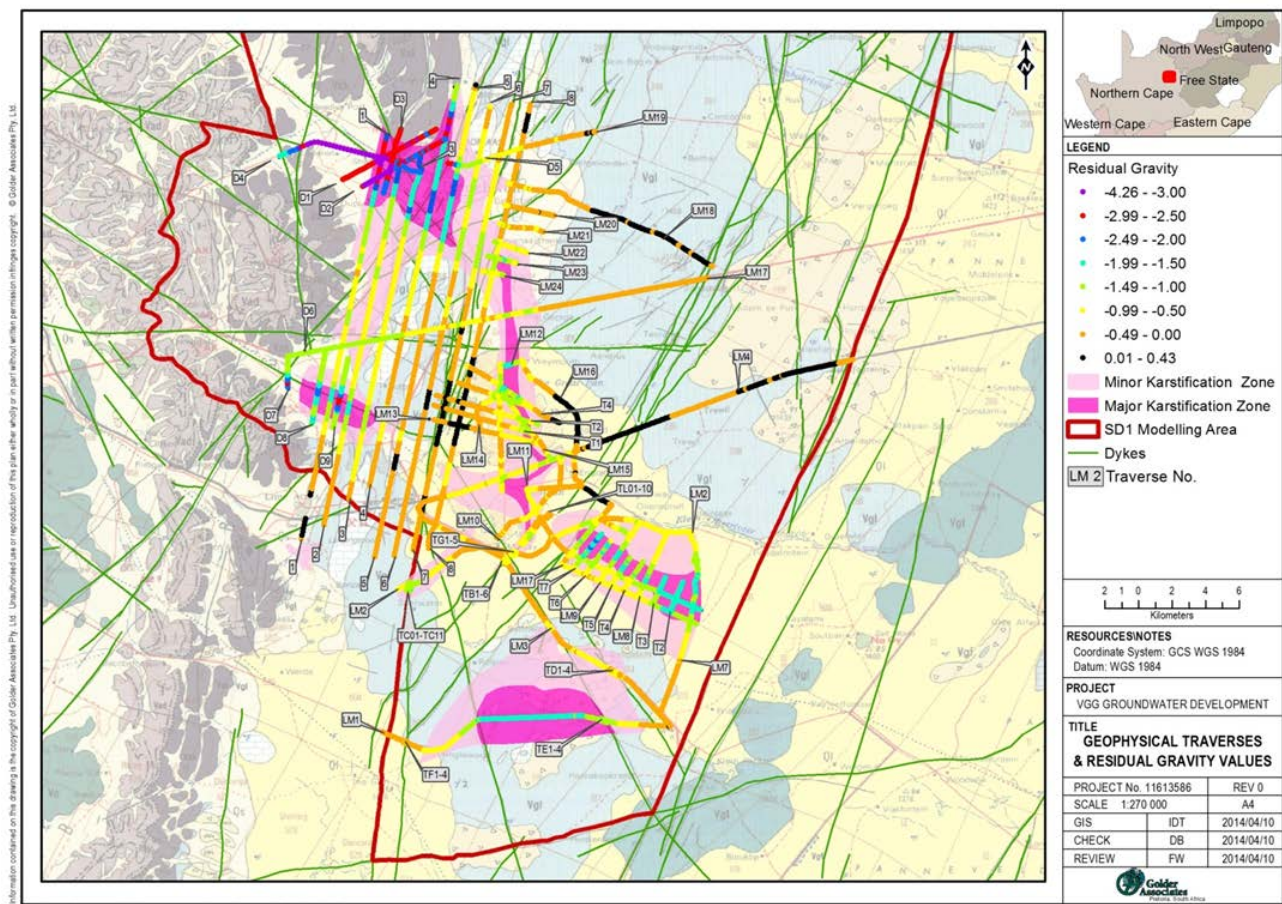


Figure 14: Geophysical Traverses and Residual Gravity Values

- 1: 500 000 Hydrogeological Map Series of RSA (1996),
- Existing borehole information were obtained from the following database:
 - Department of Water Affairs (DWA) National Groundwater Database (NGDB),
 - Borehole information from Golder's database namely Aquabase, and
 - Monitoring data from the DWA Kimberley office.
- Previous hydrogeological reports related to resource assessment, development, and monitoring studies from DWA and hydrogeological consulting firms; and
- Reconciliation strategy for Sedibeng Water's Vaal Gamagara pipeline scheme and Water Master Plan compiled by Golder Associates Africa in 2010.

DWS Historical and Current Groundwater Monitoring

The positions of boreholes monitored by DWA historically and current are listed in Table 1 and are indicated on Figure 15.

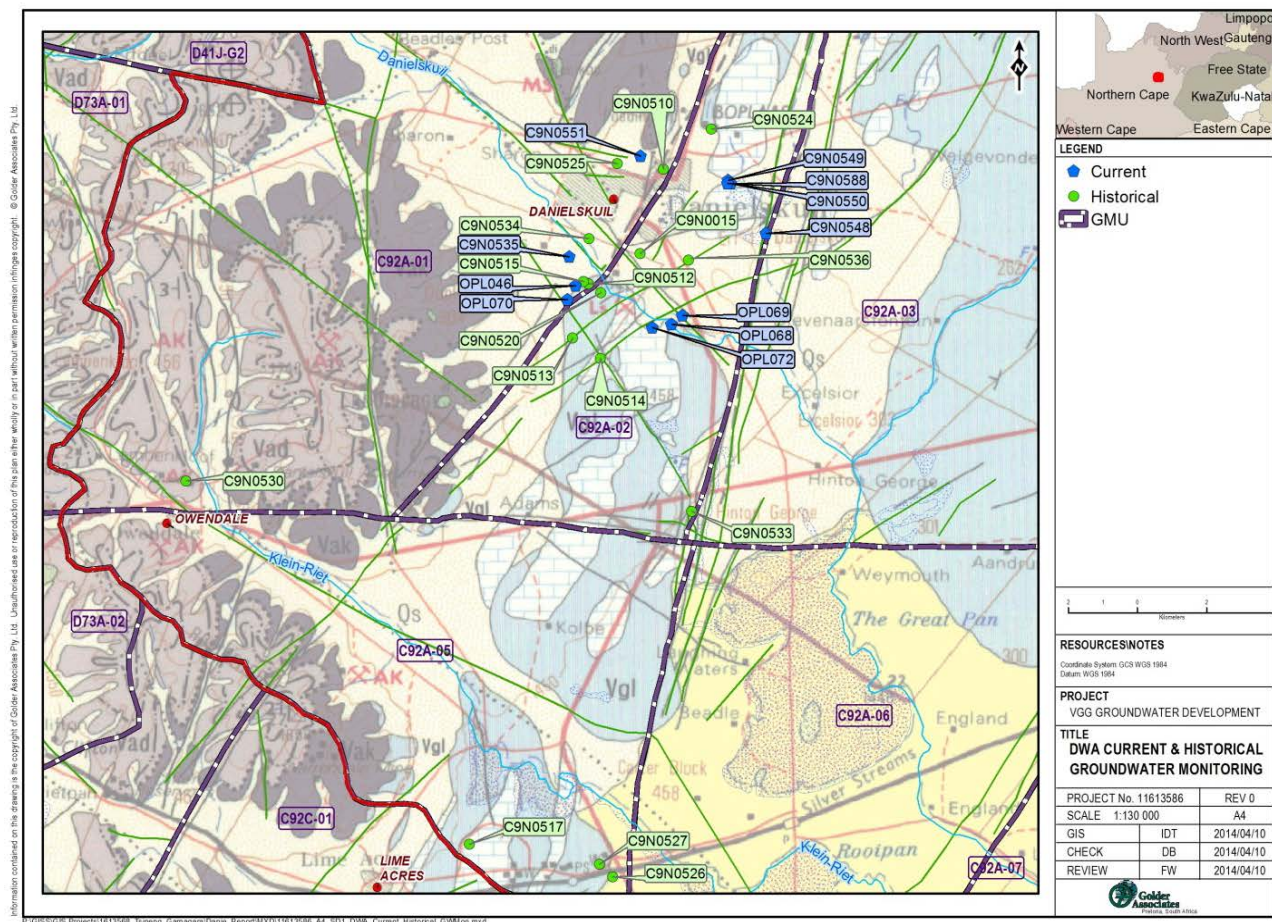


Figure 15: Location of DWA Historical and Current Groundwater Monitoring Points

Table 1: Historical and Current Groundwater Monitoring

GMU	BH Number	Starting WL (mbgl)	Last WL date	WL (mbgl)	Min	Max	Mean	WL Difference	Comment
C92A-05	C9N0526	9.9	05/01/1998	16.6	9.9	16.6	13.3	-6.7	Historical
C92A-05	C9N0527	8.7	25/07/1998	19.3	8.7	19.3	14.0	-10.6	Historical
C92A-05	C9N0517	16.2	06/01/1993	9.7	9.7	16.2	13.0	6.5	Historical
C92A-02	C9N0533	4.5	25/07/1998	11.8	4.5	11.8	8.1	-7.4	Historical
C92A-01	C9N0530	23.7	25/07/1998	28.0	23.7	28.0	25.8	-4.3	Historical
C92A-02	C9N0514	18.7	04/01/1993	14.0	14.0	18.7	16.3	4.6	Historical
C92A-02	C9N0513	27.8	20/06/1992	26.6	26.6	27.8	27.2	1.2	Historical
C92A-02	C9N0520	13.8	17/02/1988	16.4	13.8	16.4	15.1	-2.7	Historical
C92A-01	C9N0512	16.2	26/07/1998	17.2	16.2	17.2	16.7	-1.0	Historical
C92A-01	C9N0515	5.6	25/07/1998	7.2	5.6	7.2	6.4	-1.6	Historical

GMU	BH Number	Starting WL (mbgl)	Last WL date	WL (mbgl)	Min	Max	Mean	WL Difference	Comment
C92A-02	C9N0536	7.7	20/04/1996	12.3	7.7	12.3	10.0	-4.6	Historical
C92A-01	C9N0510	5.2	21/01/1999	7.4	5.2	7.4	6.3	-2.2	Historical
C92A-01	C9N0015	4.5	26/07/1998	8.9	4.5	8.9	6.7	-4.4	Historical
C92A-01	C9N0534	0.3	25/07/1998	7.3	0.3	7.3	3.8	-7.1	Historical
C92A-01	C9N0525	7.0	25/07/1998	20.3	7.0	20.3	13.7	-13.3	Historical
C92A-02	C9N0524	1.8	25/07/1998	14.7	1.8	14.7	8.3	-12.9	Historical
C92A-02	C9N0548	12.1	26/11/2012	10.0	10.0	12.1	11.0	2.1	Current
C92A-02	C9N0550	8.0	26/11/2012	9.6	8.0	9.6	8.8	-1.6	Current
C92A-02	C9N0588	8.3	01/02/2007	12.0	8.3	12.0	10.1	-3.7	Current
C92A-02	C9N0549	8.3	26/11/2012	9.8	8.3	9.8	9.0	-1.6	Current
C92A-01	C9N0535	3.1	25/07/1998	10.0	3.1	10.0	6.6	-6.9	Current
C92A-01	C9N0551	22.8	05/04/2011	9.4	9.4	22.8	16.1	13.3	Current
C92A-02	OPL072	0.0	26/05/2013	0.0	0.0	0.0	0.0	-6.7	Current
C92A-01	OPL070	0.0	28/04/2013	0.0	0.0	0.0	0.0	-10.6	Current
C92A-02	OPL069	0.0	15/07/1999	0.0	0.0	0.0	0.0	6.5	Current
C92A-02	OPL068	0.0	15/10/2001	0.0	0.0	0.0	0.0	-7.4	Current
C92A-01	OPL046	0.0	26/06/1986	0.0	0.0	0.0	0.0	0.0	Current

Historical water level monitoring records of monitoring borehole C9N0530, displaying seasonal water level fluctuations, is shown in Figure 16.

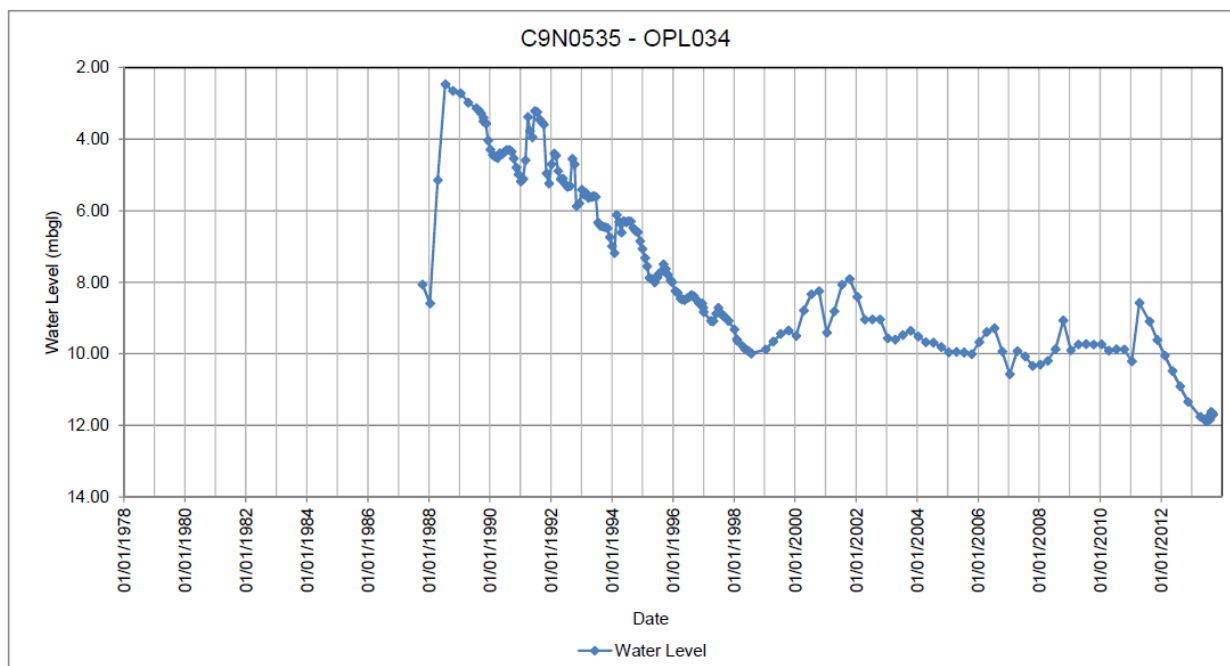


Figure 16: DWA Water Level Record of C9N0535

2.2.3.2 Remote Sensing

An extensive GIS mapping exercise was conducted, using Spot and Google satellite imagery to map linear structures (dykes, faults or lineaments). These linear structures mostly represent intrusive dykes, which are generally near vertical (85 to 90 degrees) and have strike lengths exceeding 100 km. The general strike directions are WSW – ENE, SSW – NNE, and ESE – WNW.

2.2.3.3 Landowner Engagement

The Department of Water Affairs and Sedibeng Water requested early commence with stakeholder communication during the assessment phase of the project through pro-active and transparent landowner engagement, rather than *ad-hoc* and reactionary engagement, or relying only on the regulatory public consultation that is being triggered by the environmental authorisation processes.

The Communication and Stakeholder Engagement involved:

- Confirmation of land ownership in the SD1 area. This was done title deeds searches, verification and confirmation of details of landowners, surface rights permit holders and lawful occupiers of land through a process of networking and referral (e.g. liaising with the local agricultural union's chairperson),
- Identification of the relevant authorities with jurisdiction in the proposed demarcated project areas,
- Created community and landowner awareness as follows:
 - Compilation and distribution of a background information letter accompanied by a full-colour map of the proposed project area and comment sheet to the relevant authorities (national, regional and local) and directly affected landowners within the SD1 area.
- Golder convened small focus group meetings, as follows:
 - District Municipalities and Local Municipalities with jurisdiction in the proposed demarcated project areas (SD1),
 - Agricultural Union and water bodies (e.g., water board, WUA – Tsiping Water),
 - Relevant national and provincial government department(s).

- Golder convened group consultations with directly affected landowners/lawful occupiers of land for SD1.

2.2.3.4 Hydrocensus

The hydrocensus borehole locations are indicated on and information summarised in Figure 17. Appendix A

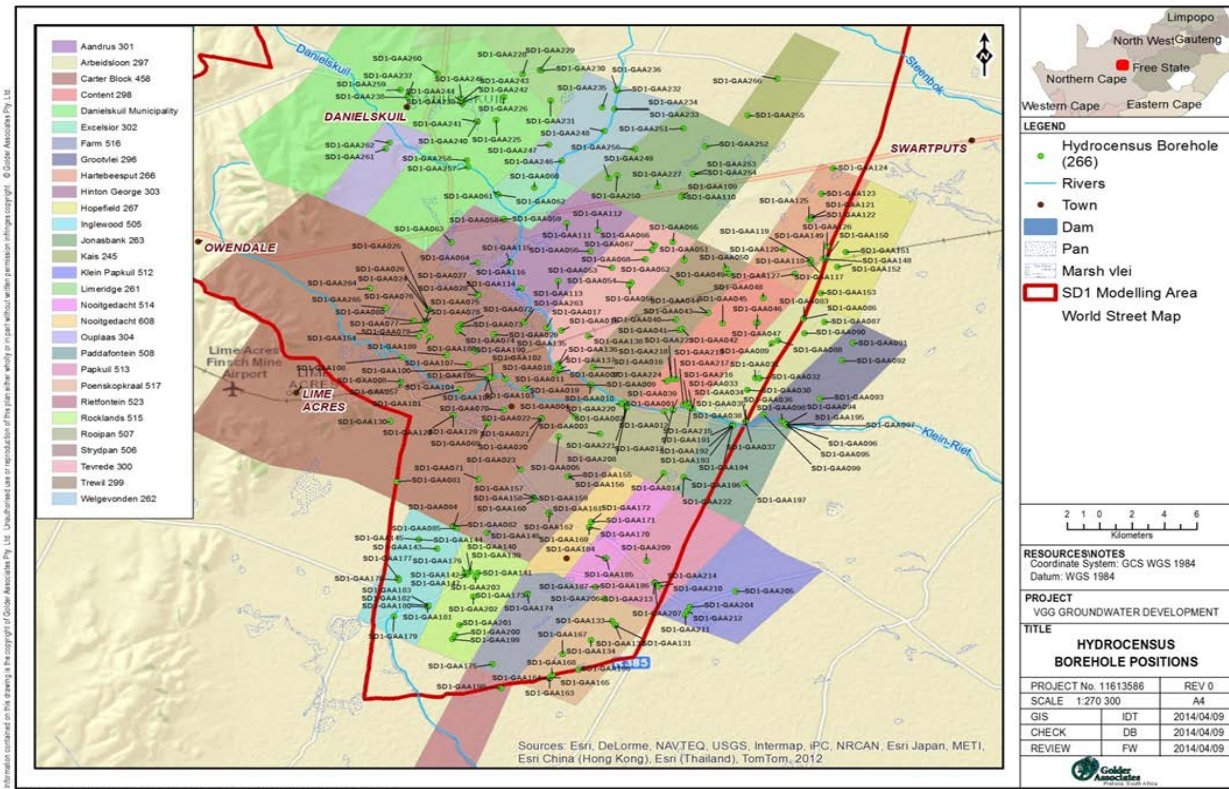


Figure 17: Hydrocensus Borehole Locations

The hydrocensus survey was conducted in 2012. A total of 266 boreholes and fountains were surveyed in the SD1 exploration target area, with the co-operation of the landowners.

On some private land areas farmers did not allow access, which was not forced to maintain good relationships with landowners as alternative exploration options were available. The hydrocensus further included groundwater users with high abstraction rates, namely Danielskuil Municipality and Idwala Lime mine production boreholes.

Existing borehole information obtained revealed the following:

- recorded borehole depths vary between 4.2m and 130m with an average depth of 38.8m,
- 168 water level depth measurements were obtained, which range between 0.45m and 43.9m with an average water level of 8.2mbgl.
- Reported borehole discharge rates range between 0.02l/s to 28l/s with an average of 3.3l/s.

Registered Water Use is as follows:

- A total of 10 groundwater users within the SD1 modelling area are registered with WARMS and their location indicated on Figure 18 and information summarised in Table 2.

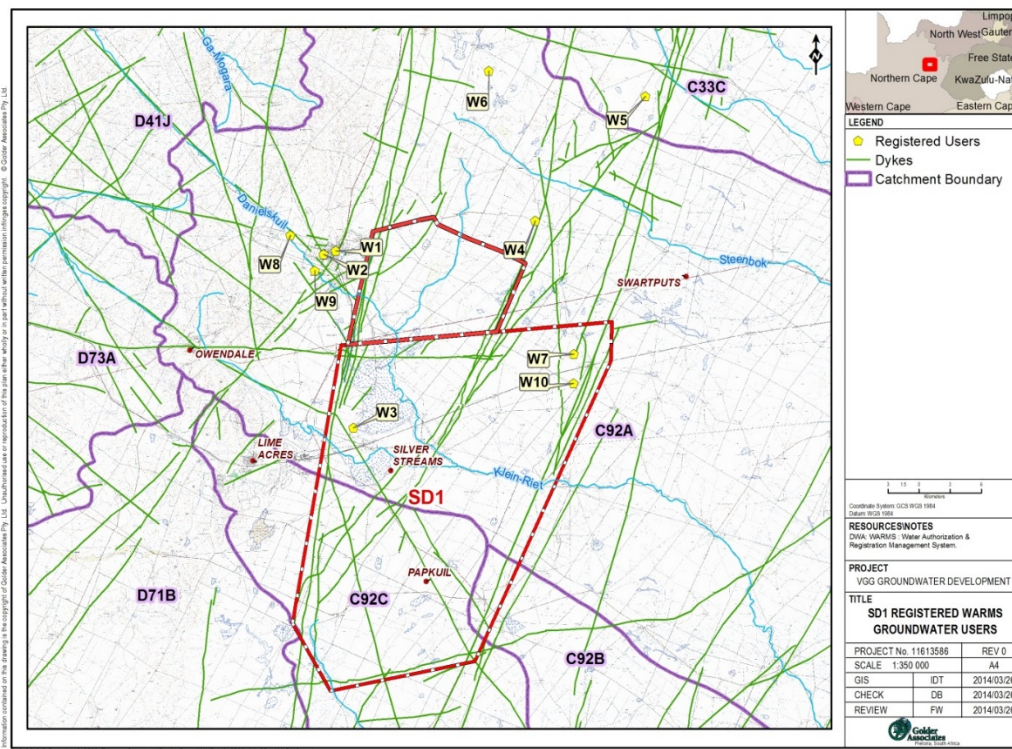


Figure 18: SD1 Registered WARMS Groundwater Users

Water quality field measurements (pH and EC) indicate:

- pH values range between 4.8 and 9.3 with an average value of 7.23 (alkaline).
- EC values range between 27.0 and 488mS/m with an average of 116mS/m. Most of the samples are below the DWAF 1998 Class1 drinking water limit.

Table 2: WARMS Registered Groundwater Users

Groundwater user Name	No. on Map	Latitude	Longitude	Licence number	Drainage Region	WARMS Mm ³ /Year
Idwala Industrial Holdings	W1	-28.185717	23.546489	25007019	C92A	380 000
Danielskuil Municipality	W2	-28.188473	23.535934	10080342/1	C92A	630 720
A.D. Scheepers	W3	-28.334688	23.561645	-	C92A	11 200
H.K. van Niekerk	W4	-28.160419	23.719550	25017730	C92A	63 000
J.G. van Heerden	W5	-28.055425	23.815110	-	C33C	58 000
Heinrich Poolman	W6	-28.034037	23.679272	25006877	C92A	32 200
Bernean Boerdery BK	W7	-28.272579	23.752884	-	C92A	97 500
M.G. Willemse	W8	-28.172507	23.507034	25040081	C92A	10 330
J.M. Bezuidenhout	W9	-28.202136	23.528064	25021306/1	C92A	51 000

Groundwater user Name	No. on Map	Latitude	Longitude	Licence number	Drainage Region	WARMS Mm ² /Year
J.A. & B.J. Visser	W10	-28.297328	23.752773	-	C92A	97 500
Total						1 431 450

A total of 76 water samples were collected at existing boreholes during the hydrocensus to determine the baseline water quality of the existing groundwater users. The samples were sampled as per Golder standards and were submitted to the UIS Analytical Services (SABS Accredited) in Centurion for analysis.

A total of 6 fountains and pools were identified with their positions indicated on Figure 19.

2.2.3.5 Exploration Drilling

The exploration drilling programme was completed 18 August 2013 with a total of 53 exploration boreholes drilled as indicated on Figure 19.

The objective of the exploration drilling was to quantify the sustainable groundwater of the source development area and to determine the feasibility of the source to contribute to the VGG pipeline.

The boreholes were drilled according to a sustainable yield approach, where boreholes were drilled over the entire major karstification zone of SD1 to minimize draw-down of the water level. This approach is contradictory to a mining approach of de-watering, where deep (>100m) production boreholes are concentrated in an area in order to lower/dewater the water table.

Drilling depths of exploration boreholes were controlled by geology, water strike depths and yields. Exploration boreholes with air-lift yields (>10l/s) were constructed as possible production boreholes.

Three monitoring boreholes (SD1-17M, SD1-32M, and SD1-40M) were drilled within 20 to 40m distance from high yielding boreholes. The purposes of these monitoring boreholes apart from dedicated monitoring facilities are to determine hydraulic parameters of the formation during long term test pumping. These monitoring boreholes were marked using the after-fix "M" after the borehole number (SD1-17M).

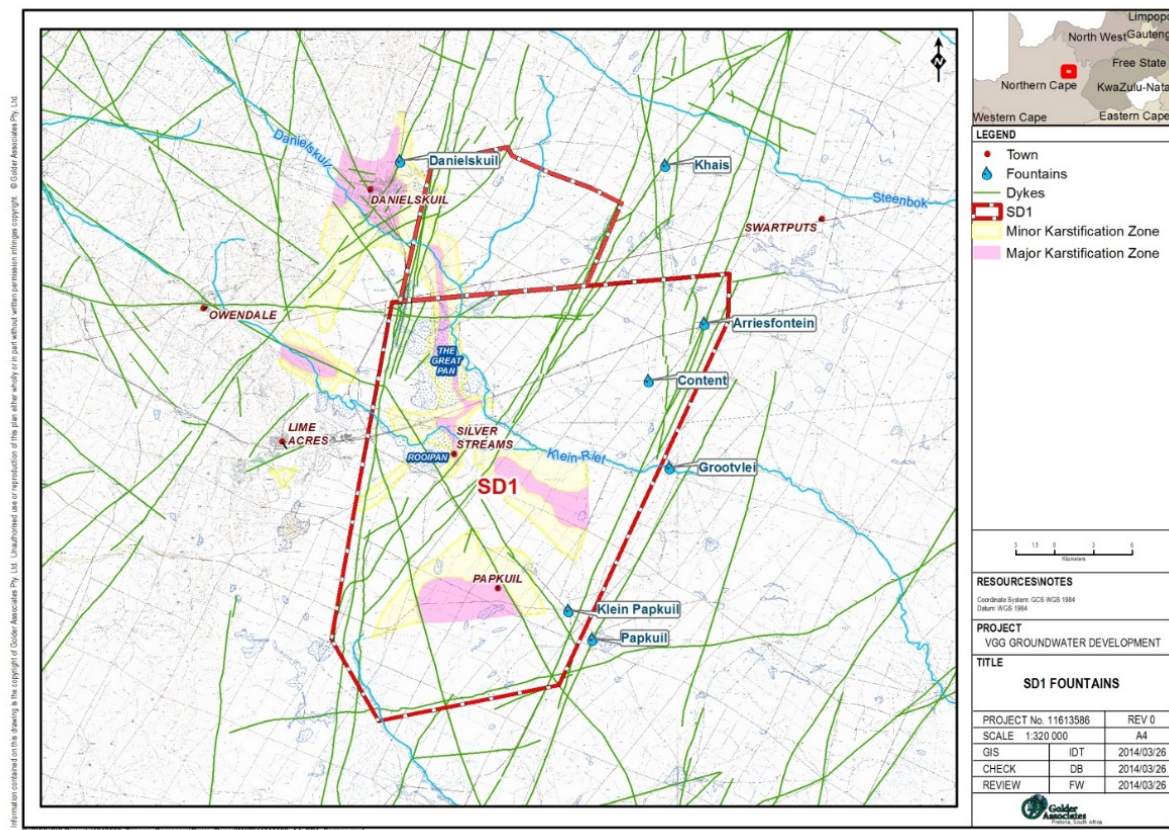


Figure 19: SD1 Fountain Locations

Four shallow boreholes (SD1-14S, SD1-16S, SD1-27S and SD1-32S) to investigate hydrogeological conditions of the upper Kalahari Aquifer (calcrete) were drilled next to exploration boreholes. The depths of the shallow monitoring boreholes were restricted to the thickness of the calcrete layer. These shallow boreholes were marked using the after-fix “S” after the borehole number (SD1-14S).

The drilling approach entails specialized drilling (large diameter percussion) and construction of monitor/production boreholes in areas underlain by dolomite, banded iron formation and Kalahari sediments.

Exploration boreholes were drilled by air percussion drilling rigs, using the telescoping drilling approach. Drilling diameters started at 381mm diameter as a maximum and reducing to 305, 254, 203 and 165mm as minimum pending on the geology and water strikes intersected. boreholes were cased with steel casing (4 and 6mm thickness). High yielding boreholes were developed as potential production boreholes and low yielding boreholes as monitoring boreholes.

Gravel packs were installed in the annulus between the sides of the borehole and the casing of the borehole to stabilise the geological formation and allow groundwater inflow into the borehole. Bentonite seals of 3m to 5m were installed above the gravel pack at surface.

Three exploration boreholes (SD1-33 SD1-34 and SD1-45) were allocated to Danielskuil municipality to help fulfil their future municipality water demand. SD1-45 was drilled to the east of Danielskuil close to the Tlhakalatlou settlement

Drilling Results

A total of 53 exploration boreholes were drilled, from which 32 boreholes were constructed as potential production status and 21 as monitoring status Figure 20. The drilling results are summarised in Appendix B

listing details of water strike depths, strike yields and main geology intersected. Borehole altitudes were surveyed to an accuracy within <20mm amsl.

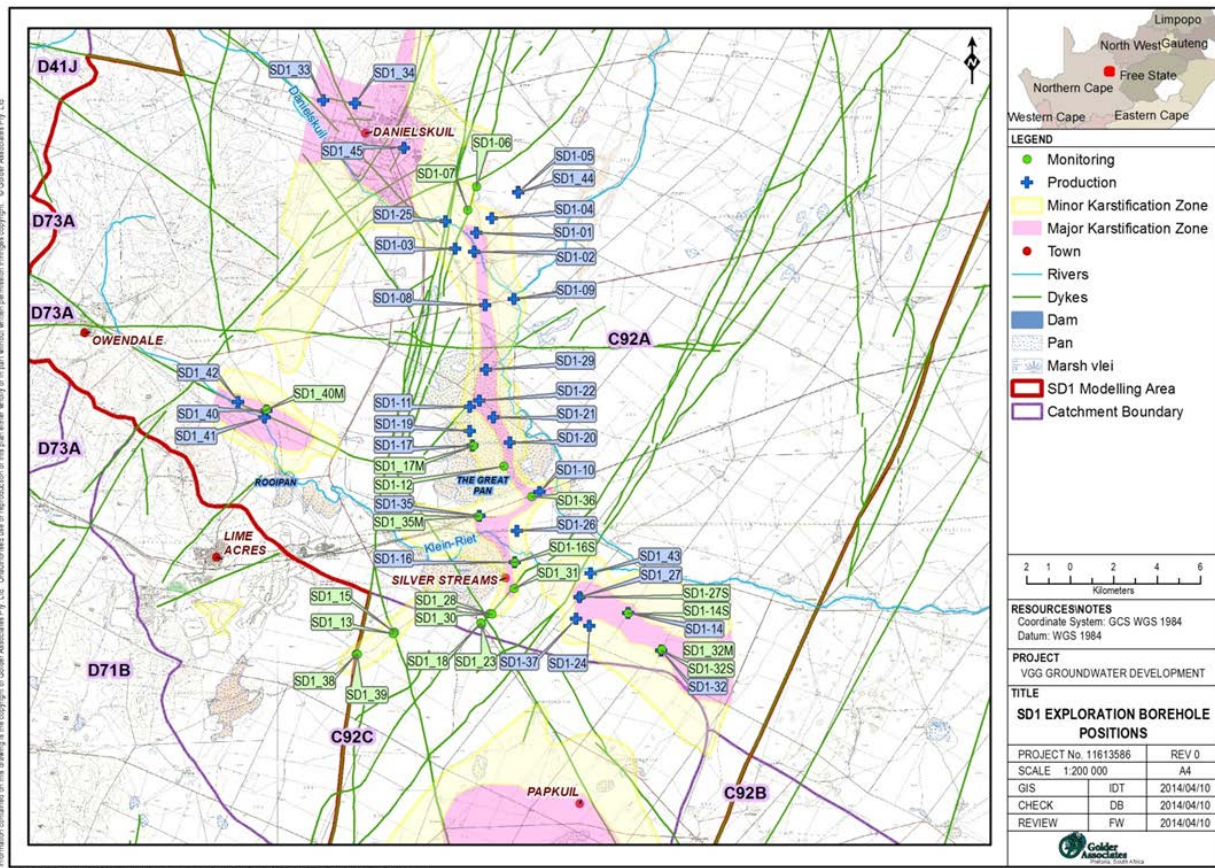


Figure 20: SD1 Exploration Borehole Locations

The drilling results for SD1 can be summarised as follows:

- Drilling depths range between 16m shallow calcrete boreholes and 137m (SD1-34) with an average of 63.3m,
- Intersected groundwater strike depths range between 6m and 110m with an average of 46m,
- Final blow yields range between 0.2l/s and 62l/s (SD1-25) with an average of 18.6l/s, and
- Recorded water level depths range between 2m (SD1-21) and 67m (SD1-38) with an average of 14m.

The combined air-lift yield from the 23 potential production boreholes is 792 l/s. The final blow yield ranges, as a percentage of the number of exploration boreholes drilled are as follows:

- Seepage intersected: 6 boreholes – 11%,
- Yields <10l/s: 13 boreholes – 24%,
- Yields 10l/s to 20 l/s: 22 boreholes – 42%, and
- Yields >20l/s: 12 boreholes – 23%.

Delineation of Kalahari Sediment Thickness

Lithological information from the exploration drilling were used to delineate and contour the thickness of the Kalahari sediments (calcrete and clay) as indicated on Figure 21. These sediments thickness range up to 60m below surface, have a low permeability, retards and restrict groundwater movement and acts as storage

unit. These delineated Kalahari sediment thicknesses correlate closely with the residual gravity values outlining areas of low formation density.

2.2.3.6 *Aquifer Testing*

Aquifer testing was performed on 32 existing boreholes (Figure 22) and 38 newly drilled exploration boreholes (Figure 23) (Figure 69). The testing programme, using a positive displacement pump, in SD1 area was completed in September 2013.

The aquifer testing programme consists out of a step drawdown/discharge test (SDT) followed by a constant discharge test (CDT), and a water level recovery test. Each SDT comprised three to four 60-minute steps at increasing pumping rates. The aim of the SDT is to assess the performance of the borehole under different pumping yields and determine the pumping rate for the CDT.

The CDT is conducted to determine the hydraulic parameters of the aquifer and identify possible aquifer boundaries. The CDT at the exploration boreholes were conducted for periods of between 24 and 72 hours, after which the water level recovery was measured. The CDT pumping rates were set at yields determined from the SDT to be sustainable for the planned duration of the test.

Pumping rates varied from 0.1 l/s to 30.0 l/s. Water-level recovery measurements were taken for the same period as pumping during the SDT and CDT or to 100% recovery of the original water level. The recovery of the boreholes provides an independent measure of the Transmissivity of the aquifer. Water levels were monitored in adjacent boreholes during the CDT to determine if there is connectivity between the boreholes.

At low yielding boreholes only a SDT was conducted. Falling head testing was conducted at the four shallow calcrete boreholes. During the SDT's if the last discharge rate reached pump inlet the yield at pump-inlet was measured.

In the case of existing boreholes with limited yield a calibration test (Cal) comprising 4 to 5, 15 minutes, steps were carried out.

The test pumping programmes of existing and exploration boreholes are summarised in Table 4.

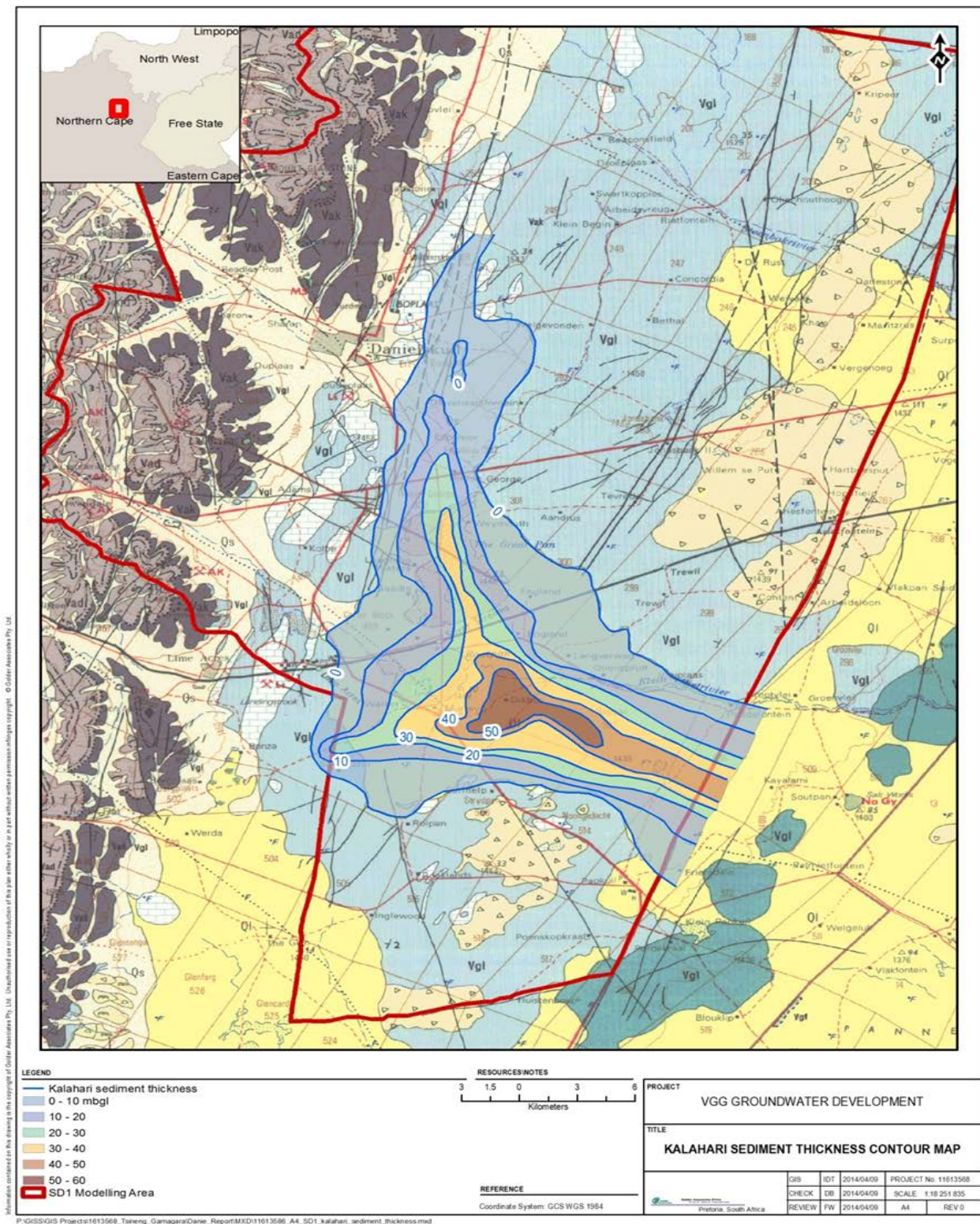


Figure 21: Kalahari Sediment Thickness

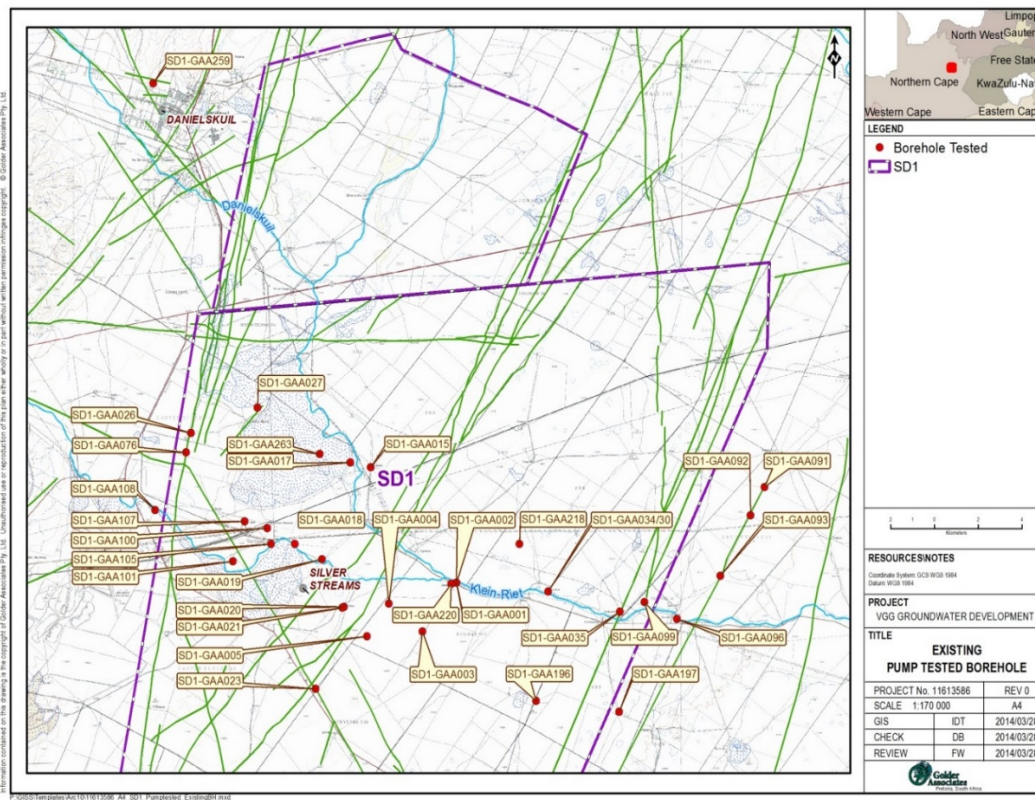


Figure 22: Location of SD 1 Existing Test Pumped Boreholes

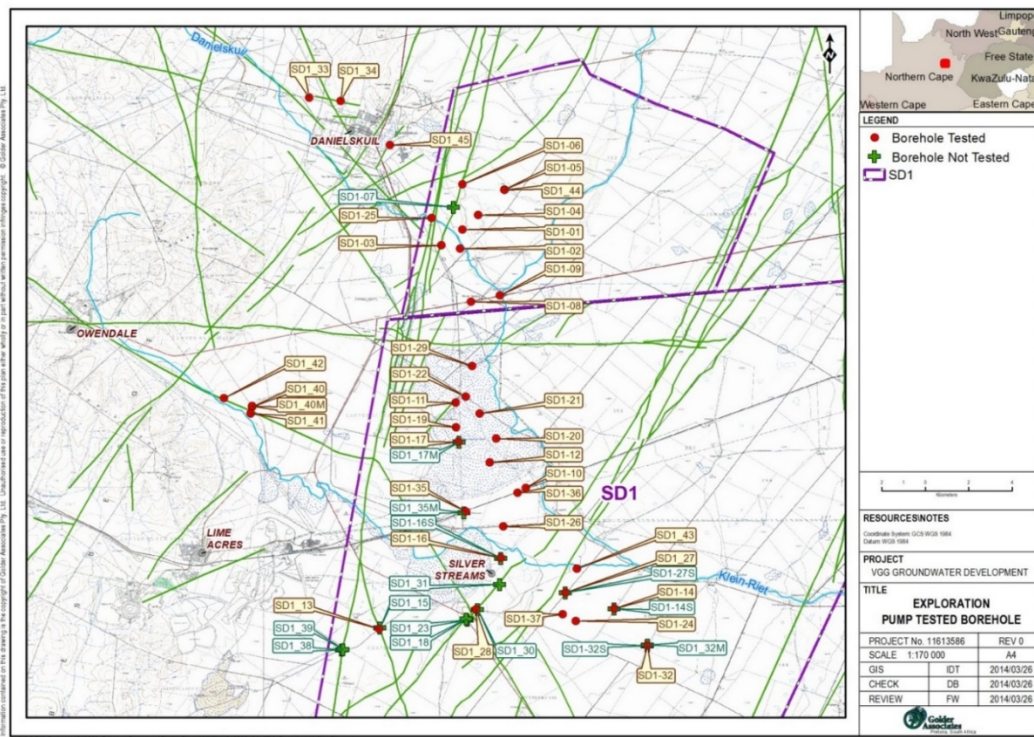


Figure 23: Location of SD 1 Exploration Boreholes Test Pumped

Falling Head Testing

Falling head testing provides a rapid means of assessing the in-situ hydraulic conductivity in “dry” boreholes or boreholes with insufficient water for slug testing. The test involves measuring the water-level response in a borehole to a displacement of water. The displacement was induced through the introduction of additional water to the rest water level. The rate of recession of the water level displacement provides an indication of the hydraulic conductivity of the borehole. The water level responses were measured using an electronic water level data recorder.

Four falling head tests were conducted in the shallow calcrete aquifer present at surface. This low yielding aquifer zone is also the hosting formation of a large indigenous *Olea Africana* (“Olienhoutboom”) forest. The impact of well field on these trees were of concern to the landowners and hence the investigation of the hydraulic parameters of the calcrete aquifer zone. The results of the falling head test are summarised in Table 3.

The results confirmed that this aquifer zone have low permeability, retards and restrict water movement and acts as storage unit.

Table 3: Calculated Conductivity (K) Values of Shallow Aquifer

Borehole No.	Latitude	Longitude	Altitude (mamsl)	Drill Depth (m)	K Conductivity(m/d)
SD1-16S	-28.36441	23.59788	1441.142	16	0.00654
SD1-27S	-28.37873	23.62472	1437.378	18	0.00151
SD1-32S	-28.40079	23.65846	1436.591	16	0.00493
SD1-14S	-28.38538	23.64476	1437.544	18	0.00101

Test Pumping Results

Test pumping results were interpreted by means of WHI Aquifer Test version 3 software, by Waterloo Hydrogeologic Inc. and the FC Method Institute for Groundwater Studies at Bloemfontein University.

The test pumping results interpreted from test pumping software are summarised in Table 4.

Storativity (S) values calculated for existing and new exploration boreholes are summarised in Table 5.

The drilling and test pumping results confirm the presence of a semi-confined aquifer system in the dolomite and BIF formations, as an aquifer that is partly confined by layers of lower permeability (calcrete) material through which recharge and discharge may occur.

The calcrete layer, however, acts as an unconfined aquifer system where the water table is the upper boundary and with no confining layer between the water table and the ground surface and can fluctuate up and down.

Table 4: Calculated Transmissivity Values - SD1

Borehole Number	Borehole Depth (m)	Static Water level (mbgl)	Constant Draw Down Test			Recovery		Transmissivity (T)		Borehole Diameter (mm)	Primary aquifer/ Geology	FC-Method Interpreted Yield for 20 Hours per Day (l/s)	Boreholes Status
								Duration (Min)	Yield (l/s)				
			(Min)	%									
Existing Boreholes													
SD1-GAA001	50.39	5.97	1080	6.0	0.07	3	100	6529	7230	110	Dolomite	51.0	Existing
SD1-GAA005	38.31	10.90	720	3.0	14.06	3	100	22	18	165	Dolomite	0.7	Existing
SD1-GAA021	25.82	14	720	1.25	3.96	720	99	75	48	165	Dolomite	0.6	Existing
SD1-GAA035	9.83	2.51	960	6.0	0.31	120	100	245	2890	165	Dolomite	5.0	Existing
SD1-GAA076	24.34	15.46	720	9.0	4.24	720	97	1731	1560	165	Dolomite	3.0	Existing
SD1-GAA105	56.04	11	720	1.4	9.87	720	95	15	10	165	Dolomite	0.3	Existing
SD1-GAA218	51.18	6.09	480	3.3	41.91	480	98	5	8	165	Dolomite	0.2	Existing
SD1-GAA019	29	9.56	720	0.5	2.35	50	100	7	-	165	Dolomite	0.3	Existing
SD1-GAA023	37.48	11.65	720	0.5	8.86	720	95	8	-	165	Dolomite	0.1	Existing
SD1-GAA027	75.20	14.11	720	6.2	0.24	5	100	500	-	165	Dolomite	19.0	Existing
SD1-GAA030	33	2.69	720	1.3	5.38	720	95	82	-	165	Dolomite	0.5	Existing
SD1-GAA093	17.12	3.5	1440	8.0	2.59	240	100	375	-	165	Dolomite	6.0	Existing
SD1-GAA096	28.04	1.28	720	1.8	0.78	300	100	208	-	165	Dolomite	4.0	Existing
SD1-GAA099	35.60	4.51	270	0.45	27.59	300	99	0.7	-	165	Dolomite	0.03	Existing

Borehole Number	Borehole Depth (m)	Static Water level (mbgl)	Constant Draw Down Test			Recovery		Transmissivity (T)		Borehole Diameter (mm)	Primary aquifer/ Geology	FC-Method Interpreted Yield for 20 Hours per Day (l/s)	Boreholes Status
								Duration (Min)	Yield (l/s)				
			(Min)	%									
SD1-GAA108	39	22.02	720	2.8	1.24	3	100	786	-	165	Dolomite	5.0	Existing
SD1-GAA197	47.18	16.10	480	1.2	8.23	120	100	7	-	165	Dolomite	0.2	Existing
SD1-GAA220	52.24	10.87	720	0.53	14.05	480	100	7	-	165	Dolomite	0.1	Existing
Exploration Boreholes													
SD1-01	82.0	11.75	1440	12.0	4.16	300	100	658	541	165	Dolomite	6.0	Production
SD1-02	30.0	10.80	1440	15.0	3.36	240	100	194	274	165	Dolomite	5.0	Production
SD1-03	82.60	13.35	1440	12.0	19.78	1440	97	85.5	-	203	Dolomite	5.0	Production
SD1-04	61.55	12.99	1440	20.0	1.31	960	100	1686	1680	203	Dolomite	25.0	Production
SD1-05	36.67	18.61	1440	20.0	0.62	60	100	10273	-	165	Dolomite	69.0	Production
SD1-08	39.85	13.76	1440	30.0	0.71	10	100	2573	-	254	Dolomite	32.0	Production
SD1-09	40.30	8.04	1440	25.0	2.11	150	100	987	-	203	Dolomite	19.0	Production
SD1-10	27.0	12.90	1440	25.0	3.24	150	100	917	-	254	BIF	15.0	Production
SD1-11	61.0	14.61	1440	20.0	0.73	30	100	3424	-	165	Dolomite	48.0	Production
SD1-13	60.0	19.0	1440	3.5	8.67	240	100	35	23.1	165	Dolomite	0.8	Monitoring
SD1-14	67.50	14.53	2880	16.0	7.17	360	100	684	317	254	Dolomite	5.0	Production

Borehole Number	Borehole Depth (m)	Static Water level (mbgl)	Constant Draw Down Test			Recovery		Transmissivity (T)		Borehole Diameter (mm)	Primary aquifer/ Geology	FC-Method Interpreted Yield for 20 Hours per Day (l/s)	Boreholes Status
								CJ Method (m²/day)	Aquifer Test (m²/day)				
			Duration (Min)	Yield (l/s)	Drawdown (m)	(Min)	%						
SD1-16	59.40	10.28	2880	20.0	3.07	240	100	934	624	165	Dolomite	15.0	Production
SD1-17	57.60	3.53	1440	30.0	0.74	90	100	855	1170	203	Dolomite	33.0	Production
SD1-17_2	57.60	3.34	4320	30.0	1.25	5	100	620	708	203	Dolomite	27.0	Production
SD1-19	40.22	3.24	1440	25.0	0.74	60	100	1290	-	203	Dolomite	38.0	Production
SD1-20	49.40	4.26	1440	30.0	0.77	30	100	3082	-	203	Dolomite	55.0	Production
SD1-21	103.0	3.32	1440	20.0	2.70	150	100	714	-	165	Dolomite	13.0	Production
SD1-22	49.0	4.24	1440	20.0	11.59	120	100	681	-	203	Dolomite	5.0	Production
SD1-24	68.50	14.15	1440	30.0	1.16	180	100	486	-	203	Dolomite	37.0	Production
SD1-25	51.50	8.20	2880	30.0	1.83	30	100	2533	2180	203	Dolomite	55.0	Production
SD1-26	69.0	10.90	1440	16.0	3.79	210	100	747	-	203	Dolomite	10.0	Production
SD1-27	104.0	13.45	2880	30.0	4.12	300	100	273	299	203	Dolomite	11.0	Production
SD1-28	66.0	15.45	1440	15.0	6.27	360	100	326	-	165	Dolomite	5.0	Production
SD1-29	68.65	11.07	2880	10.0	21.98	300	100	35	-	165	BIF	1.5	Production
SD1-32	73.0	13.92	2880	25.0	3.91	120	100	480	905	203	Dolomite	19.0	Production
SD1-32(2)	73.0	13.92	4320	30.0	5.33	40	100	1078	997	203	Dolomite	18.0	Production

Borehole Number	Borehole Depth (m)	Static Water level (mbgl)	Constant Draw Down Test			Recovery		Transmissivity (T)		Borehole Diameter (mm)	Primary aquifer/ Geology	FC-Method Interpreted Yield for 20 Hours per Day (l/s)	Boreholes Status
			(Min)	%	CJ Method (m²/day)			Aquifer Test (m²/day)					
SD1-35	28.70	10.82	2880	30.0	1.76	120	100	2568	3600	254	Dolomite	61.0	Production
SD1-35(2)	28.70	10.82	4320	30.0	2.37		100	3852	3600	254	Dolomite	61.0	Production
SD1-37	82.0	13.77	1440	15.0	12.63	90	100	156	-	254	Dolomite	2.6	Production
SD1-43	68.0	14.81	1440	15.0	6.27	1440	100	313	-	203	Dolomite	5.0	Production
SD1-44	34.42	19.15	4320	30.0	1.14	20	100	748	720	203	Dolomite	25	Production
SD1-40	97.6	29.77	4320	10.0	14.37	1320	100	79	73	165	BIF	5.0	Production
SD1-41	97.0	44.07	4320	12.0	14.21	600	100	83	83.5	203	BIF	6.0	Production
SD1-42	112.0	35.90	2880	10.0	10.38	360	100	52	143	165	BIF	5.0	Production
SD1-33	79.0	25.08	4320	12.0	15.74	1080	100	68	-	203	BIF/Chert	5.0	Production
SD1-34	137	25.43	4320	12.0	13.47	2160	100	71	-	203	Dolomite	6.0	Production
SD1-45	44.9	19.15	2880	30.0	2.05	540	100	1948	1340	203	Dolomite	25.0	Production

Table 5: Calculated Storativity Values - SD1

Borehole Number	Borehole Depth (m)	Static Water level (mbgl)	Monitor borehole	Draw Down (m)	Storativity (S)	Storativity (S)
Existing Boreholes						
SD1-GAA001	50.39	5.97	SD1-GAA002	0.089	3.80×10^{-1}	0.380
SD1-GAA021	25.82	14.0	SD1-GAA020	0.51	2.83×10^{-5}	0.0000283
			SD1-GAA022	1.19	7.61×10^{-5}	0.0000119
SD1-GAA035	9.83	2.51	SD1-GAA036	0.06	2.39×10^{-2}	0.0239
			SD1-GAA037	0.48	4.09×10^{-2}	0.0409
			SD1-GAA038	0.43	3.14×10^{-2}	0.0314
SD1-GAA076	24.34	15.46	SD1-GAA075	0.33	1.22×10^{-3}	0.0033
			SD1-GAA077	0.69	1.06×10^{-3}	0.0069
			SD1-GAA078	0.49	1.06×10^{-3}	0.0049
SD1-GAA105	56.04	11.0	SD1-GAA103	3.21	6.37×10^{-4}	0.000321
			SD1-GAA104	2.86	7.02×10^{-3}	0.00702
SD1-GAA218	51.18	6.09	SD1-GAA223	34.69	2.63×10^{-3}	0.00263
New Exploration Boreholes						
SD1_25	51.50	8.20	SD1_GAA257	0.07	1.97×10^{-2}	0.0197
SD1_32	73.0	12.6	SD1_32M	0.33	3.21×10^{-4}	0.000321
SD1_13	60.0	18.76	SD1_15	0.64	2.24×10^{-8}	0.0000000224
SD1_14	67.50	14.53	SD1_GAA003	0.08	6.60×10^{-4}	0.000660

Borehole Number	Borehole Depth (m)	Static Water level (mbgl)	Monitor borehole	Draw Down (m)	Storativity (S)	Storativity (S)
SD1_35	28.70	10.62	SD1_35M	0.11	3.49×10^{-1}	34.9
SD1_40	97.6	31.0	SD1_40M	0.33	3.22×10^{-2}	0.0322
SD1_45	44.9	19.15	SD1_5	0.0	-	-
SD1_17	57.60	3.53	SD1_17M	0.0	-	-

2.2.4 SD1 Groundwater Resource Assessment

2.2.4.1 Groundwater Use

Existing Groundwater Users

The existing groundwater use is summarised in Table 6 and was calculated from data and abstraction rates required during the hydrocensus. The existing groundwater users are divided into three main use categories mining, municipal and private use.

Private used boreholes where no yields were reported were calculated based on an average of:

- Windmill 0.3l/s for 8 hours per day; and
- Motorized pumps at 0.5l/s for 8 hours per day.

Table 6: SD1 Existing Groundwater Use - 2013

Groundwater use	Borehole number	Abstraction Rate M ³ /Month	Abstraction Rate M ³ /Year
Mining sector	SD1-GAA261; SD1-GAA262	39 615	475 376
Municipality	SD1-GAA237; SD1-GAA239	96 163	1 153 958
Private	SD1-GAA numbers (including fountains) and WARMS registered use	215 687	2 588 246
Total Use		351 465	4 217 581

Fountains

Various fountains (springs) were located during the hydrocensus and are summarised in Table 7.

Table 7: SD1 Fountains

Fountain	Hydrocensus number	Latitude	Longitude	Altitude (mamsl)	Estimated/Report ed Flow (l/s)	Estimated Flow M ³ /Month	Estimated Flow M ³ /Year
Danielskuil	SD1-GAA260	-28.166480	23.557010	1464.53	25.0	64800	777 600
Content	SD1-GAA047	-28.319330	23.730070	1433.79	Pool/Not Flowing	-	-
Arriesfontein	SD1-GAA150	-28.279570	23.768960	1423.16	Pool/Not Flowing	-	-
Klein Papkuil	SD1-GAA214	-28.479270	23.674000	1420.19	Pump house	432	5 184
Papkuil	SD1-GAA211	-28.499080	23.690650	1400.74	0.83	2151.4	25816.3
Grootvlei	SD1- GAA097/98	-28.379790	23.744550	1409.90	Pool/Not Flowing	-	-
Khais	SD1-GAA266	-28.16944	23.74168	1456.29	0.5	1296.0	15552.0
Total					26.33	68679.4	824 152

2.2.4.2 Groundwater Levels and Flow Direction

Manual derived groundwater piezometric contours were compiled at 10 metre intervals for the SD1 study area. The contours are based on 373 water level elevation data points, sourced from the Golder in-house database, as indicated in Figure 24.

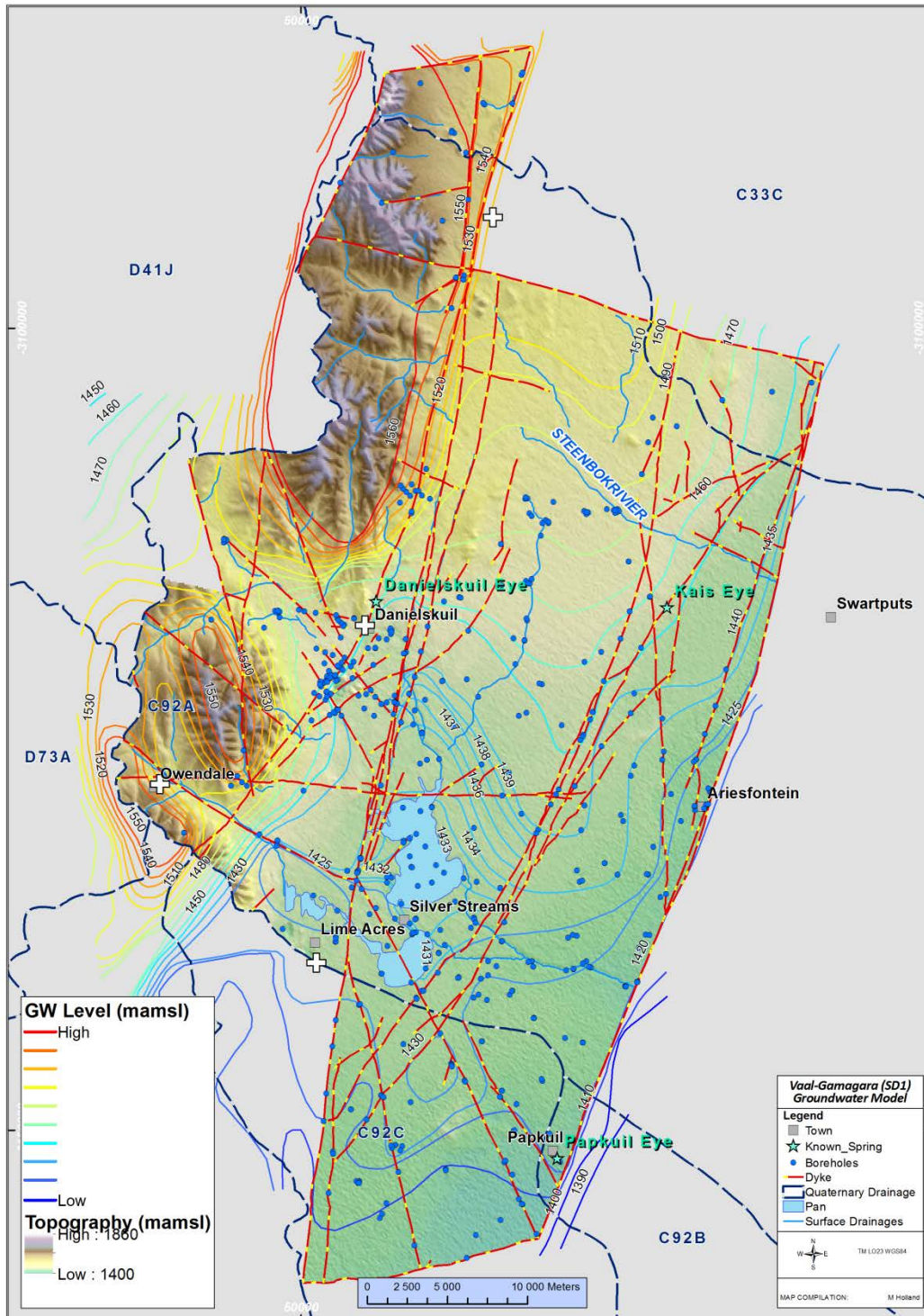


Figure 24: SD1 Groundwater Piezometric Contour Map

Information used during manual contouring included:

- Surface topography contours at 10metre interval,

- Mapped geological formations, faults and intrusive dykes,
- Surface elevation of spring flows; and
- Surface drainage features.

The manual compiled contours were all digitized. These digitized contours were used as input values and contoured on Surfer software, to compile the final groundwater piezometric contours, at 10 meter intervals, as depicted in Figure 24.

The regional groundwater flow direction for the SD1 study area is towards the west. Groundwater piezometric contours mimic the surface topography, and regional the groundwater flow is from higher lying ground toward lower lying valleys, where groundwater accumulates in the alluvial deposits and contributes to baseflow.

Groundwater piezometric contour levels ranges from 1390mamsl in the east to 1560mamsl in the north-west, representing a maximum head of 170 metres for the study area.

Groundwater piezometric contours within the vicinity south and west of the Danielskuil dyke have a low hydraulic gradient due to high aquifer transmissivity within the dolomitic compartments, bounded by dolerite dykes with moderate steps (~ 5m) in the piezometric levels.

Piezometric levels north and northwest of the model domain show steeper gradients, indicating lower transmissivity in the bedrock aquifer.

2.2.4.3 Groundwater Management Units

Groundwater Management Units (GMU's) were delineated for the entire SD1 modelling area to quantify available water resources, estimate recharge volumes, and calculate water balances. A total of 11 GMU's were delineated for the SD1 modelling area as shown in Figure 25.

The geological formations, structural information (dykes), piezometric surface and water quality indicators were used to delineate groundwater compartments and management units. This allows assessment of groundwater recharge at local scale and to assess how much water is locally available for use.

2.2.4.4 Aquifer Recharge Estimates

The quantity of rainfall and intensity of rainfall (monthly rainfall) are the major drivers of aquifer recharge in the study area. Groundwater recharge (excluding lateral inflows) is sustained by direct rainfall on the surface area and the evaluation thereof is dependent on various factors:

- Volume of rain during a rainfall season as well as the rainfall intensity. Larger rainfall intensity effects surface runoff with increased recharge occurring in areas comprising surface depressions,
- Type of surface cover. Aquifer recharge increases in areas with outcropping BIF and dolomite geological formations, gravel, and sand cover. Limited to no recharge occurs where Kalahari Group Sediment thicknesses exceed 15 metres,
- Depth to groundwater level. Shallow groundwater level areas or areas with relative lower water level depths may represent areas with increased recharge from rainfall,
- Groundwater quality. The relative electrical conductivity and chloride content of water can be used to identify areas with increased recharge from rainfall, and
- Local surface depressions also represent areas with increased recharge potential due to the accumulation of surface run-off water.

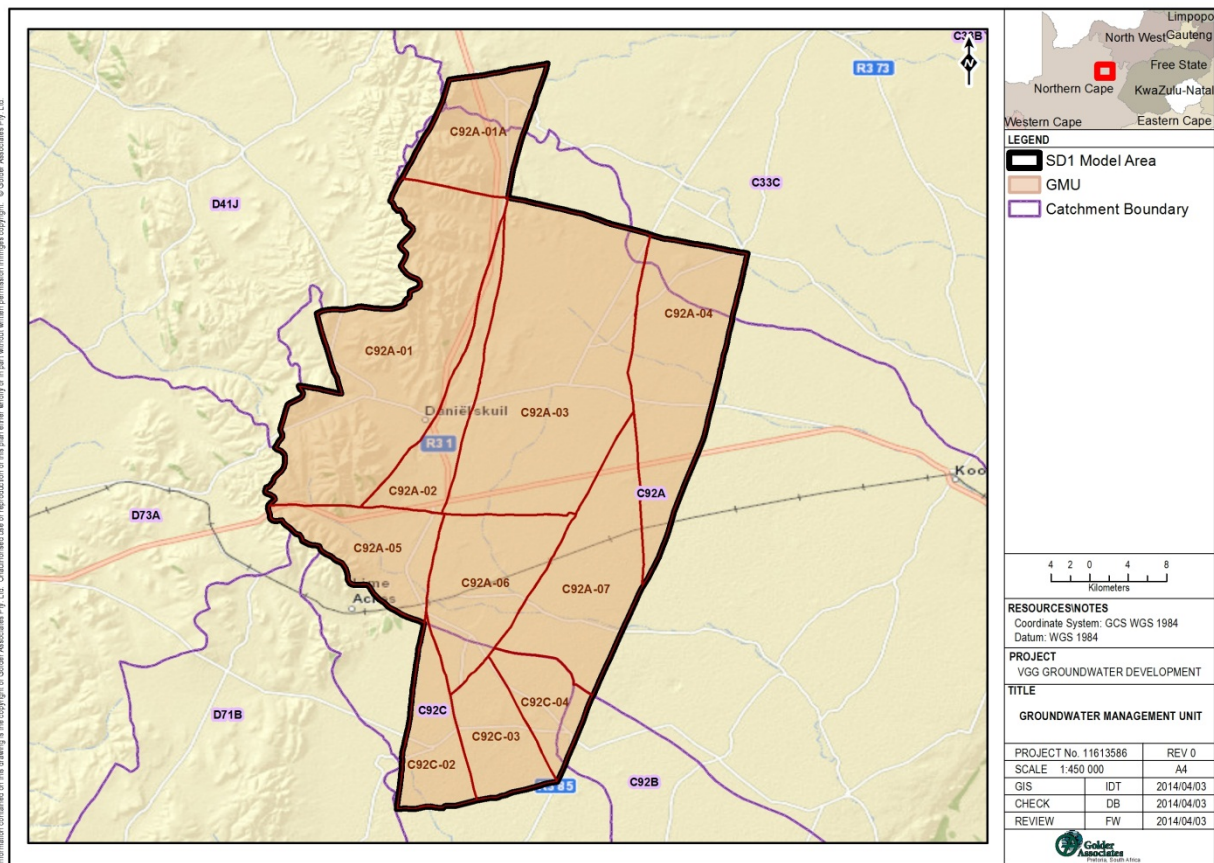


Figure 25: SD1 Groundwater Management Units

From the published hydrogeological maps (DWA 1996) the average recharge for the study area is 5mm to 10 mm per annum.

Various recharge estimates methods are available for use, depending on the availability of data. The Chloride Ratio Method was used for this study as the method works well for areas underlain by dolomite and BIF formations.

Chloride is a conservative tracer and enters an aquifer by the rainfall recharging the aquifer. The percentage rainfall, representing average annual recharge, can be derived from the ratio of the chloride concentration in rainfall relative to that of groundwater, (Bredenkamp et al, 1995). A specific requirement is that no chloride was added by dissolution of aquifer material, from salts contained within the aquifer matrix, or has entered the aquifer via pollution.

If the specific requirement above is not valid, it should be noted that the chloride ratio method will result in an underestimate of rainfall recharge and not an overestimate. Once the mean annual rainfall is determined for a local area, the mean annual recharge can be estimated by means of the chloride ratio method.

SD1 modelling area was delineated into 5 recharge zones (refer Figure 26) based on related groundwater chloride values. These recharge estimate zones were delineated using chloride values from higher yielding boreholes and boreholes considered uncontaminated. In areas with sparse or no chloride values, values from similar geological and rainfall terrains were used. These values were used to determine the % recharge from mean annual precipitation (MAP).

The mean annual recharge is the long-term maximum recharge expressed as a long-term average. Rainfall variability and intensity (depth) as well as extended droughts are important aspects which determine the

sustainability of a resource. Recharge often occurs during episodic recharge events and aquifer storage is important for sustainable abstraction to bridge extended drought periods. The median recharge is the minimum recharge that is available for 5 out of 10 years and considered the volume of water which is available for sustainable use.

The mean and median annual recharge for the SD1 modelling area recharge zones is presented in Table 8. The sustainable ground resource (median recharge) for the SD1 area for all 11 GMU's amounts 17.0 million m³/a.

Table 8: Summarised Recharges Estimates for SD1 study area based on the Chloride Ratio Method

Recharge Zone	Representative Cl (mg/l)	% Recharge	Area km ²	Mean (mm/a)	Median (mm/a)	Mean (million m ³ /a)	Median (million m ³ /a)	Quaternary Catchment Area	GMU Number
1	6.2	9.1	453	35	23.8	15.9	10.8	C92A	C92A-01
									C92A-01A
2	8.5	7.0	12	25	17	0.3	0.2	C92A	C92A-07
3	15	4.0	192	15	10.2	2.9	2.0	C92A	C92A-02
									C92A-05
4	28	2.1	56	8	5.4	0.4	0.3	C92A	C92A-03
									C92A-06
5	38	1.6	1113	5	3.4	5.6	3.8	C92A C92C	C92A-03
									C92A-04
									C92A-06
									C92A-07
									C92C-02
									C92C-03
									C92C-04
Total			1826	-	-	25.0	17.0	-	-



2.2.4.5 Groundwater Reserve



GOLDER

was done using a Groundwater Yield Model for the Reserve (GYMR). Results are summarised in the table below and indicate a groundwater balance of 12.67 million m³/a available for use in the C92A quaternary catchment.

Table 9: Groundwater reserve determination (GYMR)

Scenarios	Surface Area (km ²)	Total Inflow (Mm ³ /a)	Total Outflow before losses (sinks) Mm ³ /a	Total abstraction (WARMS) + calculated (Mm ³ /a)	Evapotranspiration flow loss along streams (Mm ³ /a)	Net Base Flow (Mm ³ /a)	Net Base Flow EWR (Mm ³ /a)	Usable GW Component from base flow (Mm ³ /a)	GRDM status Category
GYMR Present Day	3913	27.50	-3.19	-0.63	-6.21	-18.10	-5.43	12.67	B

2.2.4.6 Groundwater Quality

Baseline Water Quality

The baseline water quality of SD1 exploration boreholes (43) is based on macro chemistry analysed for the sampled boreholes. The concentrations are compared to the SANS 241:2011 water quality standard and the baseline quality are represented by the median of the concentrations. The baseline water quality of the new exploration boreholes is summarised in the table below.

Table 10: Groundwater quality parameters for the SD1 Well Field Area

Item	Physical Parameters			Macro Determinants (Major Ions)								Minor Determinant		
	pH	EC mS/m	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	SO4 mg/l	NO3 mg/l	MALK Mg/l	F mg/l	Fe mg/l	Mn mg/l
No. of Records	43	43	43	43	43	43	43	43	43	43	43	43	43	43
10 % Percentile	7.25	26.72	174.40	35.00	12.06	5.34	1.72	8.31	11.20	0.30	143.60	0.10	0.05	0.05
Median Baseline water Quality	7.54	67.1	420	86.3	33.8	11.7	2.49	29.3	28.2	3.325	292	0.1	0.05	0.05
Average	7.52	61.42	410.93	78.87	33.18	17.20	3.45	39.99	34.12	3.48	273.05	0.13	0.08	0.08
90% Percentile	7.72	87.70	588.40	98.72	50.56	35.84	5.96	80.86	66.94	5.99	377.20	0.16	0.05	0.15
Max. Allowable Limit (SANS 241:2011)	<5 >9	<170	<1200	<300	<100	<200	<100	<300	<500	<11	-	<1.5	<0.3	<0.5

The background groundwater type for SD1 study area are calcium magnesium bicarbonate type of water (Ca, Mg) (HCO₃)₂, representing unpolluted groundwater.

2.2.4.6.1 Point Source Pollution

From the analytical results existing point source pollution was reported in eight of the existing boreholes and one newly drilled exploration borehole. Existing boreholes impacted by point source pollution exceeding the DWAF (1998) Class 1 drinking water quality standard are listed in Table 11 and indicated on Figure 27.

Table 11: SD1 Existing Point Source Pollution

Borehole No.	Farm	Chemical Determinants Exceeding DWAF drinking Water Standard Class I	DWS Water Quality Class
SD1-GAA017	Carter Block Ptn. Dikbos	Mg, NO3	II
SD1-GAA018	Carter Block Ptn. Dikbos	NO3	II
SD1-GAA020	Carter Block Ptn. Dikbos	Ca, NO3	II
SD1-GAA066	Tevrede	EC, TDS, Mg, NO3	II
SD1-GAA105	Carter Block Ptn. Siver Streams	NO3	III
SD1-GAA107	Carter Block Ptn. Outpost	EC, TDS, Ca, Cl, NO3	II
SD1-GAA159	Strydpan Ptn. Selfhelp	EC, TDS, K, NO3	III
SD1-GAA227	Jonasbank	Mg, NO3	II
SD1-10	Carter Block Ptn. Dikbos	NO3	II

Point source pollution is from well-defined and specific sources e.g. animal farming and stockades.

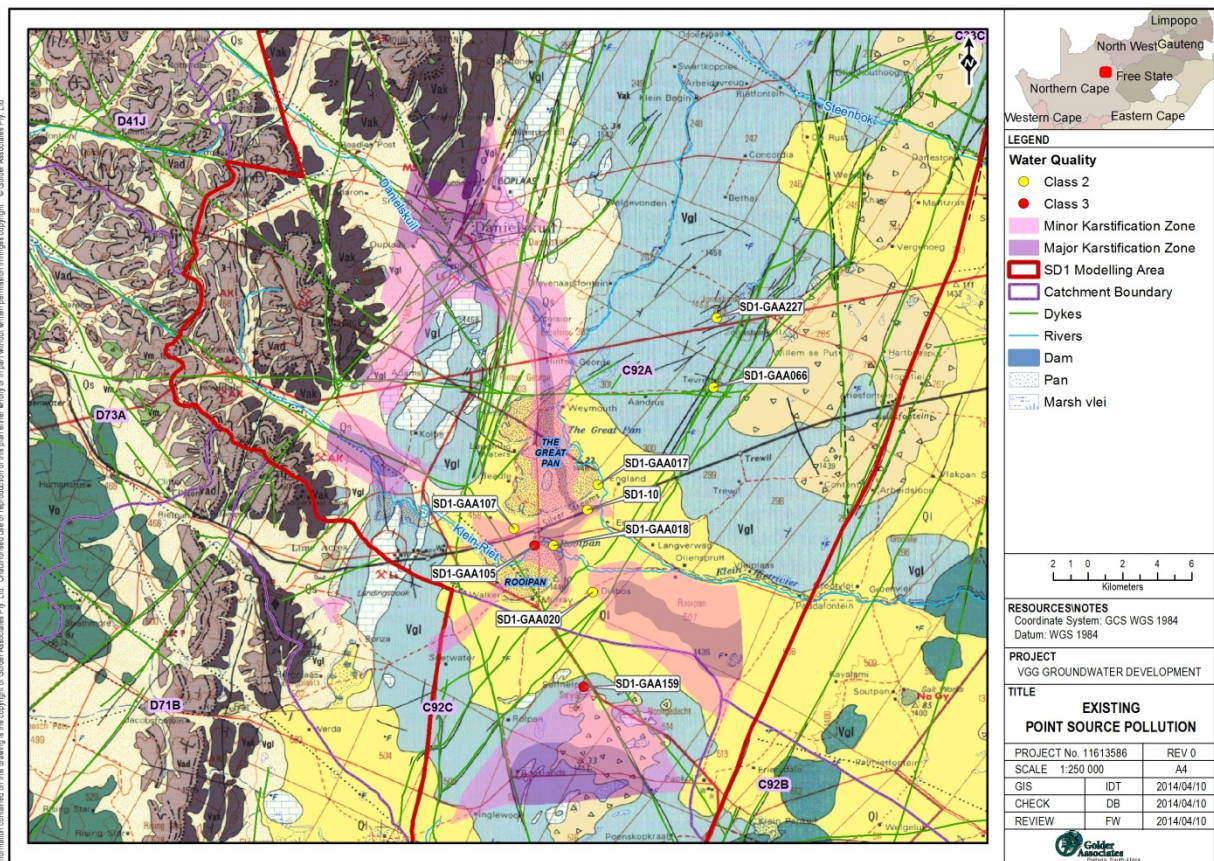


Figure 27: SD1 Existing Point Source Pollution

2.2.4.7 Hydrogeological Conceptualizing

The hydrogeological conceptualizing for SD1 was developed from data gathered during the exploration phase. The conceptualizing forms the basis for the understanding of the groundwater occurrence and flow mechanisms of the study area and is used as basis for the numerical groundwater model.

Because of the extent of the investigation area the hydrogeology is conceptualised and represented as three hydrogeological sections, the positions of sections are indicated on Figure 28:

- Cross Section A – B,
- Cross Section B – C, and
- Cross Section D – E.

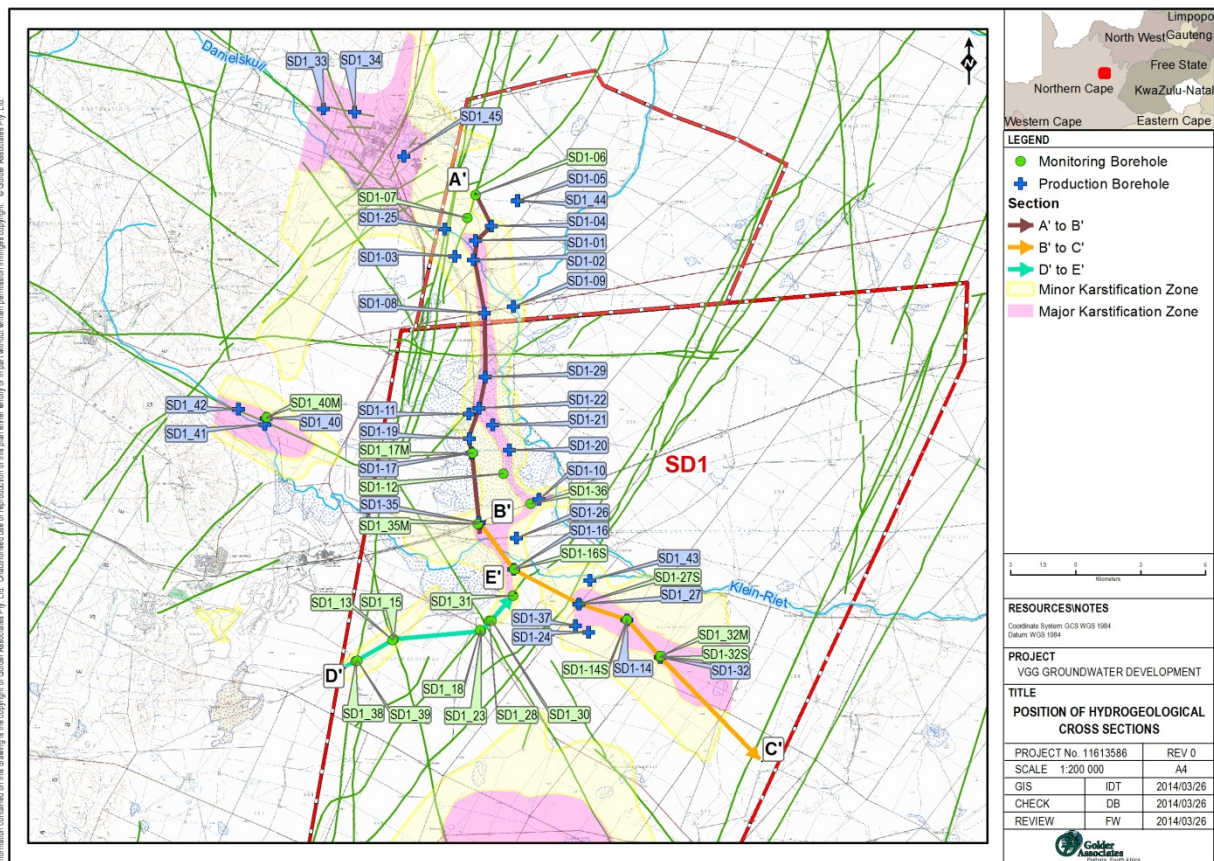


Figure 28: Position of Hydrogeological Cross Sections

Hydrogeological Cross Section A – B

A hydrological cross section was done in a north – south direction to illustrate the geological and hydrogeological information associated with the main karstification zone and the paleo-river channel as delineated by the aerial geophysical survey (Figure 29).

The cross-section shows the presence of a thin calcrete layer (2 to 6m) at surface with a low permeability. Semi consolidated BIF which filled in the paleo-river channel, chert rich dolomite and wad zones is present, with major karstification in the dolomites.

These karstification zones which developed below the paleo channel and along dolerite dyke contact are highly permeable with blow yields intersected as high as 50l/s (SD1-17).

The groundwater flow direction is towards the south, with Transmissivity values ranging from 35 to 2573 (SD1-8).

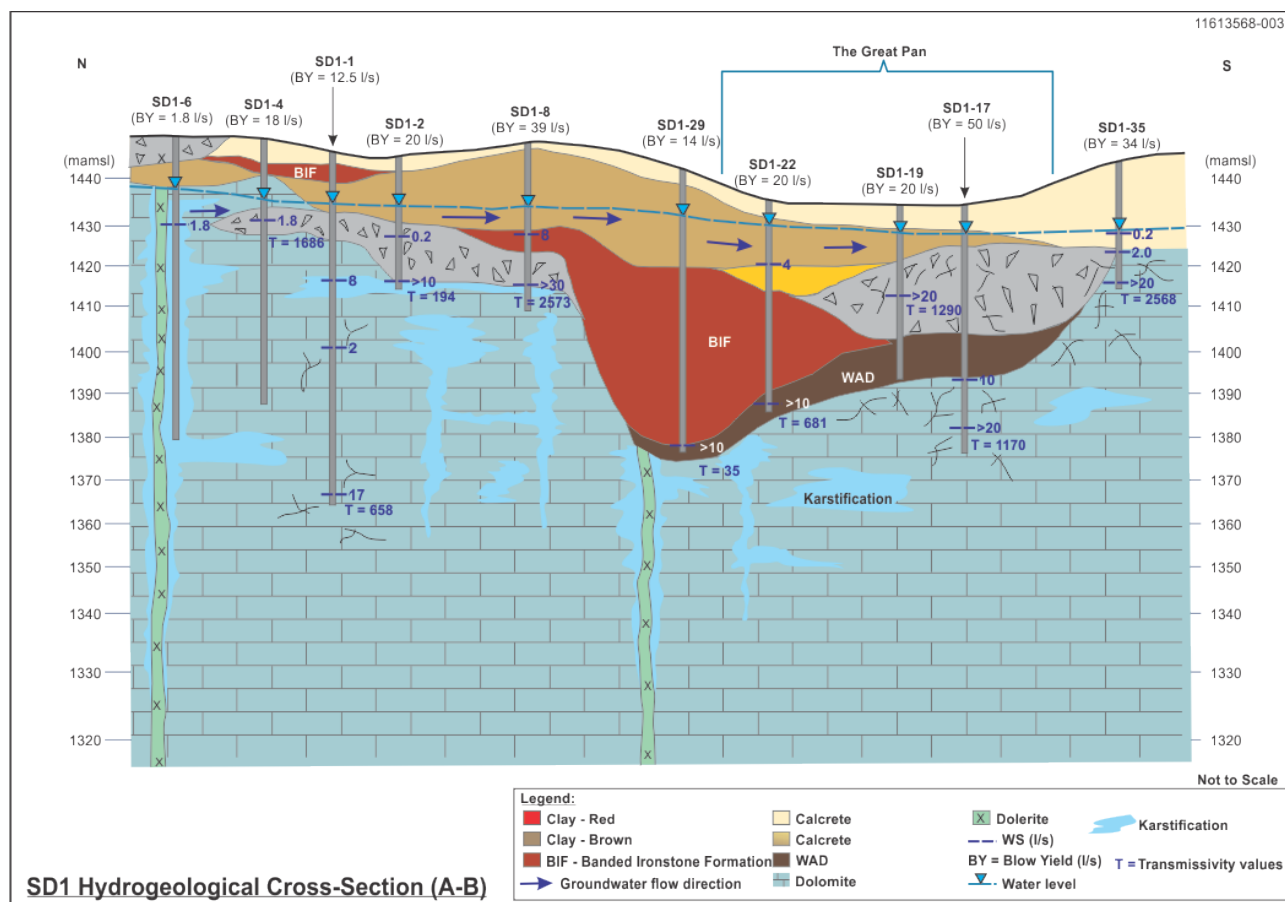


Figure 29: Hydrogeological Cross Section A - B

Hydrogeological Cross Section B – C

A hydrological cross section was done in a northwest – southeast direction to illustrate the geological and hydrogeological information obtained from the borehole drilling and is illustrated in Figure 30

The cross-section shows the presence of a thick calcrete layer (20 to 60m) at surface with a low permeability and is the host formation of the 'Olienhoutboom' forest. Semi conciliated BIF which filled in the paleo river channel is present below the calcrete layer, with major karstification in the dolomites.

These karstification zones which developed below the paleo channel and along dolerite dyke contact are highly permeable with blow yield intersect ranging from 10 to 40l/s.

The groundwater flow direction is towards the south-east, with Transmissivity value as high as 2568 (SD1 - 35).

Hydrogeological Cross Section D – E

A hydrological cross section was also done in a southwest – northeast direction to illustrate the geological and hydrogeological information obtained from the boreholes drilled in this area and illustrated in Figure 31.

The cross-section shows the presence of a calcrete layer 10 to 30m in thickness at surface. This area of calcrete is also the hosting formation of the 'Olienhoutboom' forest.

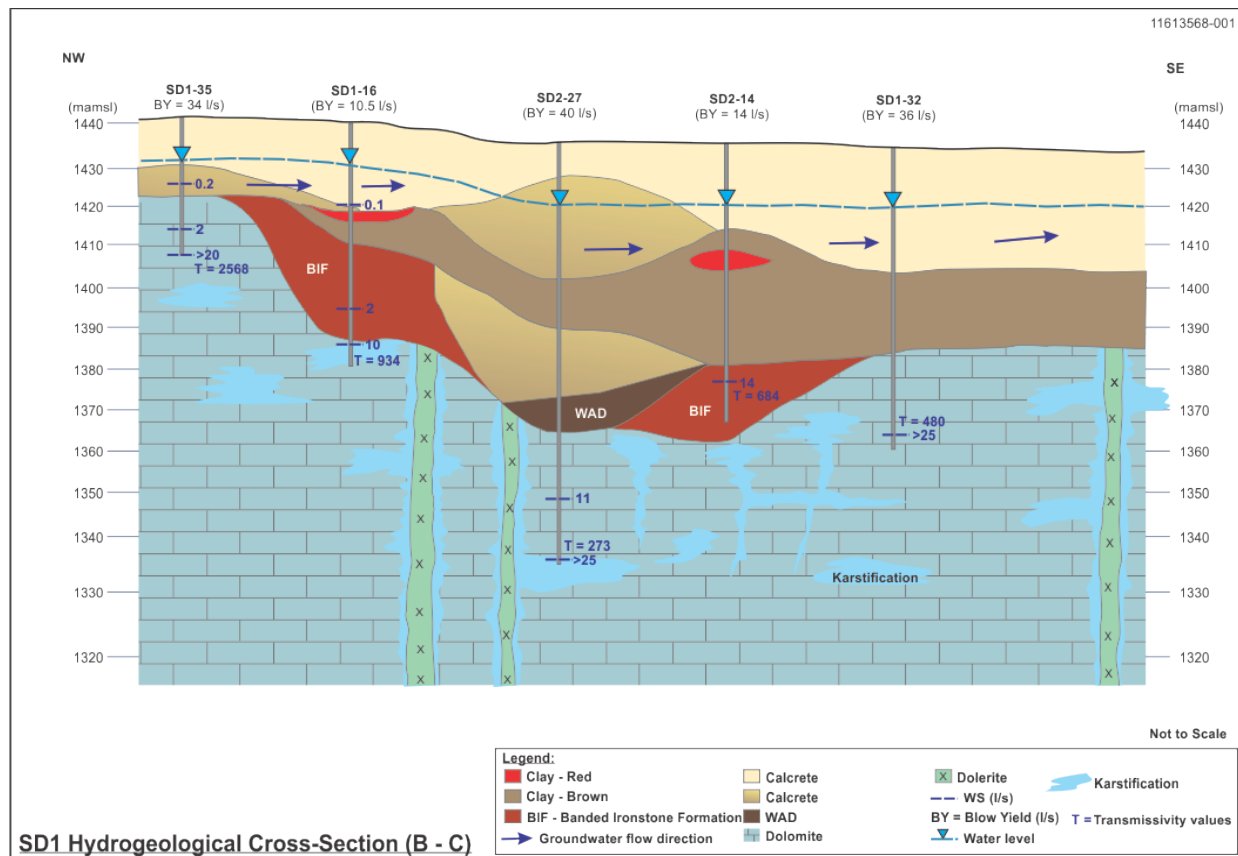


Figure 30: Hydrogeological Cross Section B - C

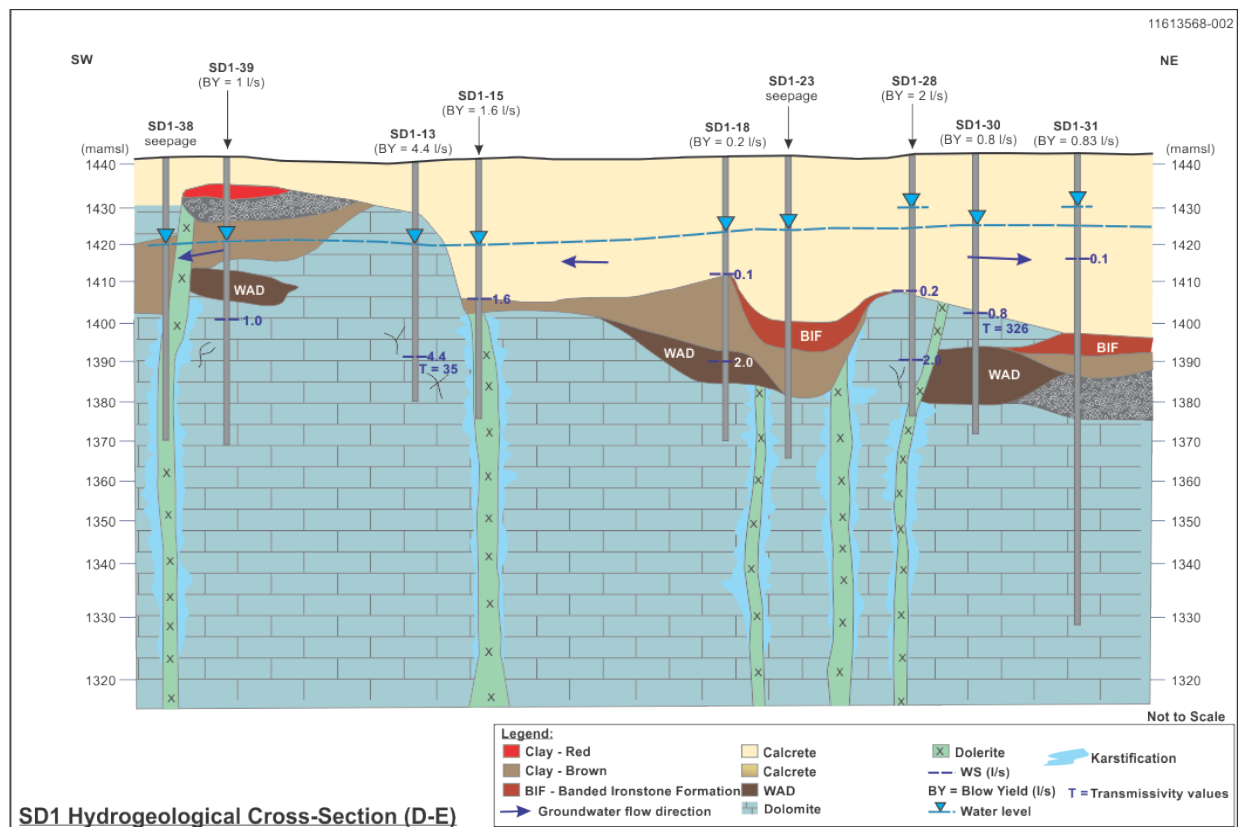


Figure 31: Hydrogeological Cross Section D - E

Minor karstification is dominant in this cross section and is mainly restricted to dolerite and dolomite contact zones. The permeability of the boreholes intersected in this section is low with the highest blow yield intersected 4.4l/s (SD1-13). Transmissivity values range between 35 and 326.

SD1 Aquifer Zones

From the available drilling and test pumping data of SD1, three aquifer systems were identified in the different geological formations:

- Upper Kalahari Sediments - intergranular unconfined aquifer system comprising mainly out of calcrete, gravel and clay. This aquifer zone has a low permeability retards and restrict water movement and acts as storage unit,
- Fractured and weathered semi consolidated Banded Ironstone Formation (BIF), semi confined aquifer system,
- Dolomite karst aquifer system, unconfined to semi confined aquifer system, compartmentalised by dolerite dykes and highly permeable, and
- The conceptual assumption is made that dolerite dykes are partially permeable for +/- 4m below SWL, allowing groundwater interflow between compartments. Below 4m the dolerite dykes are impermeable and acts as groundwater flow barriers responsible for compartmentalization in the formations.

The hydraulic parameters of the three defined aquifer zones are summarized in Table 12.

Table 12: Summarised Hydraulic Parameters

Aquifer zone	No. of BH'S	Storativity S	Average S	T (m ² /d)	K(m/d)	Average T (m ² /d)	Average K (m/d)
New Exploration Boreholes							
Upper Kalahari Calcrete and Gravel	4	-	-	-	0.00101 to 0.00654	-	0.003498
Fractured and Weathered semi consolidated BIF	6	0.03220	-	35 to 917	-	308	-
Karstification in Dolomite	28	2.24E-08 to 34.90	6.98414	23 to 10273	-	1432	-
Existing Boreholes							
Aquifer Zones not Differentiated	17	0.00001 to 0.38000	0.04178	0.7 to 6526	-	623	-

2.2.5 SD1 Groundwater Modelling

A comprehensive 3D numerical groundwater flow model was constructed at quaternary catchment scale to assess the impact of the proposed SD1well field on the regional groundwater flow, aquifer storage and discharge.

The software code chosen for the numerical finite-element modelling work was the 3D groundwater flow model SPRING. The program was first published in 1970, and since then has undergone several revisions

and is widely accepted by environmental scientists and associated professionals. SPRING uses the finite-element approximation to solve the groundwater flow equation. This means that the model area or domain is represented by several nodes and elements. Hydraulic properties are assigned to these nodes and elements and an equation is developed for each node, based on the surrounding nodes. A series of iterations are then run to solve the resulting matrix problem utilising a pre-conditioning conjugate gradient (PCG) matrix solver for the current model. The model is said to have “converged” when errors reduce to within an acceptable range. SPRING can simulate steady and non-steady flow, in aquifers of irregular dimensions.

2.2.5.1 Groundwater Model Construction

Model Domain

The model domain boundaries were established during the hydrogeological conceptualisation and adapted accordingly during model construction. The model boundaries were selected along mapped dykes, often coinciding with the quaternary catchment (C92A) boundaries, to ensure a dependable water balance for the model with recharge being the main driver of groundwater flow. A number of head dependant boundary conditions were assigned mainly along the eastern and southern edge of the model domain representing potential groundwater outflow towards adjacent aquifer systems (Figure 32).

The total model domain covers an area of 1 826 km² and was spatially discretised into 111 512 nodes on 5 node layers, which make up 4 element layers with 121 468 elements (triangles and quadrangles) per layer, to account for the various hydrogeological units underlying the proposed SD1 well fields (Delta H; 2014).

Groundwater Model Layers

The finite-element model was set-up as a three-dimensional four element layer groundwater flow model. The vertical model discretisation respectively model layer coincides with the conceptual hydrogeological model.

The upper layer (split into two model layers to increase the accuracy of the unsaturated flow calculations) represent the highly weathered- and karst aquifer to a depth of 4 m below the interpolated groundwater level. The third layer represents the highly karstified hydrogeological unit to a depth of 15 m below the interpolated groundwater level.

The bottom elevation of the groundwater flow system was set at approximately 90 m below the current groundwater level, resulting in a model thickness ranging from 92 to 370 m. The layer arrangement is summarised in Table 13 and shown in a cross-section in Figure 33.

Table 13: SD1 Groundwater Model Layer Arrangement

Node layer	Element layer	Map colour	Aquifer feature	Data used for interpolation
1	I, top		Surface elevation	SRTM 90 m Digital Elevation Model (DEM)
2	I, bottom		Weathered- and Karst Aquifer	Divide Layer 1 into 2 (Equal proportion)
3	II, bottom		Weathered- and Karst Aquifer	Fixed offset of 4 m from interpolated water level
4	III, bottom		Karst Aquifer	Fixed offset of 15 m from interpolated water level
5	IV, bottom		Karst Aquifer	90 m below Water Table

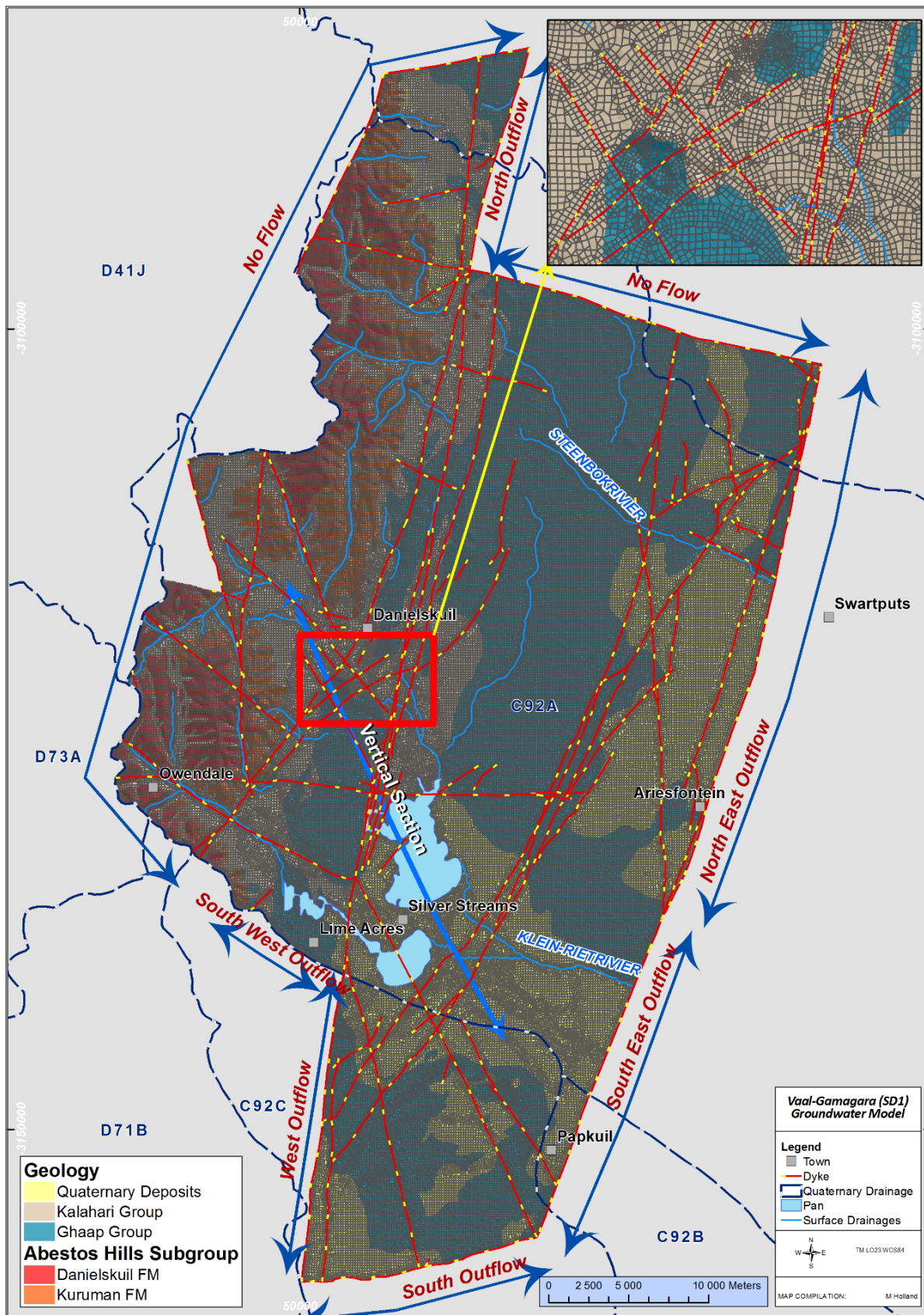


Figure 32: SD1 Groundwater Model Domain

The vertical section, chosen along the Idwala Mine Quarry and The Great Pan (north of Silver Streams) (Figure 33) shows the vertical discretisation of the model domain.

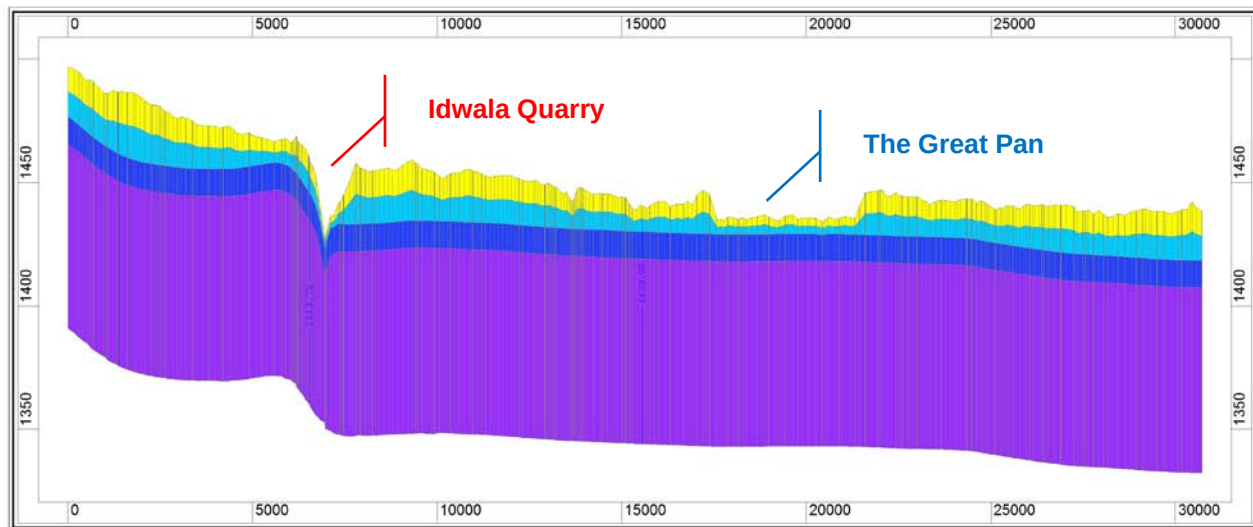


Figure 33: SD1 Vertical Grid Layout Example

Groundwater Recharge

Groundwater enters the model domains as direct recharge from rainfall. It was implied that certain areas may have greater recharge potential and may thus contribute a larger proportion of recharge towards the aquifer system respectively. Based on the conceptual understanding of the SD1 groundwater system, the median annual recharge for different zones varies from 3.5 to 16mm (Figure 34).

The spatial distribution of existing groundwater monitoring boreholes is shown in Figure 34. Available groundwater monitoring data is mainly located within recharge zone 1, 3 and 4, and absent in recharge zone 2 and 5. It must also be noted that not all monitoring boreholes have complete records of water levels, or represent in some cases water levels during pumping conditions and not static (rest) water levels.

Nevertheless, monitoring data show a good relationship between the Cumulative Rainfall Departures (CRD) from the mean rainfall (for the Danielskuil rainfall station) and observed water level fluctuations in the dolomitic aquifer, which indicates dynamic recharge (Figure 35). Since the direct cause/effect relationship between the CRD and water levels was observed, an empirical relationship between rainfall and recharge events can be assumed. Based on earlier modelling studies conducted on dolomitic terrain, an exponential relationship between recharge and rainfall produced acceptable results. The resulting recharge (mm/month) was derived as a fraction of rainfall based on the following formula: $\text{Recharge Fraction} = .05e^{(0.01 \cdot \text{Rainfall})}$.

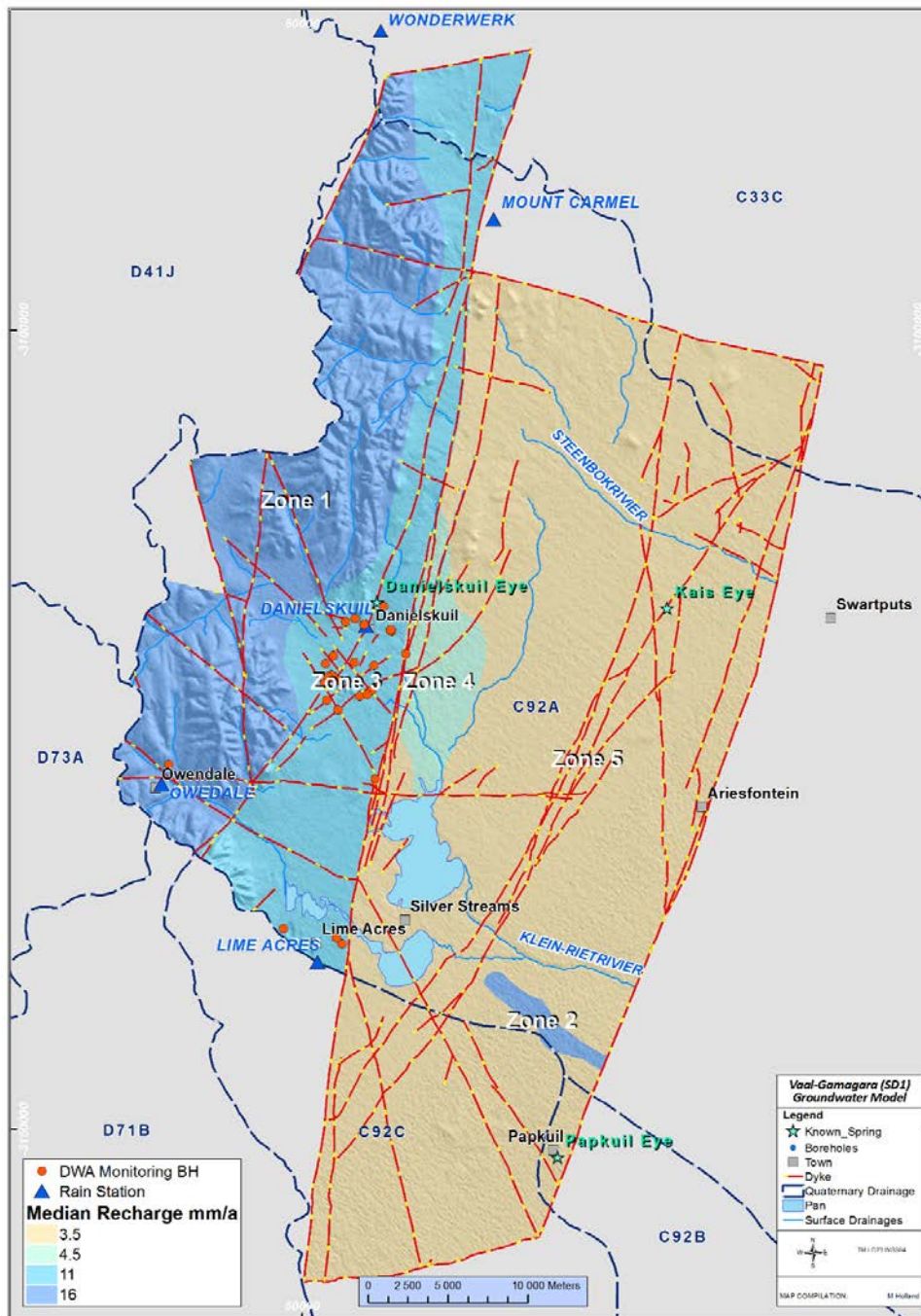


Figure 34: SD1Assigned Recharge Zones and Rates.

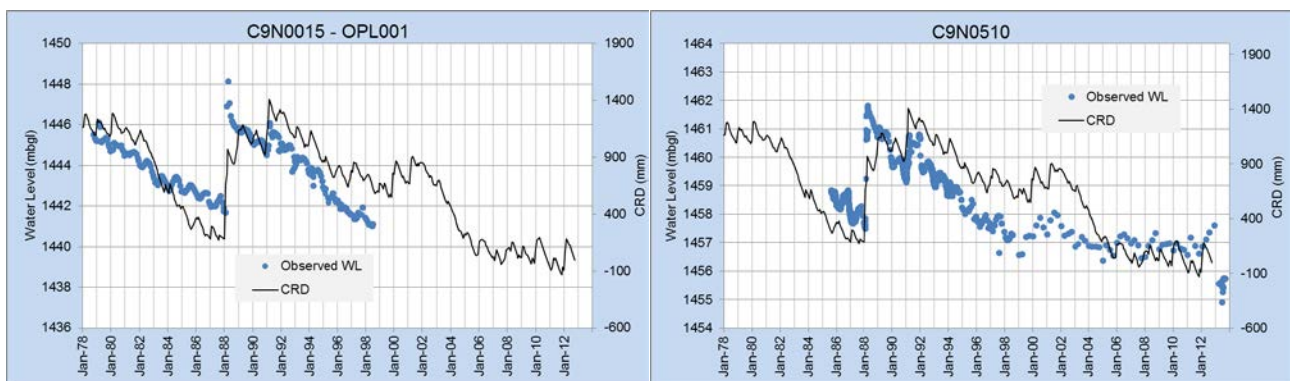


Figure 35: Groundwater level versus the Cumulative Rainfall Departure

Groundwater Abstraction

The Both steady state and transient borehole abstraction from the model domain was simulated using the withdrawal well boundary condition. Outflow rates were assigned to single nodes (at the appropriate elevation) within the model mesh. For fully penetrating wells, equal heads were prescribed for all applicable well nodes and the inflows for each node automatically calculated by the software. The annual abstraction rate applied to the steady state model amounts to 231,797m³/month or 2,781,564m³/annum.

River Courses and Springs

Groundwater within the study area was assumed to originate as spatially distributed rainfall recharge within the model domain. It is thought that a portion of the groundwater recharge occurring within the model domain discharges internally to surface drainage systems via springs or as discharge to the river drainage systems (baseflow).

The interaction between groundwater and surface water courses was simulated under the assumption of continuous gaining river systems (i.e. groundwater is only allowed to discharge into them and not vice versa). These drainages were therefore described within the model using SPRING's 'river package', with no exfiltration of surface water allowed. The stage of each river node was carefully aligned with the height of the Digital Elevation Model (DEM) at that point and an incision the river bottom of 2 m below topography assumed. A riverbed conductance of 1E-7 m/s was assumed. Known springs within the SD1 area were incorporated as leakage boundary conditions at the specific node of the spring location.

Mine Quarry

The Idwala open cast mine working (pit) was integrated into the model domain for the predictive simulations by updating the digital elevation model for the pit area and assigning a free seepage boundary to the pit area. It is assumed that any groundwater entering the pit is removed (pumped out) and that the pit bottom represents therefore the lowest drainage elevation. Groundwater seeps freely into the pit, with a subsequent development of a cone of dewatering. It must be noted that the computation of the free groundwater table and pit inflows consider partially saturated flow conditions using the van Genuchten equation to calculate the relative permeability as a function of the capillary pressure, saturation, residual saturation and entry pressure.

2.2.5.2 Model Calibration

Steady State Calibration

Once a reasonable fit of the piezometric contours respectively their gradients was established using the gradient method within the SPRING software package, the measured groundwater levels (in metres above mean sea level) observed in 373 boreholes were used as calibration targets. The regional water level measurements spread over decades and represent therefore by no means a single snapshot of water levels taken under the same climatic conditions and land uses or average conditions. The project team biased therefore the steady state calibration towards a reasonable fit of the most recent water levels respectively abstraction and recharge conditions. The three available spring outflows together with the Idwala Pit inflows were considered as secondary targets in the calibration process.

Since the modelled groundwater levels are directly related to the assigned recharge rates and hydraulic conductivities, an independent estimate of one or the other parameter is required to arrive at a potentially unique solution of the model calibration. The estimated recharge rates were therefore considered fixed for the steady state calibration and only hydraulic conductivities considered variable, i.e. adjusted within reasonable boundaries to represent the observed flow system.

The spatial distribution of the calibrated conductivity values for layer I is shown in Figure 36 and the values for all model layers summarised in Table 14.

Table 14: Calibrated Hydraulic Conductivity Ranges for SD1 Groundwater Model

Layer	Aquifer	Hydraulic conductivity (m/s)	
		Min	Max
I-IV	Dyke (Barriers to Flow)	1E-9	1E-7
I, II and III	Weathered- and Karst Aquifers	1E-6	4E-4
	BIF	1E-7	5E-6
IV	Deep Karst Aquifer	5e-7	1e-5

Transient Calibration

To simulate the temporal responses of the aquifers to variable rainfall recharge and external stresses (abstractions), a transient calibration of the steady-state model is required. Although transient calibration introduces another uncertain fitting parameter, namely the storage coefficient *S* (as a sum of specific storativity and yield for unconfined aquifers), it partially eliminates the non-uniqueness of the steady-state calibration parameters and provides additional insight into the appropriateness of the conceptual model.

Transient simulations require the definition of stress periods, during which boundary conditions remain constant, and time steps, for which model calculations are made. Since the frequency of the rainfall measurements were provided monthly the water balance of the model was calculated on a monthly time-step. Stress periods assigned in the present model can be divided into two components:

- The first component covers the transient calibration phase from 1978 to 2012 and entailed 421 (months) stress periods with variable monthly recharge rates; and
- The second component entails stress periods assigned for the predictive model runs considering various aquifer management scenarios for the period 2013 to 2030 (205 stress periods).

The model was further optimised by calibrating the simulated heads to observed pumping test drawdown data for 10 SD1 production boreholes. The pumping tests ranged from 24 to 72 hours and the transient model comprised of 73 one-hour time steps. A summary of the calibration targets is shown in Table 15. The pumping tests do not represent the entire the model domain and is limited to the SD1 well field region.

For the transient calibration, the available long-term water level monitoring and 10 (SD1) pumping test datasets were used as calibration. The main aim of the calibration was to match the “signature” or behaviour of temporal water table fluctuations observed, rather than the actual head itself.

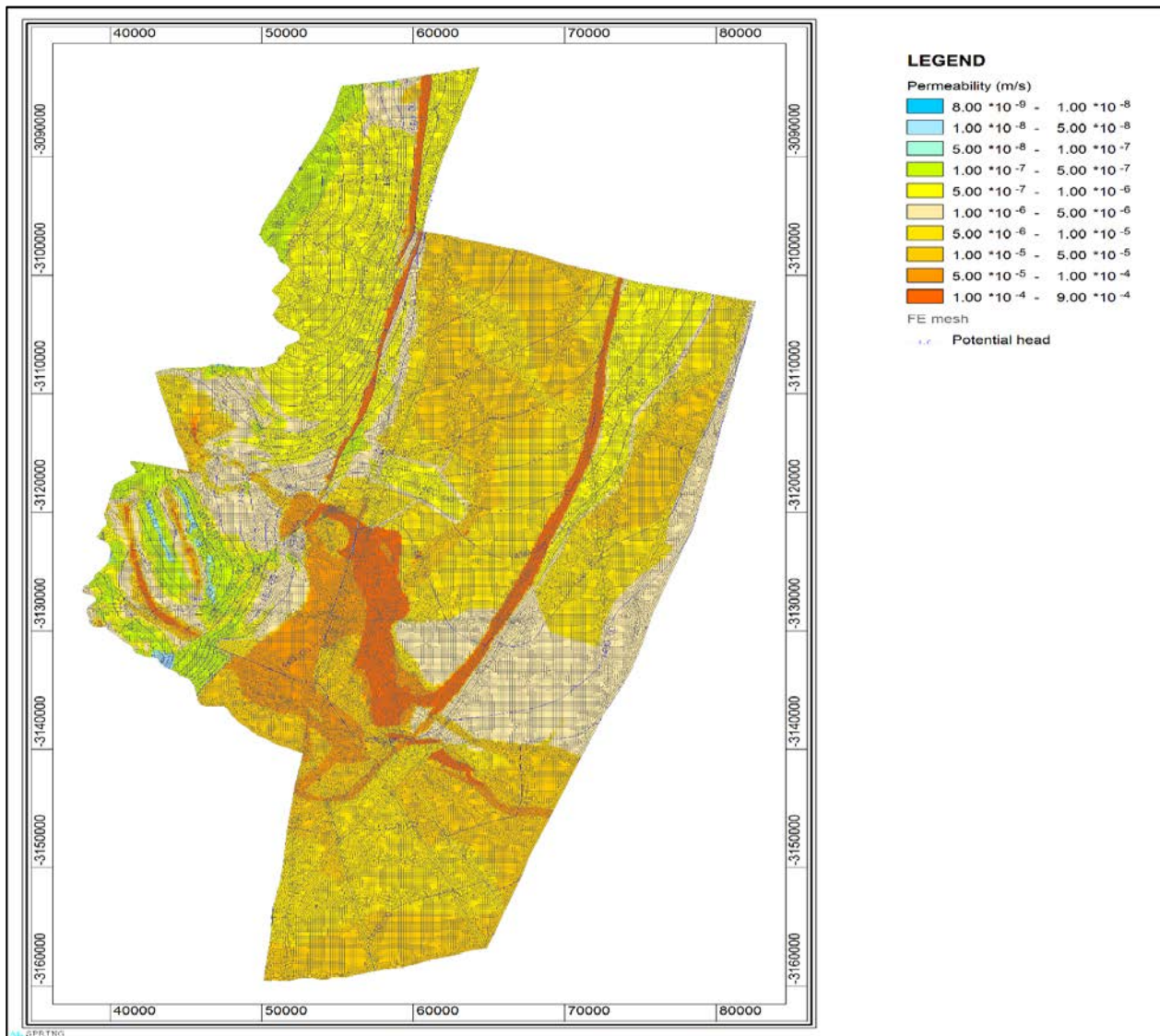


Figure 36: Distribution of Permeability in Layer 1 together with Steady State Heads (10 m Contour Interval)

Table 15: SD1 Transient Calibration of Target Boreholes

BH ID	Model Node	L/S	m ³ /hour	Time (Minutes)
SD1-08	69	30	108	1440
SD1-16	77	20	72	2880
SD1-17M	163	30	108	4320
SD1-20	82	30	108	1440
SD1-25	87	30	108	4320
SD1-27	89	30	108	2880
SD1-32M	95	30	108	4320
SD1-35M	101	30	108	4320

BH ID	Model Node	L/S	m ³ /hour	Time (Minutes)
SD1-40	105	10	36	4320
SD1-44	109	30	108	4320

Figure 37 shows a comparison of long-term trend (1978 to 2012) simulated vs. observed heads for several representative boreholes. Results show that in most cases the “signature” of the temporal water level fluctuations is sufficiently well represented by the model. The “off-set” between observed and simulated heads for some boreholes appears to be a result of the assigned steady state starting water levels, which reflect average and not actual historical water levels at a given point in time. In all cases, this “off-set” is acceptable (within 2 meters) and within the seasonal range of water level fluctuations.

At this stage, seasonal monitoring data for the transient model calibration are only available for the catchment area upstream of the SD1 well field (mainly Danielskuil area). *Once monitoring data over a full hydrological year become available for the SD1 well fields area, the model should be re-calibrated and predictions updated.*

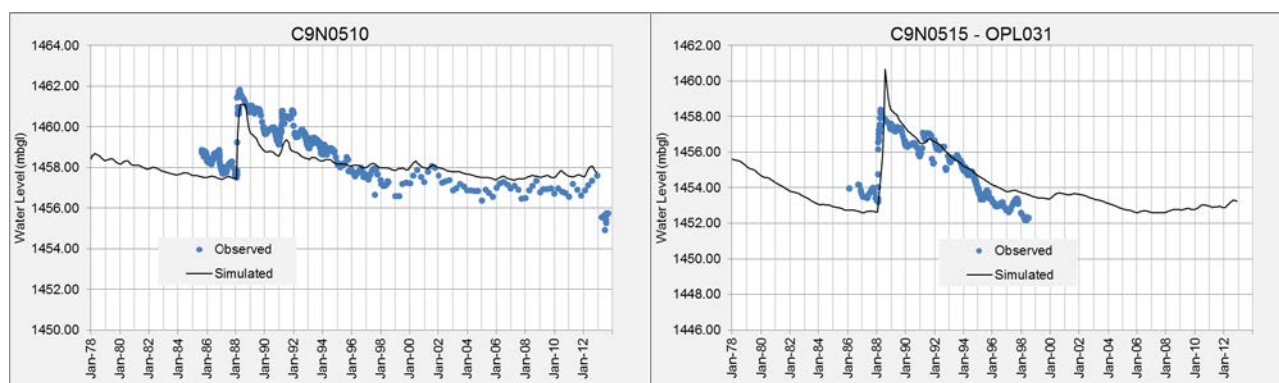


Figure 37: Simulated Versus Observed Groundwater Levels

The transient calibration of pumping test datasets (24 to 72 hours) refines and verifies the steady-state calibration by matching transient hydraulic-head trends which reflect the stresses of pumping from the production boreholes (Figure 38). The transient model calibration was used to optimize the spatial variability of storage coefficients.

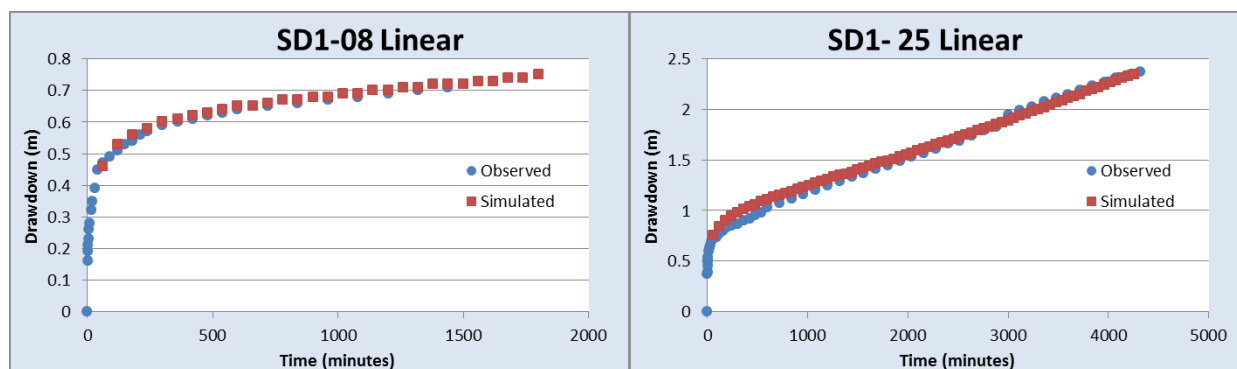


Figure 38: Transient Model Calibration using Normalized (to initial static) Drawdown

An acceptable fit is observed for most pumping test boreholes. In some cases, the drawdown behaviour cannot be accurately represented due to the heterogeneity of fracture distributions and subsequent hydraulic discontinuities proximal to the pumping well.

2.2.5.3 Predictive Stimulations

Water Balance

A summary of the steady state water balance is provided in Table 16. The steady-state water balance (Table 16) shows that the vast majority of recharge (which is the only model inflow) contributes to baseflow in drainages (including evapotranspiration losses along these drainages and pans) and spring discharges within the model domain, with only around 26 % of the inflow (recharge) reporting to the head dependent outflow boundaries, i.e. towards downstream catchments. Total (steady-state) groundwater abstractions consume for the steady-state scenario around 20% of the total recharge for the area. The Idwala pit inflows was estimated at 26,311 m³/month compared to an alleged inflow of approximately 22,000 m³/month.

Table 16: SD1 Regional Steady State Water Balance

Regional Water Balance		
Inflow	m ³ /month	m ³ /annum
Recharge	1 176 273	14 115 274
Outflow	m ³ /month	m ³ /annum
Spring Discharge	-33 523	-402 276
Boreholes Abstraction	-231 797	-2 781 564
Contribution to Drainages, pans and potential evapotranspiration	-575 713	-6 908 554
Outflow Boundary	-308 929	-3 707 148
Idwala Pit Inflows	-26 311	-315 732
Total Outflow	-1 176 273	-14 115 274

Applied Rainfall Variability (2013 to 2030)

The calibrated transient model was subsequently used to simulate the impact of proposed abstractions from the SD1 well field on the water levels and water balance of the regional aquifer system. The predictive scenario was simulated based on historically observed rainfall variability. The rainfall/recharge data from 1996 to 2012, which is regarded to be a conservative approach, was used to simulate the rainfall recharge in the predictive scenario (Figure 39).

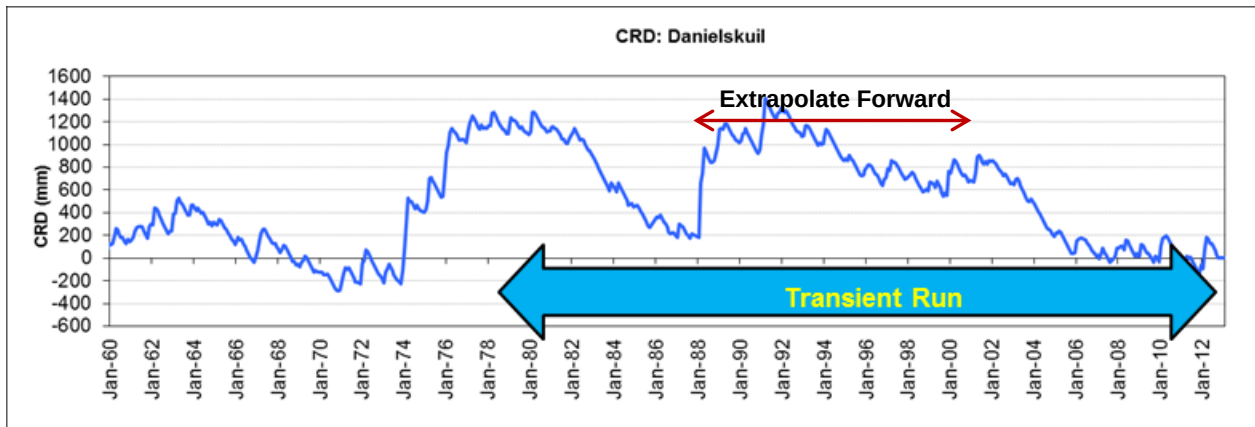


Figure 39: CRD Curve for the Danielskuil Rainfall Station showing the Extrapolated Scenario Interval (red arrow) used for the Predictive Simulations

Applied Abstraction Scenarios (2013 to 2030)

The forward simulations of the proposed SD1 Well field considered four abstraction scenarios, namely:

- Scenario 0 – Base or reference case with no abstractions, i.e. the well field project no-go option.
- Scenario 1 – 22 SD1 and 3 Danielskuil production boreholes:
 - Upper limit abstraction with a combined yield of 724,890 m³/month (**8.7 million m³/a**) for the SD1 production boreholes and 39,420 m³/month (0.47 million m³/a) for the designated Danielskuil boreholes.
- Scenario 2a – 15 SD1 and 3 Danielskuil production boreholes:
 - Optimised long-term abstractions with a combined yield of 444,132 m³/month (5.3 million m³/a) for the SD1 production boreholes and 19,710 m³/month (0.24 million m³/a) for the designated Danielskuil boreholes.
- Scenario 2b – 15 long term SD1 boreholes and 7 short term SD1 boreholes only initiated (into production) from 2015 to 2017 and again from 2024 to 2026 together with the 3 Danielskuil production boreholes:
 - Optimised long- and short-term abstractions with a combined yield of 553,632 m³/month (6.6 million m³/a) for the SD1 production boreholes and 19,710 m³/month (0.24 million m³/a) for the designated Danielskuil boreholes.

The SD1 well fields and associated (upper limit Scenario 1) abstraction rates is shown spatially in Figure 40.

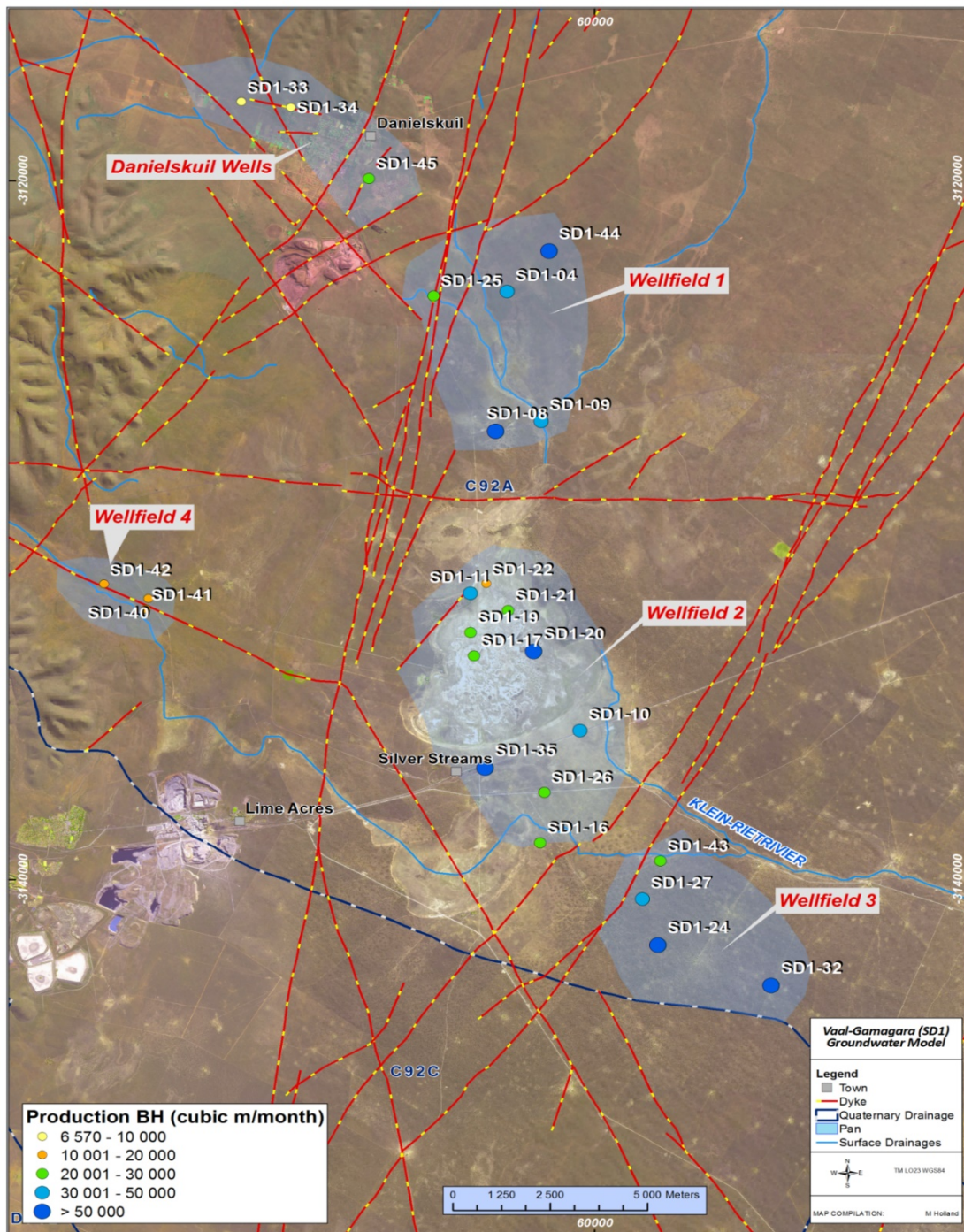


Figure 40: Locality of SD1 Well Fields

SD1 Well Field Scenario 1

Scenario 1 can be considered as a worst-case scenario with abstraction rates close to the upper limit of the recommended yields obtained through the local pumping test analysis. As a result, the predictive simulation run reveals a wide-ranging cone of depression, extending approximately 30 km north to south along the well fields and up to 18 km east to west (considering a 2 m cut-off value), due to the distribution of the well fields as shown in Figure 41. The clearly anisotropic zones of influence or groundwater drawdown are due to the presence of dykes with lower permeabilities resulting in the compartmentalisation of the aquifer system.

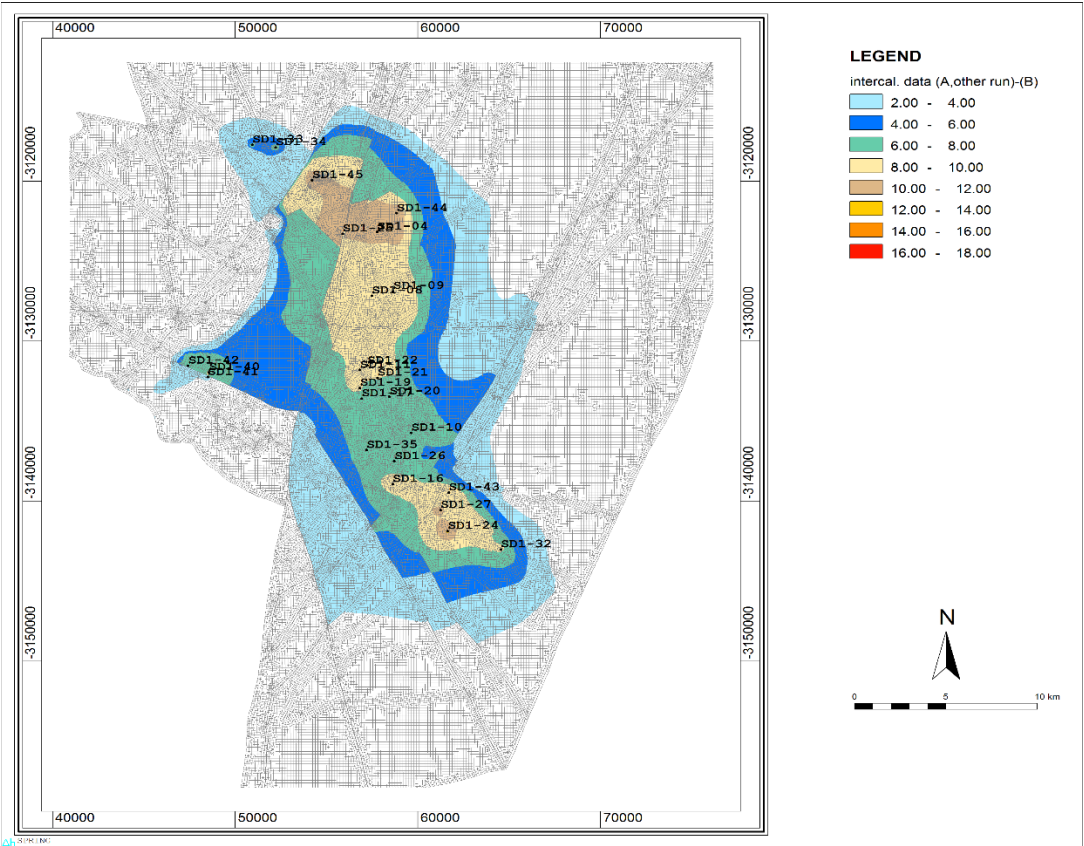


Figure 41: Scenario 1-Cone of Dewatering (m)

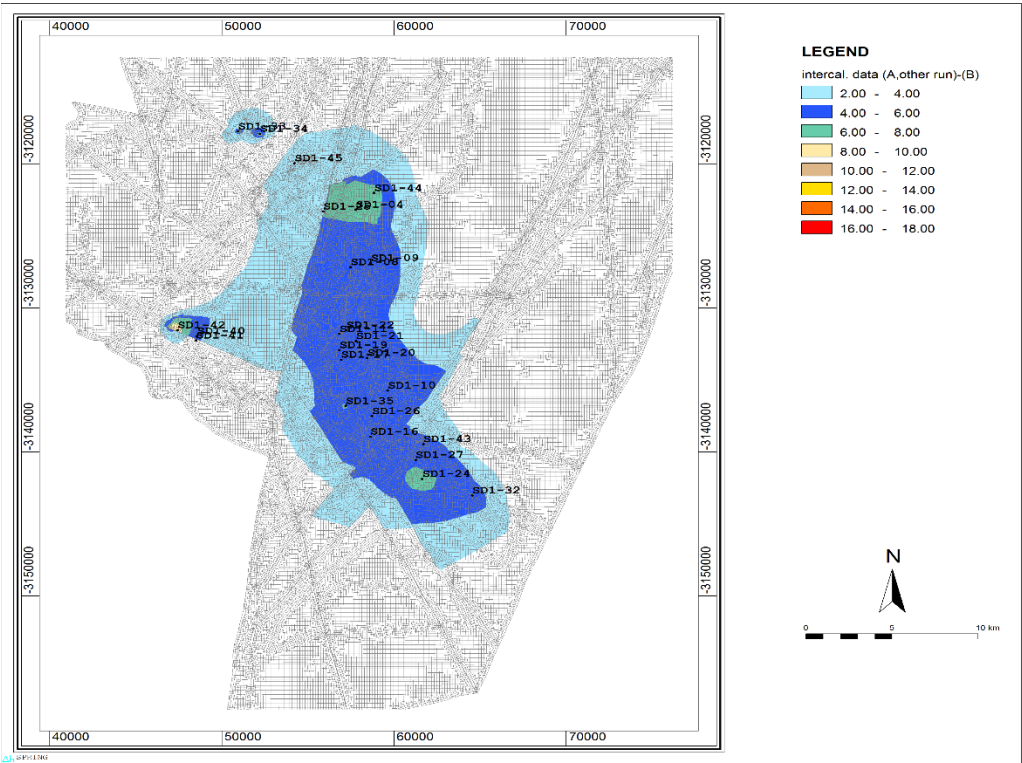


Figure 42: Scenario 2a - Cone of Dewatering (m)

SD1 Well Field Scenario 2A

The drawdown cone in the optimised Scenario (2a) is smaller in extent and depth (). The cone of dewatering is expectedly more pronounced in the central well fields (No. 2).

SD1 Well Field Scenario 2B

Based on the outcome of the water level drawdown and extent of the dewatering cone a decision was made by Sedibeng Water to put forward scenario 2b as the recommended well field abstraction rate. The impacts associated with the SD1 well field for the proposed optimal scenario (2b) will be discussed in the following sections in terms of the deviations from the base case scenario 0 (no well field abstractions).

Impact on Water Balance

Any volume of groundwater extracted by pumping in the SD1 production boreholes will be compensated by a reduction in outflow (along the south eastern- and south western outflow boundary) and a reduced volume of groundwater baseflow (towards drainages and springs). Over the long-term a new equilibrium will be reached and in order to maintain this equilibrium, groundwater abstractions must be balanced by increased recharge (increase in the amount of water entering the system) or reduced discharge (reducing the amount of water leaving the system). However, some of the water that is pumped comes from a change in amount of water stored in the subsurface (especially in the drier periods where the abstraction is greater than the difference between the inflow and residual outflow, then an additional yield (change in S) is required to maintain the abstraction). During significant recharge events, changes in outflows and contribution to baseflow continue to occur until the water that was removed from storage is replenished.

The change in the predicted water balance compared to the base case (no well field abstractions) for scenario 2b is shown in Table 17.

Table 17: Simulated Water Balance (Transient State - 2030) (Scenario 2b)

Regional Water Balance	Scenario 2b	Base Case	Diff. From Base Case
Inflow	m³/month	m³/month	m³/month
Recharge	870 492	870 492	
Outflow	m³/month	m³/month	m³/month
Spring Discharge	-27 709	-31 102	-3 393
Borehole Abstractions	-695 639	-231 797	463 842
Contribution to Drainages, pans and potential evapotranspiration	-421 928	-452 708	-30 781
Outflow Boundary	-306 442	-354 014	-47 572
Idwala Pit Inflows	-20 472	-25 439	-4 967
Total Outflow	-1 472 189	-1 095 060	
Change In Storage	-601 697	-224 568	377 129
Total Outflow	-870 492	-870 492	

Predicted Change in Storage

The abstractions from the SD1 well fields result in a change of storage together with a reduction in flows across the outflow boundaries (to downstream catchments) and groundwater contributions to drainages and pans. If the outflows are consistently greater than the inflows, water will be taken from storage, and this manifests itself as an overall decline in groundwater levels. The in- and outflows for the simulation period is shown in Figure 43 while the net change in storage for the base case (no well field abstractions) compared to Scenario 2b is shown Figure 44. The total abstraction from the model domain amounts to approximately 65 % of the average recharge of 1 082 203 m³/month (13 Mm³/a) for the simulation period.

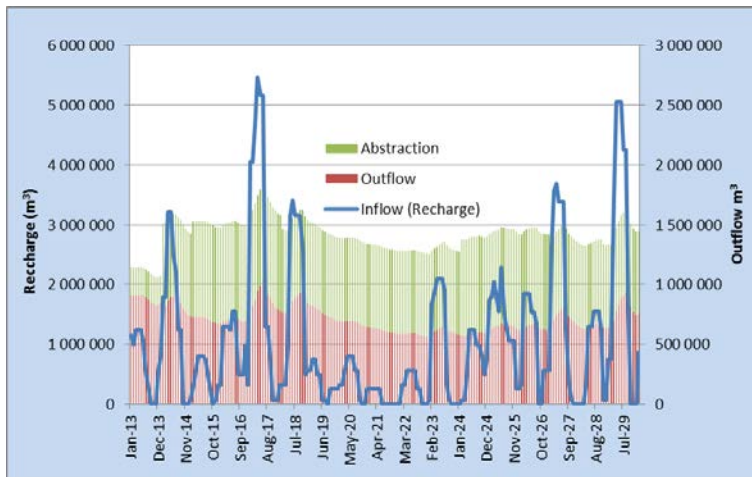


Figure 43: Simulated In- and Outflows for the Modelled Scenario 2B

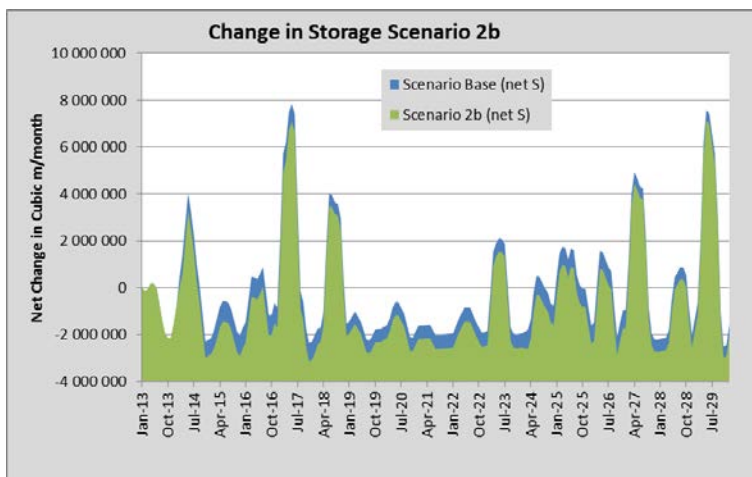


Figure 44: Net change in storage for Scenario 2b compared to the base case

Impact on Outflow Boundary

The SD1 well fields (Scenario 2B) will reduce regional groundwater outflow gradually over time until a new (dynamic) equilibrium of recharge and outflow is established (Figure 45). However, it must be emphasised that the change in outflow changes for each time period and that the change in outflow from the first time step (2013) to the last (2030) results in a net change of 2 924 m³/month as a result of the variable recharge and subsequent changes in aquifer storage. The boundaries most affected by the SD1 well fields are the south eastern- and south western outflow boundaries (Table 18).

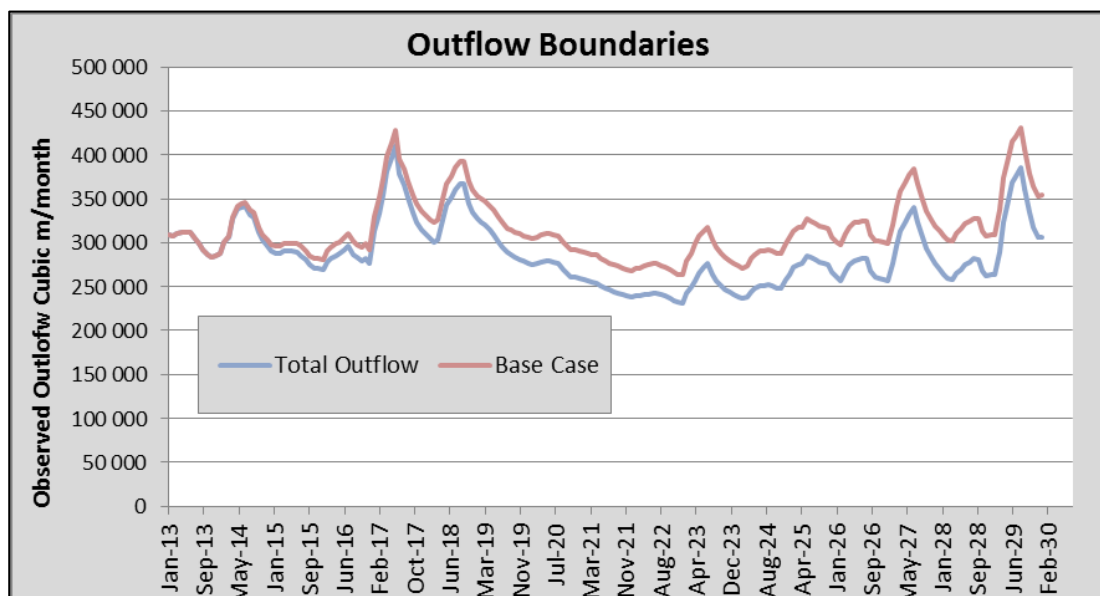


Figure 45: Simulated Mass Flow Rates across the Outflow Boundaries over time for Scenario 2B

Table 18: Simulated reduction in outflow for each outflow boundary (Transient State - 2030) (Scenario 2b)

Outflow Boundary	Scenario 2b in m ³ /month
North Outflow	0
North East Outflow	0
South East Outflow	-15 567
South Outflow	-93
West Outflow	-194
South West Outflow	-31 718
Total	-47 572

Impact on Water Levels of Production Boreholes

The simulated impacts of the groundwater abstraction from the SD1 well field on the regional groundwater levels are shown as a contour map of drawdown by comparing the water levels simulated for the last stress period of the base case (no well field) scenario against the lowered water levels due to abstraction from the SD1 well field (e.g. Scenario 2b). The cone of dewatering for simulation 2b is shown in Figure 46.

No drawdown values below 2 meters are visualised to account for the inaccuracy in the model calibration, which is within the expected seasonal variability of water table elevations. It is likely that any drawdown below 2 meters is within the range of natural water table fluctuations and therefore any potentially affected groundwater dependent ecosystem therefore adapted to it. Similarly, potential groundwater users are unlikely to recognise such drawdown as borehole yields are typically not significantly impacted by such seasonal fluctuations.

The predictive simulation model (scenario 2b) with a maximum abstraction rate of 6.6 million m³/a (from 15 long term and 7 short term SD1 production boreholes) reveals a wide-ranging cone of depression (considering a 2 m cut-off value) due to the distribution of the well fields. Simulated drawdowns for the production boreholes range from 4 to 7 m for the SD1 well field region.

A summary of the water level drawdown for the production boreholes for both simulated scenarios 1 and 2 are given in Table 19.

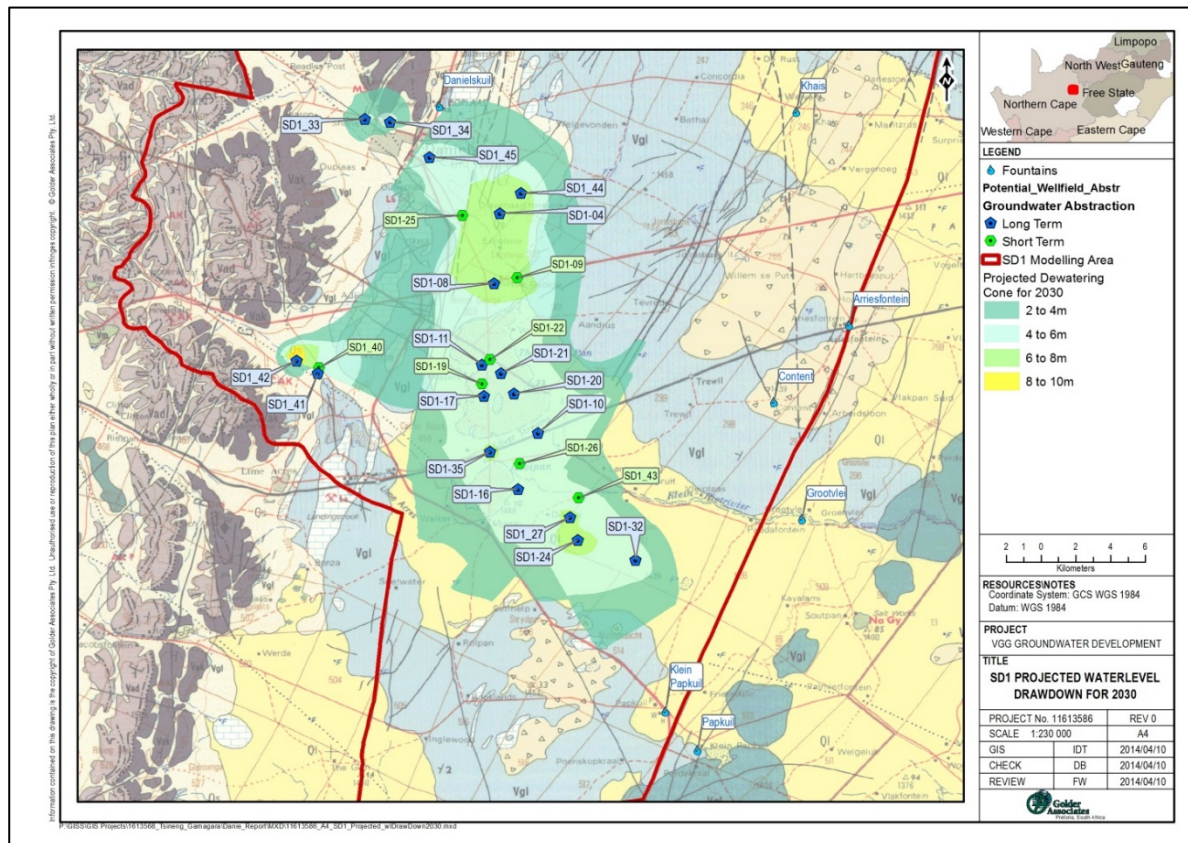


Figure 46: SD1 Projected Water Level Draw Down – 2030

Table 19: Summary of Simulated Total Water Table Drawdown at the end of 2030 for SD1 Well Fields

Well field No.	BH no.	Scenario 1 Drawdown (m)	Scenario 2a Drawdown (m)	Scenario 2b Drawdown (m)
Well field No 1	SD1-04	10.1	6.0	6.6
	SD1-08	9.4	5.6	6.1
	SD1-09	9.4	5.3	5.8
	SD1-25	11.5	3.3	4.4
	SD1-44	10.5	6.4	7.0
Average Drawdown (m)		10.2	5.3	6.0
Well field No 2	SD1-10	7.3	5.4	5.8
	SD1-11	8.2	5.1	5.5
	SD1-16	8.7	5.4	5.7
	SD1-17	8.3	5.4	5.8
	SD1-19	8.1	4.9	5.3

Well field No.	BH no.	Scenario 1 Drawdown (m)	Scenario 2a Drawdown (m)	Scenario 2b Drawdown (m)
	SD1-20	7.8	5.3	5.7
	SD1-21	8.1	5.1	5.5
	SD1-22	8.1	5.0	5.4
	SD1-26	7.4	5.2	5.6
	SD1-35	7.1	7.6	8.0
Average Drawdown (m)		7.9	5.4	5.9
Well field No 3	SD1-24	14.3	8.8	8.9
	SD1-27	10.0	5.8	6.0
	SD1-32	9.3	6.0	6.1
	SD1-43	9.8	5.2	5.4
Average Drawdown (m)		10.9	6.4	6.6
Well field No 4	SD1-40	10.5	5.0	5.6
	SD1-41	2.3	1.8	1.9
	SD1-42	6.0	12.7	13.5
Average Drawdown (m)		6.3	6.0	7.0

Impact on Water Level of Existing Groundwater Users

Due to the intrinsic heterogeneity of the dolomitic groundwater system the potential impact of the groundwater abstractions on other groundwater users may not be equally distributed (spatially) around the proposed abstraction areas. Further, some surface drainages and pans may be perched on a low-permeability substrate (i.e. the calcrete layer) and may not be in hydraulic continuity with the aquifer beneath and therefore not impacted by a drawdown of the water table.

The individual borehole pumping rates for scenario B (22 production boreholes), were optimised through three groundwater model simulations (scenario 1, 2A and 2B) to fall within the recommended critical drawdown level of 6 m, as determined during the pumping test analysis.

The existing ground water users whose boreholes (66) will be impacted by the projected 2030 dewatering cone, are indicated on Figure 47.

From the available borehole information and predicted 2030 water level drawdowns, only SD1-GAA04 will probably dry up. This low yielding borehole has a pump inlet value (PI) of 0.12l/s, has a depth of 16.24m and water level of 12.01m. This borehole has an available drawdown of 4.23m and is currently not in use.

Simulated drawdowns for the existing boreholes range from 0.27m (SD1-GAA071) to 6.05m (SD1-GAA061) with an average drawdown of 4.09 m.

The existing fountains located in the SD1 modelling area fall outside the projected 2030 dewatering cone as indicated on Figure 47 and will not be impacted by the proposed well field.

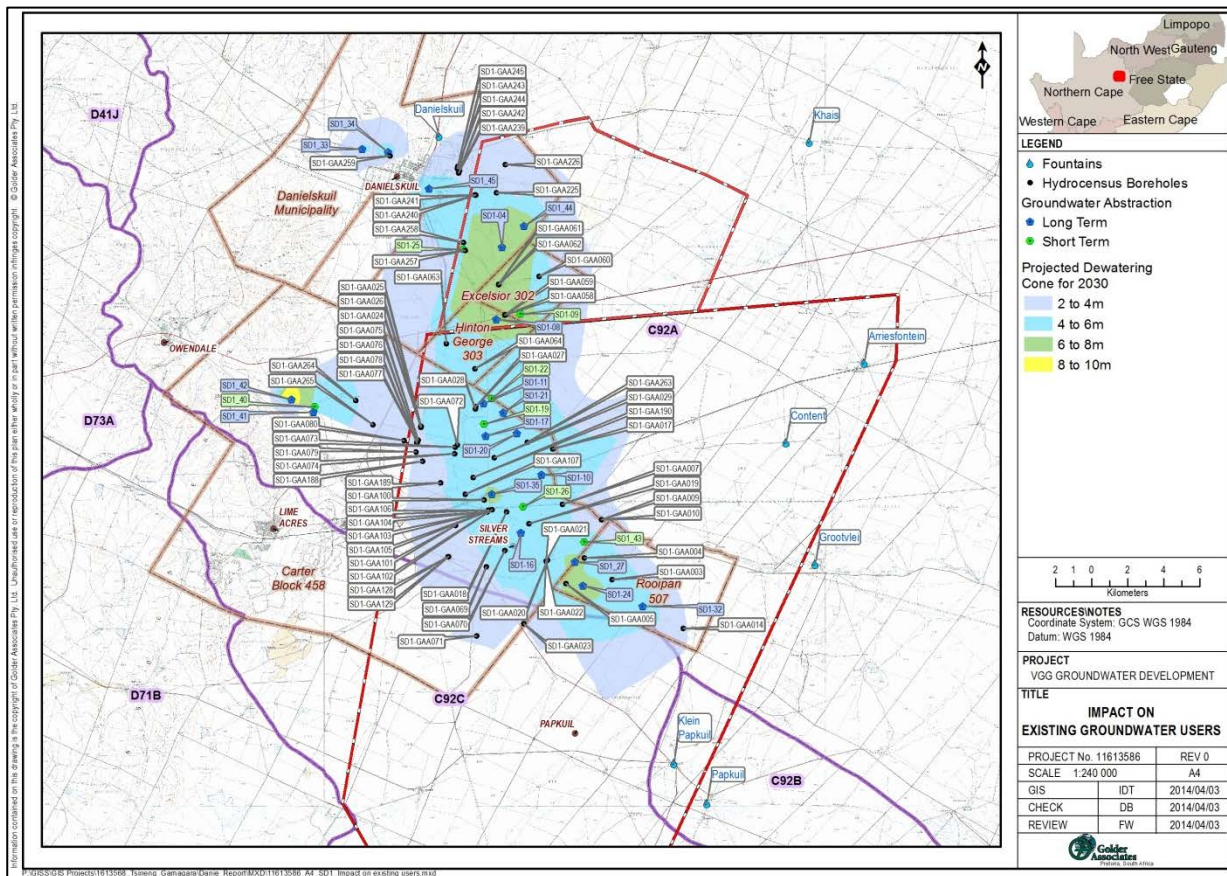


Figure 47: Simulated Impact on Existing Groundwater Users and Fountains

Well Field Protection Zone

The approach followed for delineating zones is documented in more detail in the SD1 model report by Delta-H contained in Volume II of this report. The updated model was used in combination with the reverse particle tracking method to delineate the time-of-travel based capture zones of the abstraction wells. The time-of-travel capture zones were used to rank the degree of risk based on the expected travel time of a non-retarded contaminant to reach the water supply wells. The zone 3 outer protection zone (10 year time of travel) is proposed as protection zone for the SD1 well-field scenario 2B comprising of 22 boreholes, as shown in Figure 48.

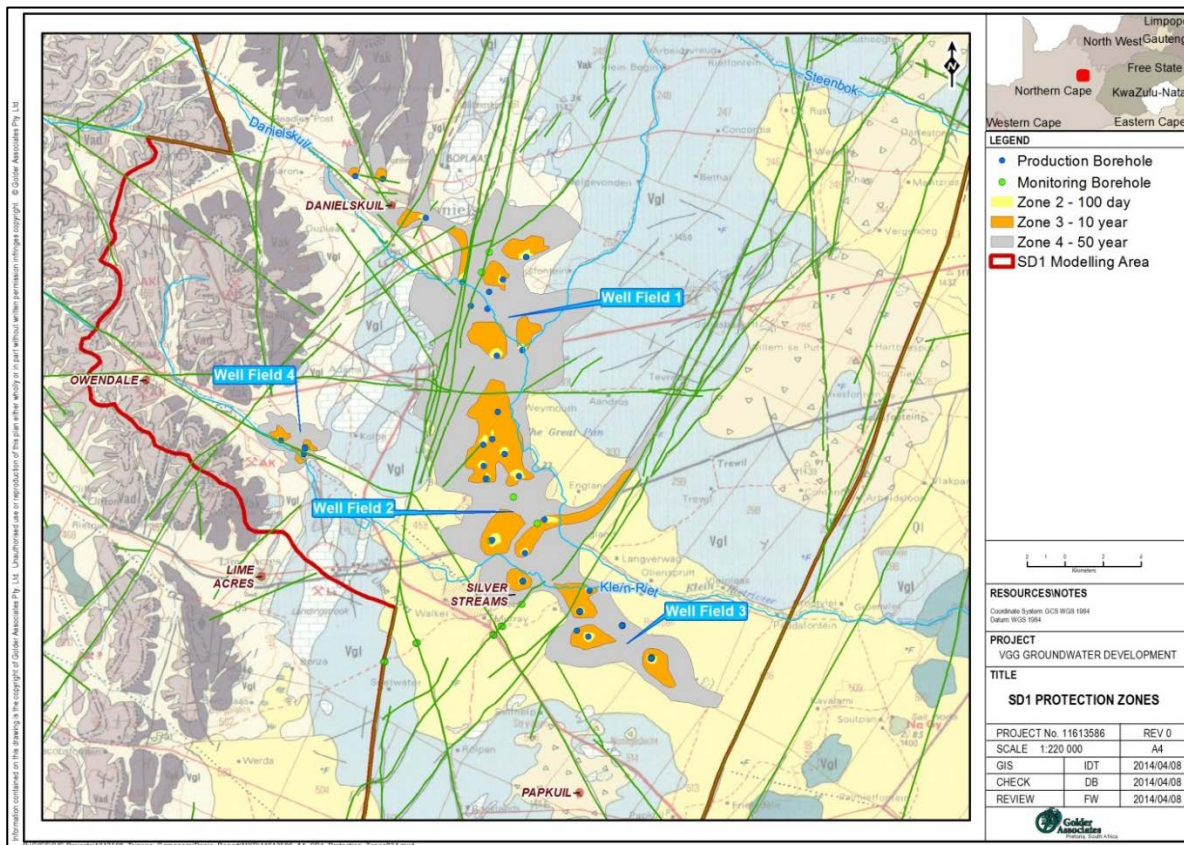


Figure 48: SD1- Groundwater Protection Zones

No household, agricultural or animal activities should be allowed within 150 m radius of all production boreholes. The aquifer protection zone 3 (for ten-year period) should be implemented, with no development being allowed within this zone that may contaminate the aquifer.

2.2.6 SD1 Recommended wellfield abstraction

The individual borehole pumping rates for scenario 2B (22 production boreholes), were optimised through three groundwater model simulations (scenario 1, 2A and 2B) to limit water level drawdowns on the regional dolomite aquifer to within 4 to 6m, to limit the risk of sinkhole occurrences.

The 2014 Scenario 2B recommended abstraction rates for the SD1 well field are listed in Table 20 and indicated on Figure 49. The recommended well field abstraction up to 2030 was as follows:

- 15 Boreholes can be implemented for long term abstraction (2030) use at a combined monthly peak rate of 444,132 m³/month,
- 7 Boreholes can be implemented for short term abstraction (3 years on and six years off) or peak supply (4 months/year) use at a combined rate of 109 500 m³/month,
- A WULA should be submitted to implement the 22 production boreholes (scenario B) to abstract **5 329 584m³/a** on a sustainable basis over the long term (2030) and **1 314 000m³/a** over a short term / peak supply for four months/a (**6 643 584m³/a** combined peak supply) to augment water supply to the VGWS,
- Critical water levels have been established for the aquifer conditions as per this point in time, however, an update of them would be required once implementation of the scheme is planned. These levels should not be exceeded – once these levels are approached, abstraction rates or duration should be reduced.

Table 20: SD1 Recommended Well Field Abstraction Rates – Scenario 2B

Well field	Borehole No.	Latitude	Longitude	Depth (m)	Diameter (mm)	WL (mamsl)	WL (m)	Critical WL Depth (m)	Discharge (l/s)	Pumping Hours Per day	Daily Abstraction M ³ /day	Monthly Abstraction M ³ /Monthly	Long Term M ³ /day	Short Term M ³ /day	Water Quality Class
WF1	SD1-04	-28.22185	23.5884	61	203	1437.41	11.58	18	10	20	720	21900	720	-	0
WF1	SD1-08	-28.25789	23.58555	40	254	1435.47	13.68	26	20	20	1440	43800	1440	-	0
WF1	SD1-09	-28.25527	23.59748	40	203	1435.48	6.84	30	10	20	720	21900	-	720	I
WF1	SD1-25	-28.22309	23.56914	51	203	1439.62	7.02	48	15	12	648	19710	-	648	0
WF1	SD1-44	-28.21134	23.59929	34	203	1439.45	17.83	23	20	24	1728	52560	1728	-	I
WF2	SD1-10	-28.33522	23.60812	28	254	1432.086	11.92	24	15	20	1080	32850	1080	-	II
WF2	SD1-11	-28.29988	23.57918	70	165	1432.93	13.44	42	10	20	720	21900	720	-	0
WF2	SD1-16	-28.36428	23.5978	69	165	1431.525	9.61	39	8	12	345.6	10512	345.6		I
WF2	SD1-17	-28.31607	23.58026	58	203	1432.86	2.29	39	15	12	648	19710	648	-	0
WF2	SD1-19	-28.31002	23.57928	40	203	1432.42	2.4	18	15	12	648	19710	-	648	0
WF2	SD1-20	-28.31478	23.59588	48	203	1432.8	2.2	43	20	24	1728	52560	1728	-	I
WF2	SD1-21	-28.30433	23.58906	103	165	1432.82	2.04	72	10	24	864	26280	864	-	0
WF2	SD1-22	-28.29738	23.58331	49	203	1432.94	2.93	37	5	12	216	6570	-	216	0
WF2	SD1-26	-28.35129	23.59879	69	203	1431.406	10.41	55	10	20	720	21900	-	720	I
WF2	SD1-35	-28.34501	23.58328	28	254	1432.748	9.58	25	20	24	1728	52560	1728	-	I
WF3	SD1-24	-28.39055	23.62879	68	203	1424.569	12.7	66	15	20	1080	32850	1080	-	0
WF3	SD1-27	-28.37868	23.6247	104	203	1424.485	12.93	84	10	20	720	21900	720	-	I

WF3	SD1-32	-28.40082	23.65853	73	203	1423.783	12.65	70	15	20	1080	32850	1080	-	II
WF3	SD1-43	-28.36883	23.62928	64	203	1423.016	14.81	59	5	20	360	10950	-	360	I
WF4	SD1-40	-28.30157	23.49494	97	165	1438.482	30.24	51	4	20	288	8760	-	288	0
WF4	SD1-41	-28.30427	23.49428	97	203	1423.46	43.43	72	5	20	360	10950	288	-	0
WF4	SD1-42	-28.29786	23.48335	112	165	1423.77	53.46	69	5	20	360	10950	360	-	0
Total									262	-	18202	553632	14529	3600	-
Long Term m³/Month												444132			
Short Term m³/Month												109500			
Long Term m³/annum												5329584			
Short Term m³/annum												1314000			
Long + Short Term m³/annum												6643584			

The recommended abstractions for the four SD1 well fields are summarised in table below:

Table 21: Recommended SD1 well field abstractions (2014)

Well Field	Number of BH's	Yield l/s	Long Term m ³ /m	Long Term m ³ /a	Short Term m ³ /m	Short Term m ³ /a	Long + Short Term m ³ /a
WF1	5	75	118 260	1 419 120	41 610	499 320	1 918 440
WF2	10	128	216 372	2 596 464	48 180	578 160	3 174 624
WF3	4	45	87 600	1 051 200	10 950	131 400	1 182 600
WF4	3	14	21 900	262 800	8 760	105 120	367 920
Total	-	262	444 132	5 329 584	109 500	1 314 000	6 643 584

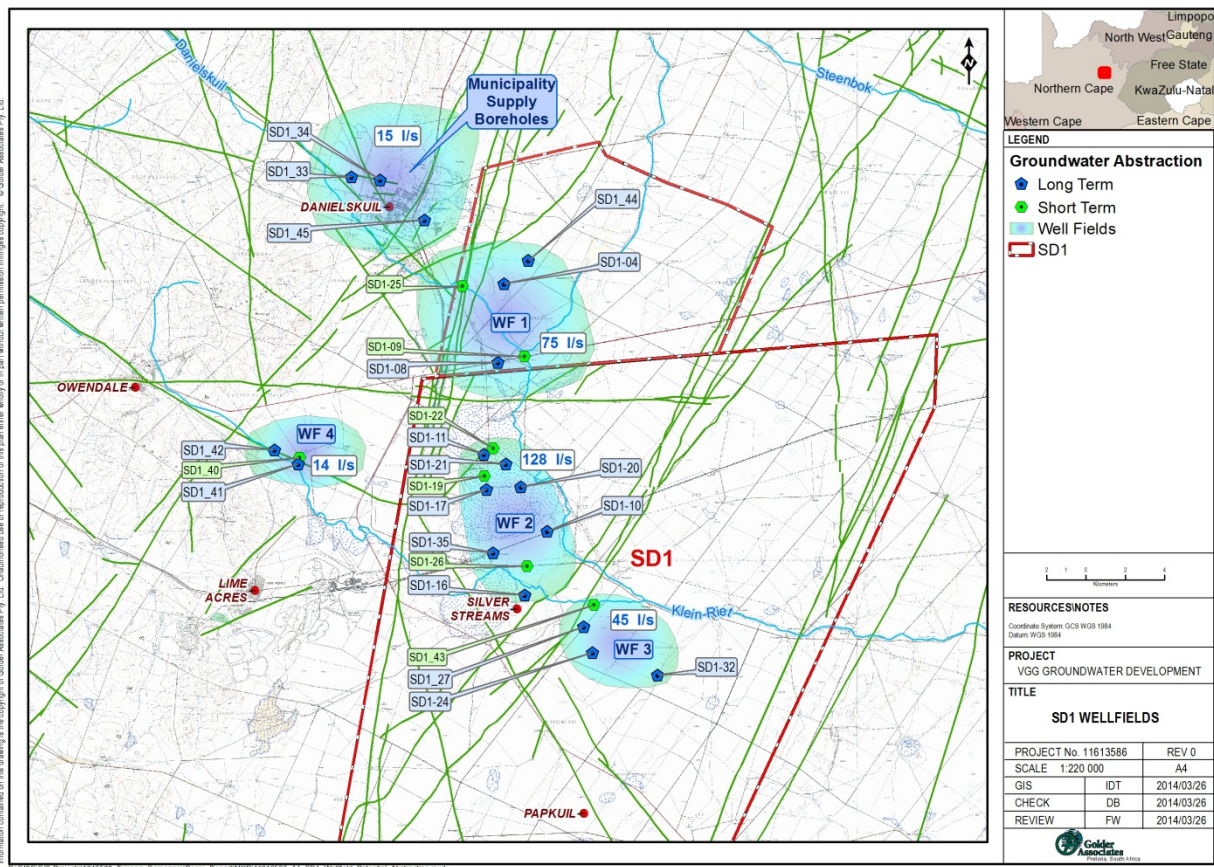


Figure 49: SD1 Well Field Borehole Positions Scenario 2B

2.3 Review of SD2 Hydrogeological Assessment Study (2014)

2.3.1 SD2 description of study area

2.3.1.1 Location

SD2 investigation area falls under the jurisdiction of Tsantsabane Local Municipality (LM), of the ZF Mgcawu District Municipality (formerly Siyanda District) and located in the Northern Cape Province. The study area is located north east of Postmasburg and extends north east to Jen Haven community.

The SD2 groundwater modelling area falls mainly onto the D73A quaternary catchment area and D41J quaternary catchment to the north, with the size of the modelling area (Figure 50) as 951km².

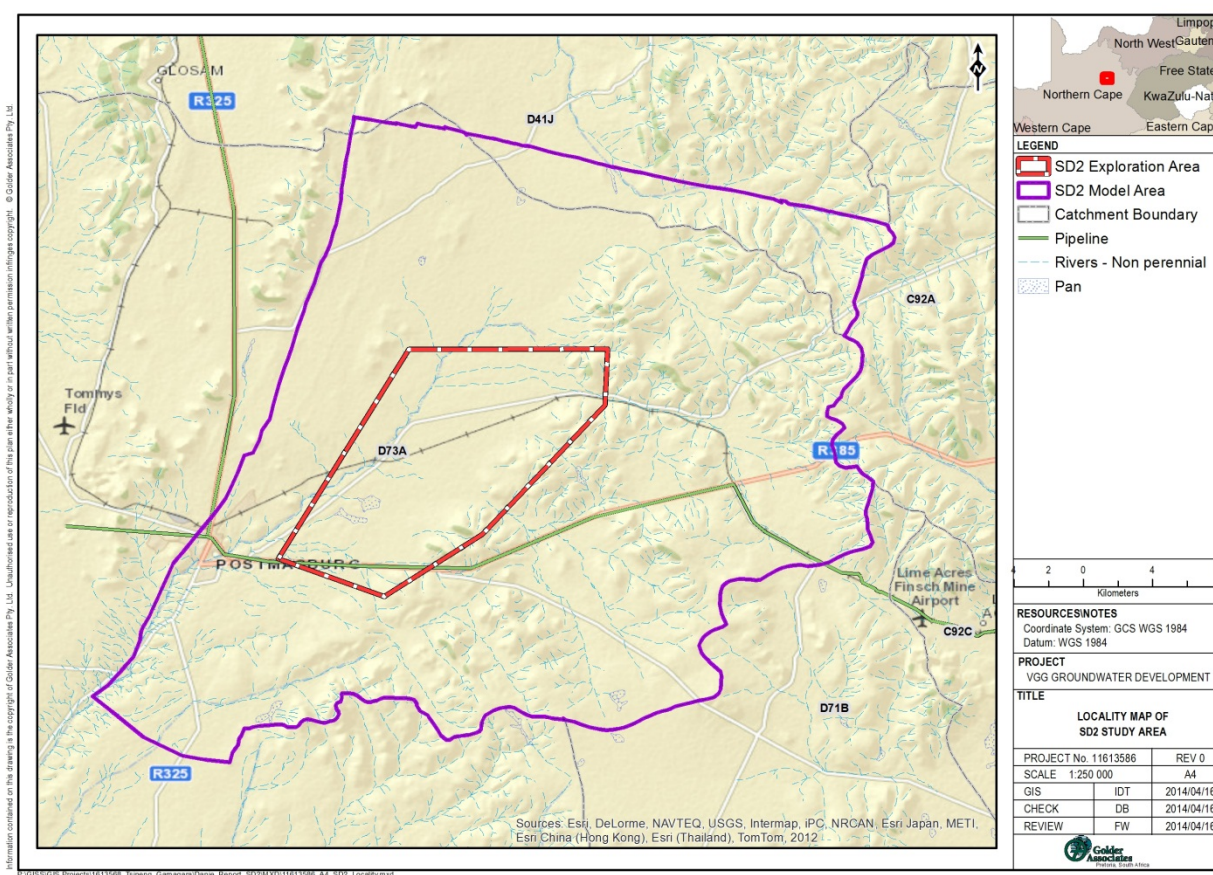


Figure 50: Locality Map of SD2 Study Area

2.3.1.2 Topography

The SD2 study area is situated on the southeastern flank of the Maremane Dome and the surface is flat, apart from low irregular hills north east of Postmasburg and Asbestos Mountains in the east.

Most of the SD2 study area topography is characterized by the flat featureless Maremane Dome. Elevations gradually decline from Jen Haven community in the north east (approximately 1490mamsl) towards Postmasburg in the south west to 1320 mamsl.

The SD2 investigation area is bounded to the east by a broken mountain ridge, namely the Asbestos Mountains. This mountain range forms the eastern margin of a regional north - south irregular highland, which resulted from positive erosion of resistant siliceous rock formations and regional tectonic events.

Elevations range from 1577mamsl at the highlands to 1320mamsl at the south-west of the investigation area. The irregularities on the escarpment are caused mostly by extensive mechanical erosion of various geological structures.

2.3.1.3 Surface Drainage

The SD2 study area fall into the Lower Vaal WMA, D73A quaternary catchment and is situated on the south-eastern flank of the Maremane Dome with no major drainage systems towards the Vaal River. Small localised pans exist and form part of a series of interior drainage basins which overflow occasionally during extremely high rainfall seasons, like during 1974 to 1976 period.

The study area is situated within the upper Groenwaterspruit catchment (Figure 51). Numerous streams collect runoff from the Asbestos Hills and flow westwards where they tend to disappear in the Kalahari sands. Run-off accumulation in surface depressions can persist for several weeks until water has evaporated or infiltrated into the ground. The main drainage, namely the ephemeral Groenwaterspruit, drains towards the southwest until it's confluence with the non-perennial Southloop. While the Groenwaterspruit is for most parts of the year dry, it flows during rainfall periods and the lush vegetation along the stream channel indicate constant damp soil conditions.

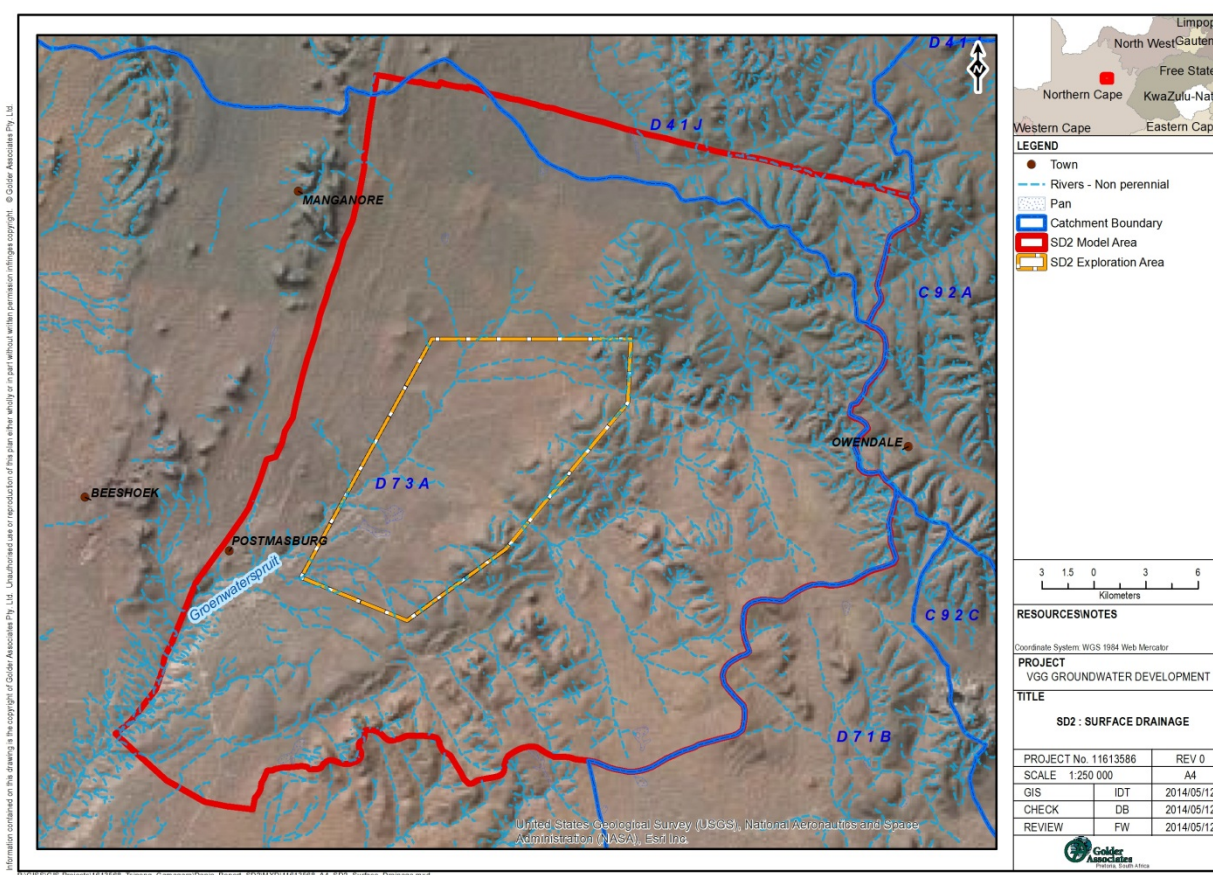


Figure 51: SD2 Surface Drainage

2.3.1.4 Vegetation

The SD2 study area is generally covered with natural grass lands, shrubs (Figure 52) and some thorn trees. The occurrence of shrubs and trees is determined by the availability of deeper soil moisture for more extensive root systems.

The bedrock outcrop areas are sparsely vegetated, with greater abundance of shrubs and trees occurring along drainage areas and pans, along dykes and along the edge of scree slopes surrounding mountains to the east of the study area.

The vegetation belongs mainly to the Vryburg Shrub Bushveld, a subdivision of the Khalahari Thornveld. This veld type occurs on rocky soil and hard rock formation and shows minor variations from north to south.



Figure 52: Typical Grasslands and Shrubs in SD2 – Area

2.3.1.5 Climate and Rainfall

The study area lies in a semi-arid area. The climate of SD2 is typical continental with large seasonal and diurnal variations in temperature. The mean maximum temperature range between 24° C and 37° C, with the mean minimum temperature range varies between -4° C and 11° C. Maximum temperatures are experienced in January and minimum temperatures usually occur in July.

The climate of the subcontinent is controlled by a low-pressure system, during the hot summer months, allowing moist air to flow from the Indian Ocean toward the interior land. In the Northern Cape the movement of air masses is characterised by a dry north to north-easterly wind with a low precipitation rate.

The low temperatures result in a high-pressure system to develop over the Northern Cape region during the winter. The area is semi-arid with the annual evaporation nearly five times the annual precipitation. The Average evaporation range between 2000 and 2100mm per year. Prevailing wind directions is north-west to west during the dry and dusty July to October period (Van Wyk, 1986).

The SD2 study area lies in the Lower Vaal WMA, in a summer rainfall region, with an irregular rainfall pattern and occurs mostly in the form of thunderstorms during January, February and March (Figure 53) when moist tropical air from the north reach the area due to frontal systems.

The annual precipitation is erratic with wet and dry cycles evident. An extreme wet cycle that peaked 1974 to 1976 (3 years) was followed by a dry cycle from 1978 to 1987 (9 years). This was followed by a wet cycle 1988 to 1991 (4 years) with an extreme dry year in 1992 with a dry period lasting till 1998 (6 years). From 1999 to 2002 (3 years) above average precipitation prevailed. From 2002 below average precipitation indicate a dry cycle.

The average rainfall for the SD2 area is portrayed by Postmasburg rainfall stations. The MAP rainfall for Postmasburg rainfall station for the period 1917 to 2014 is indicated in Figure 53, with the MAP for the period as 328mm/a. The amount of annual rainfall and rainfall intensity (monthly rainfall) are the major driving forces of groundwater recharge.

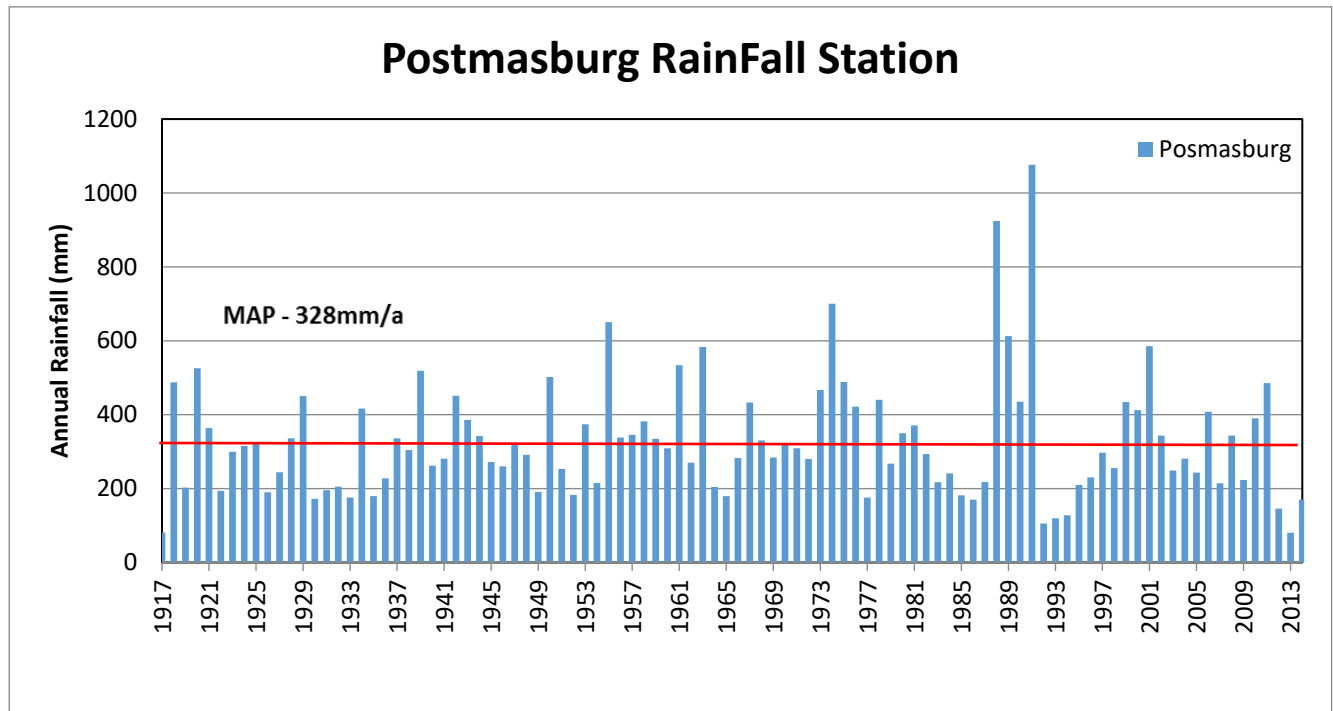


Figure 53: Postmasburg MAP (mm/a)

2.3.1.6 Local Geology

SD2 study area falls onto the Council of Geoscience 1:250 000, (2822 Map Reference) Postmasburg geology map as shown in Figure 54.

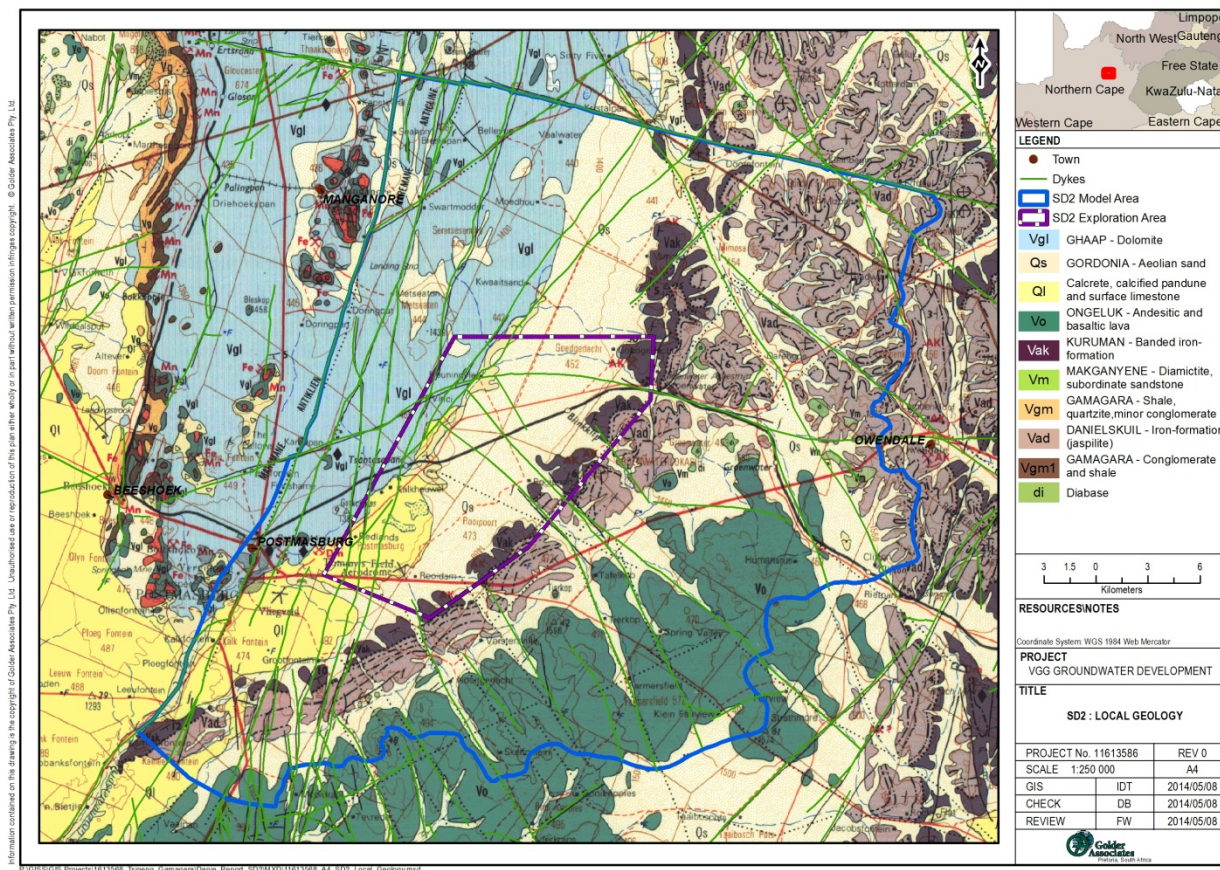


Figure 54: Local Geology

The Ventersdorp Supergroup overlies the basement granite and is unconformably overlain by the Vryburg and Schmidtsdrift Formation's which form the lowest unit of the Campbell Rand Subgroup.

The Campbell Rand Subgroup manifests itself in the Maremane Dome or anticline and consists of alternating layers of oolitic and stromatolitic dolomite with thin interbedded layers of shale and quartzite. The shale becomes more prominent higher up in the succession with the result that the middle member consists mainly of ferruginous shale with siltstone and interbedded thin dolomite. The upper layer consists mainly of calcitic dolomite and thin interbedded shale and siltstone.

The Koegas and Asbestos hills Subgroups lie conformably on the Campbell Rand Subgroup. The subgroups contain the Kuruman and Danielskuil marker formations which are also magnetic markers. The uppermost chert grades into banded iron stone of the Kuruman Formation which varies in thickness from 180 to 240m. It consists of a succession of thin alternating layers of light-colored chert and jasper and dark-colored ferruginous jaspilite. The jaspilite contains mainly magnetite, haematite and limonite. The rock also contains several crocidolite-bearing zones. The "blinklip breccia", a basal layer of banded iron stone, lies on the Campbell Rand Formation in the Maremane Anticline. The Danielskuil Formation has an undulating structure and consists of brown jaspilite with thin magnetite layers and lenticular breccias and chert nodules. The overlying jaspilite attains a thickness of 150m and several marker layers.

The Gamagara Formation was deposited on the Maremane Anticline and rests unconformably on dolomite and banded iron stone of the underlying formations. It consists of a basal conglomerate with pebbles of jasper, ironstone, shale with lenses of conglomerate, iron-rich flagstone and quartzite. The Formation has a thickness of 300m and when resting on banded ironstone are ferruginised and manganised where they lie on dolomite.

The SD2 area specifically, is situated on the southeastern flank of the Maremane Dome and the surface is mostly covered by Quaternary sand and calcrete, which overlies the Ongeluk lava Formation of the Olifantshoek Group. The Ongeluk Lava Formation overlies the Makganyane formation, Danielskuil (also named the Griquaastad Iron Formation) and Kuruman Formations which are underlain by the Campbell Rand Subgroup. The Kuruman and Danielskuil formations may have a thrust contact with the Campbell Rand dolomite as will be discussed later in this report, but this has to be tested by field observations. The current geology map used in this report does not indicate this. The units targeted for groundwater are major faults in the Danielskuil and Kuruman formation's and low density highly permeable areas in the Campbell Rand dolomites.

Kalahari and Quaternary Deposits

The bedrock geology in the SD2 study area is partially concealed by sediments of the Kalahari group and Quaternary deposits. The Kalahari formation consists primarily of calcrete, gravel and clay beds. In the eastern parts of the study area the superficial cover becomes thin and patchy and large areas of bedrock are exposed.

Kalahari sediments with roughly a NE to SW strike direction (Figure 54), which varies in thickness from millimetres to several metres (covering the middle part of the study area). Relatively thick deposits of calcrete occur as cappings of the dolerite rocks and normally causes a higher relief due to the expansion mechanism present in the calcification process.

Intrusive Structures

Intrusive dolerite dykes are a common feature in the SD2 study area but seldom outcrops. Dolerite dykes are typically observed as major linear structures and intersect the geological formations perpendicular. These dykes are subject to both positive and negative weathering, depending on the specific hydrological environment.

Chemical weathering is responsible for the deposition of secondary calcite on top of the dykes, with the intensive materializing of clayey decomposed dolerite at depth. These dykes naturally appear as ridges with depressions formed by the solution of the country rocks within the contact zone alongside the dykes. Most of the surface water drainage channels are restricted to these features. These dolerite dykes with low permeability compartmentalize the dolomite aquifer. The dyke/bedrock contact zones themselves represent on the other hand preferential groundwater flow paths.

The dykes act near surface as aquitards, restricting lateral water flow. At depth, the dykes become fresh rocks and act as aquicludes, preventing water flow across it.

2.3.1.7 Groundwater Occurrence

Groundwater resources occur throughout the SD2 study area. The major aquifers identified in the different geological formations comprise of:

- Kalahari Sediments - intergranular unconfined aquifer system - Sandstone, Gravel & Calcrete, with low permeability retards and restrict water movement and acts as storage unit,
- Banded Ironstone Formation (BIF) - weathered and fractured semi confined aquifer system; and

- Dolomite karst aquifers - unconfined to semi confined aquifer system, compartmentalised by dolerite dykes.

The intergranular aquifers are presented by the upper (Eden Formation) as well as basal sand and gravel beds (Wessel Formation) of the Kalahari sediments. These aquifers are characterised by borehole yields generally less than 2 l/s, but with the ability to store large volumes of water. They are separated by the red clays of the Budin Formation acting as a confining layer. The basal sand and gravel formation and underlying bedrock can be regarded as one aquifer. In the absence of red clay the upper sand and gravel aquifer of the Eden Formation are in hydraulic conductivity with the bedrock aquifers.

The BIF and karst aquifers associated with the Ghaap Plateau dolomite formations are quite productive and support borehole yield in excess of 40 l/s, in use at Kuruman, Sishen, Kathu, and Beeshoek. Delineation of dykes that may compartmentalize dolomite aquifers is critical to ensure sustainable use and reliable quantification of resource potential. Increased borehole yields, BIF and karst dolomite aquifers are often associated with contact ones of dykes and fault zones.

Groundwater sources are utilized and accessed through boreholes and springs.

2.3.2 SD2 Geophysical Survey

The geophysical survey at SD2 comprised of:

- SkyTEM conducted a high resolution combined airborne magnetic and Time Domain Electromagnetic (TDEM) survey to obtain resistivity data from 2 to over 250 m deep, and
- Extended ground gravity surveys, conducted at 50 and 100m station intervals, along access routes and over selected geological targets as identified via the air borne geophysical survey. The gravity survey was used to optimize the selection of drilling targets in the leached karst formation.

The position of the survey flight lines conducted by SkyTEM is indicated on Figure 55.



The topography was determined from subtracting the Laser height (altimeter) from the on-board GPS elevation, is shown in Figure 56 .



GOLDER

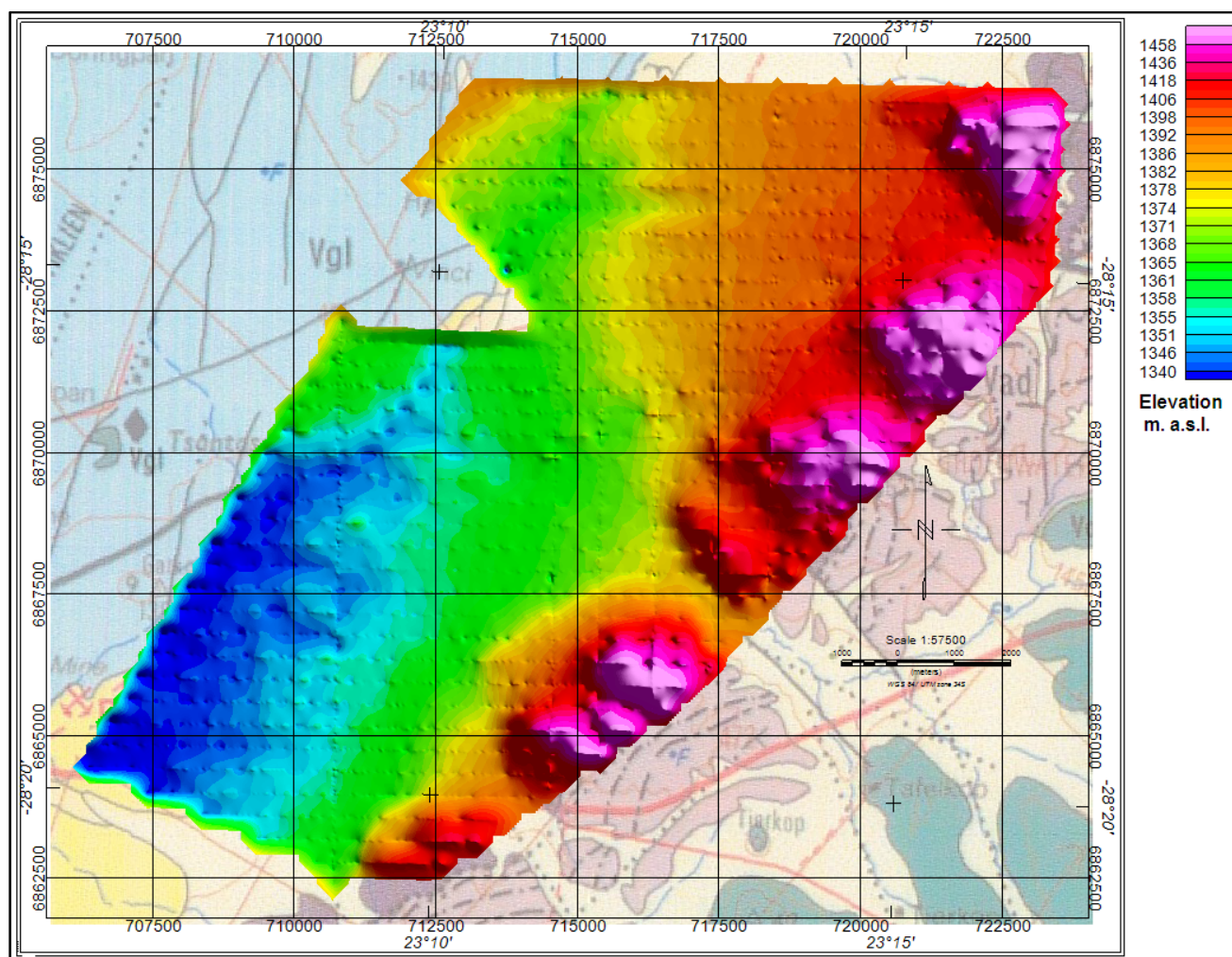


Figure 56: SD2 Digital Elevation Model

2.3.2.2 Aeromagnetic Data

The total magnetic field for SD2 is shown in Figure 57 as an artificially sun shaded color image and the warm colors indicate the magnetic highs. The data is somewhat noisy which stems from the magnetic and TDEM measurements having been done from the same airborne platform, almost simultaneously, and the presence of the Sishen-Saldanah railway line cutting through the area adding man made noise.

Since magnetic geological bodies are considered as 'bar magnets' they have two poles, a north and south seeking pole. In the southern magnetic hemisphere, the magnetic high is equated with the north seeking pole and the magnetic low (valley) with the south seeking pole. The poles are respectively at maximum field strength over the northern perimeter and minimum field strength over the southern perimeter of a magnetic body, and will have a more subdued high on its western edge and a magnetic low over the eastern perimeter indicating the extreme boundaries of a magnetic body. The body is therefore situated between the north and south seeking poles and not solely under the magnetic high as many non-geophysicists believe.

The difficulty lies in determining which poles belong to which body and is referred to as the high-low pair of a body. In the southern magnetic hemisphere, for purely induced magnetism the larger part of the causative magnetic body occurs under the magnetic high (hues of orange to red to mauve).

Spectacular and most obvious is the broad broken-up pattern of purple-red and blue colors that strike NW-SE on the eastern edge of the magnetic image. This pattern is due to the iron rich Danielskuil and Kuruman

To highlight all possible features and lineaments a ternary color image is produced as shown in Figure 58. The magnetic bodies occur under the yellow-green-black colored hues except if they exhibit strong remnant magnetism when they are marked by the strong blue hues. The ternary image figure shows the roughly north trending dyke along the western margin of the dataset more clearly than the total magnetic field image. The dyke is represented in dark pink to purple and can be identified by its linear nature. Smaller features are also highlighted by the ternary image. Multiple faults can be seen, as bright green lines along the eastern margin of the dataset.

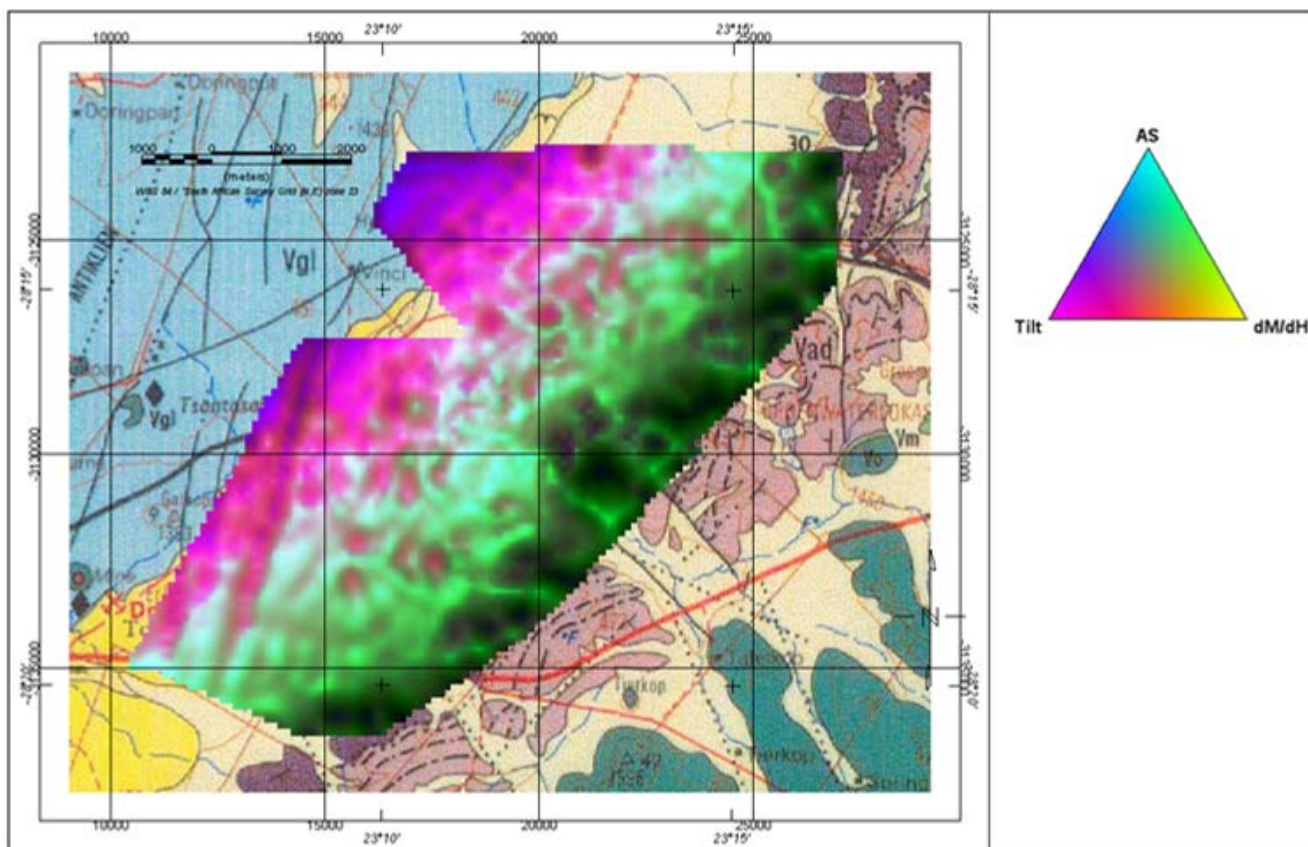


Figure 58: Ternary Plot of the Magnetic Data combining the Analytical Signal, $\partial M/\partial h$ and the Magnetic Tilt Angle

A comparison of the magnetic lineaments and the geology map demonstrates a good correlation between some of the lineaments and mapped faults in the dolomite. The identified magnetic lineaments are shown on the relative Bouguer anomaly map (Figure 58).

2.3.2.3 Airborne Time Domain Electromagnetic Data

The transmitter coil has a high and low moment and data were provided for both moments as just the signal strength measured in the receiver coil or converted into an apparent resistivity as a function of time channels which were converted into an approximate depth below surface.

The survey lines flown as indicated in Figure 55 above were flown both N-S and E-W with a line spacing of 300m to sample all possible directions. Since TDEM has the advantage that a depth sounding is recorded every ~1 s which enables the formulation of a 3D resistivity voxel that can be constructed representing the subsurface and this voxel can be dissected in any X, Y, Z direction.

Numerous plots can be generated to show how the electrical resistivity changes as a function of depth and position. As an example, Figure 59 depicts the apparent resistivities at an elevation of 1300m above sea level. The high resistivity areas on the western perimeter at this elevation (1300m) correlate to the underlying Campbell Rand dolomite that is covered by Kalahari age deposits (sand). In the eastern part of the survey area the low resistivity blue colored areas correlate with the banded iron stone of the Danielskuil and Kuruman formations. The three higher resistivity blobs in the central part of SD2 are due to the dolomite being present nearer to surface, i.e. the Quaternary Kalahari Formation is thinnest here, strengthening the possibility that the large gravity low in the center of SD2 is due to a karst area filled with Quaternary, Tertiary and perhaps even Karoo age sediments.

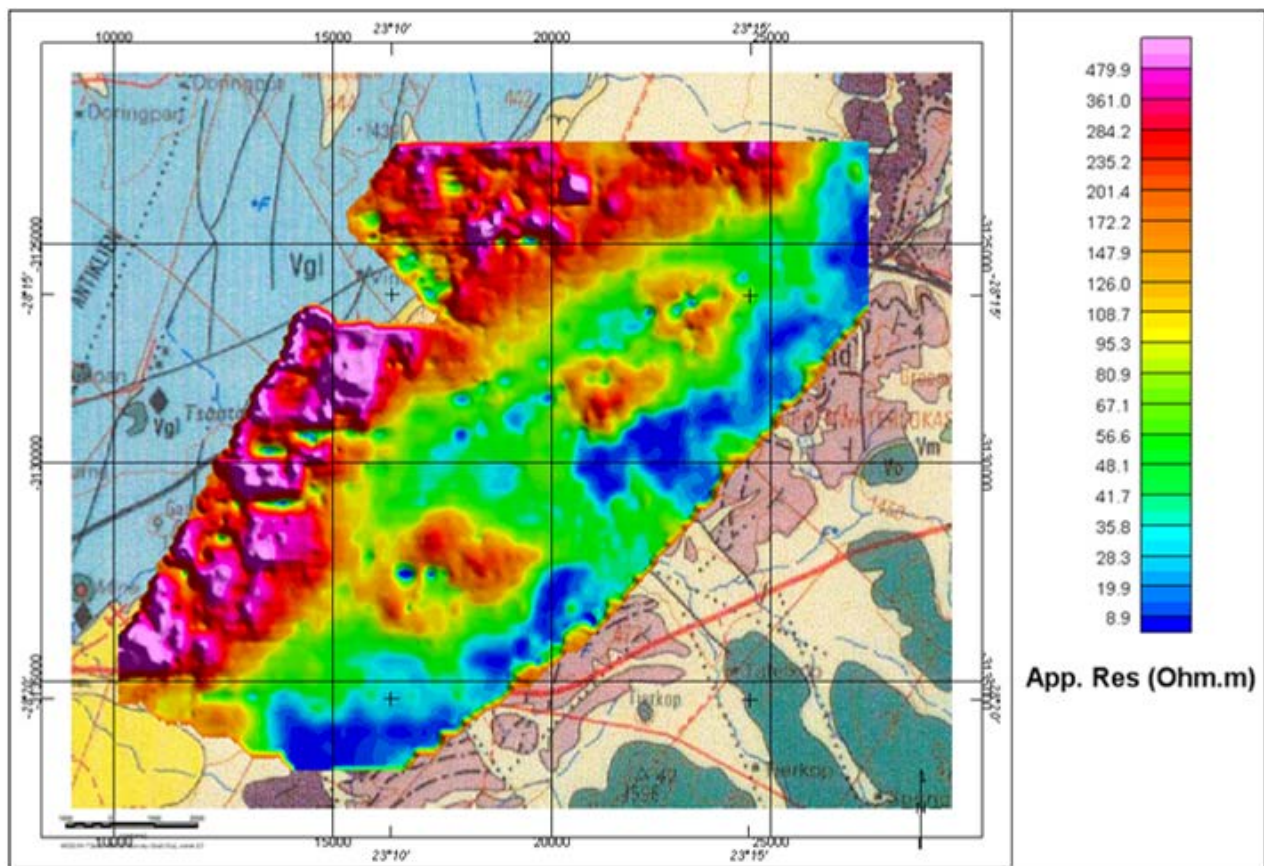


Figure 59: Apparent Resistivity over SD2 at an elevation of 1300 (mamsl)

The apparent resistivity map (Figure 59) shows N-S striking structures on the southwestern perimeter of SD2 that correlate with the mapped faults shown on the geology and the magnetic data set.

The discontinuous nature of the resistivity high values in the east (the Kuruman and Danielskuil Formation's) is due to the presence of several roughly NW-SE trending faults. These again correlate well with faults shown on the Kuruman geological map.

2.3.2.4 Ground Geophysics - Gravity Survey

The gravity method measures differences in the distribution of densities of the sub-surface. Such density variations in dolomite terrain are produced by varying thicknesses of unconsolidated deposits over bedrock, and solution cavities in bedrock. The method is effectively applied for locating zones of karstification and infilling by residual debris in dolomite strata. The survey was conducted along easily accessible fences, tracks and roads.

The residual gravity map is shown in Figure 60 and shows some deep gravity lows, indicating most likely leached out water-filled cavernous zones in the dolomite. The magnetic dykes and lineaments do not correlate clearly with any of the residual gravity.

The advantage of the gravity data is that it indicates possible leached, permeable water-bearing zones and the central large gravity low (blue color) is covered with Quaternary age sediments. This could be fill-in of an old karst area in the dolomite and the perimeter of the gravity low may be a good target area for ground water extraction. The other deep gravity lows are also to be considered as indicating target areas and are those in the northeastern and southwestern corners of the gravity coverage for SD2 (Stettler 2013).

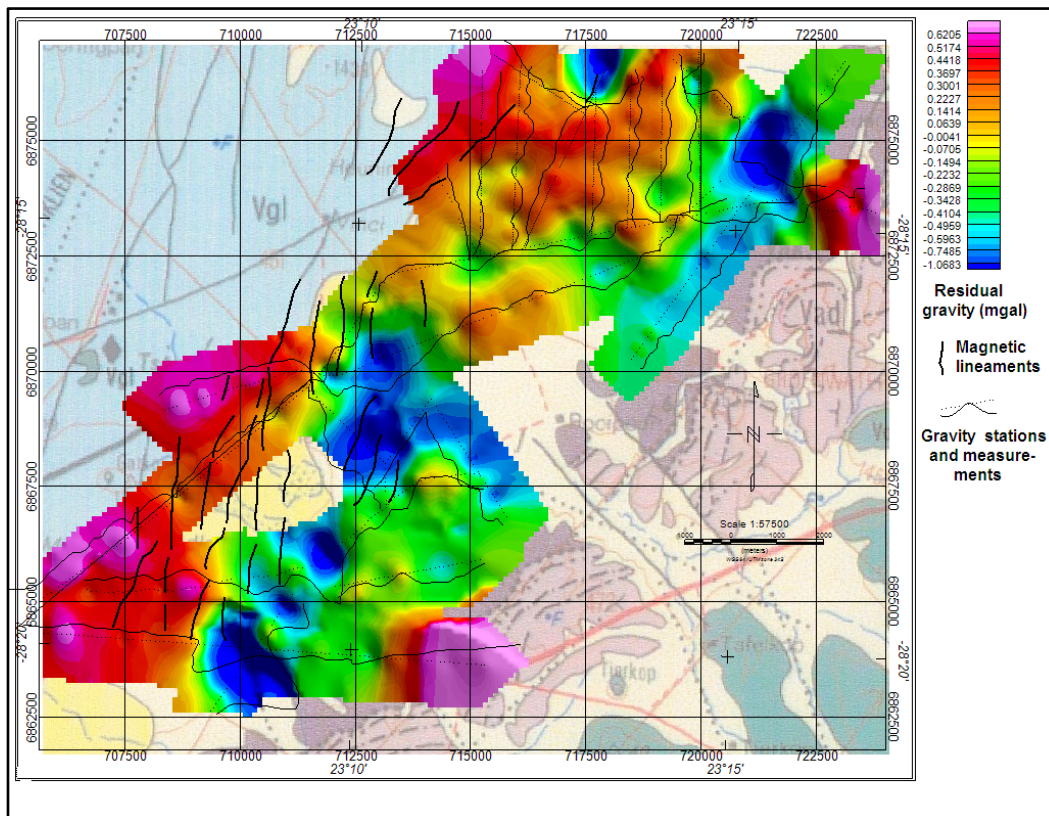


Figure 60: Residual Gravity Map

All three techniques augmented each other, and the understanding of the subsurface geology would not have been possible if not all these techniques would have been applied

The magnetic data indicate that the iron stones of the Danielskuil and Kuruman Formations overlie the dolomite of the Campbell Rand Group and the contact between them could be thrust.

The iron stones, contrary as expected, are resistive at surface and only become conductive at depth. The resistive upper part is ~100m thick. The lower conductive part is still visible at -400m below surface and may also include the thrust zone plane which is also expected to be conductive, and this may make the thickness of the Danielskuil and Kuruman Formation's to appear more than it actually is.

The magnetic lineaments can be subdivided into two groups, N-S striking lineaments in the dolomites and NW-SE striking lineaments amongst the iron formations and these lineaments curve around into the contact zone of the iron formations with the underlying dolomite. This curvature is taken as evidence to support the thrust contact.

The conductive lineaments noted on the TDEM with a NW-SE strike coincide with the magnetic lineaments in the iron formations (correlating also with Kalahari sediments orientation) while the numerous magnetic lineaments along the western boundary of SD2 don't show clearly on the TDEM data indicating that if they are dykes then the dykes are not weathered. A strongly conductive lineament strikes NNE-SSW across the central part of SD2 and its origin is unknown.

2.3.2.5 Exploration Drill Sites

Final exploration drill sites were selected mainly on the residual gravity data presented on linear graphs. The linear graphs permit an evaluation of residual gravity (milli-gal) plotted against the terrain elevation. The

The positions of gravity survey traverses with final residual gravity values are indicated on Figure 61. Examples of linear gravity graphs indicating drill sites, exploration borehole and blow yield are listed as Figure 62 to Figure 63 with the remaining of the graphs listed in the appendices volume II of the report.

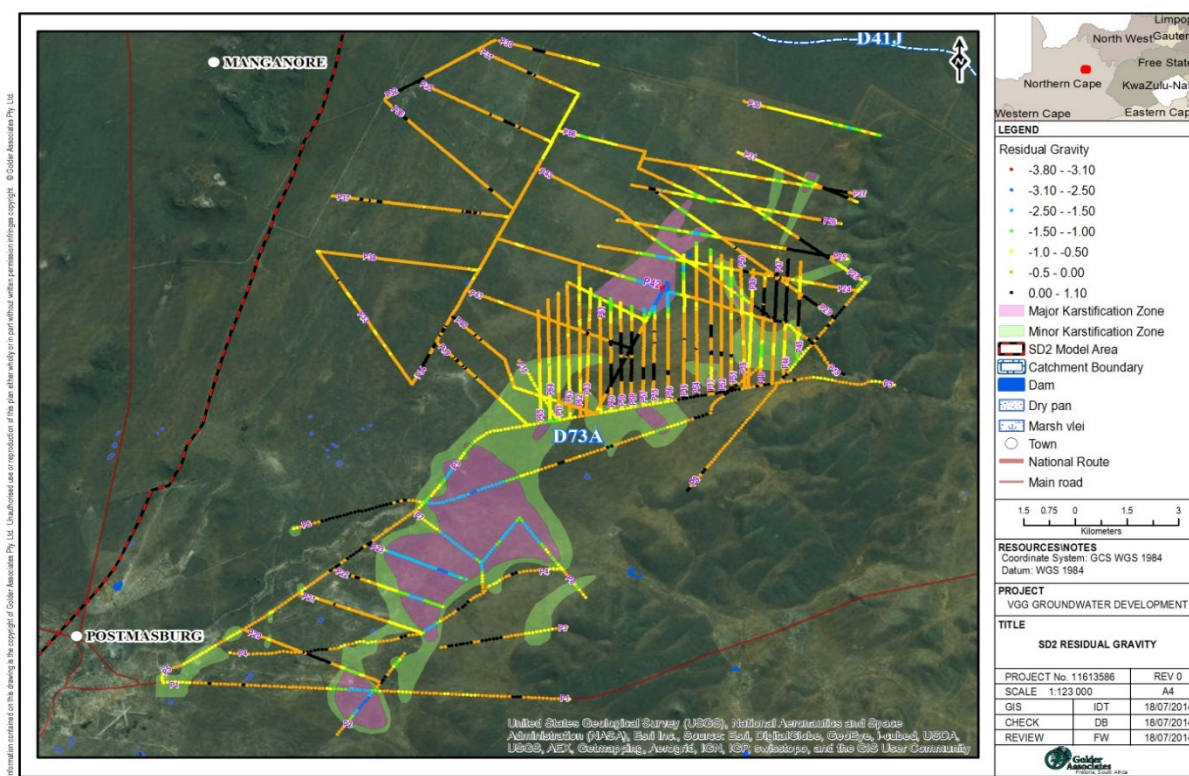


Figure 61: Geophysical Traverses and Residual Gravity Values

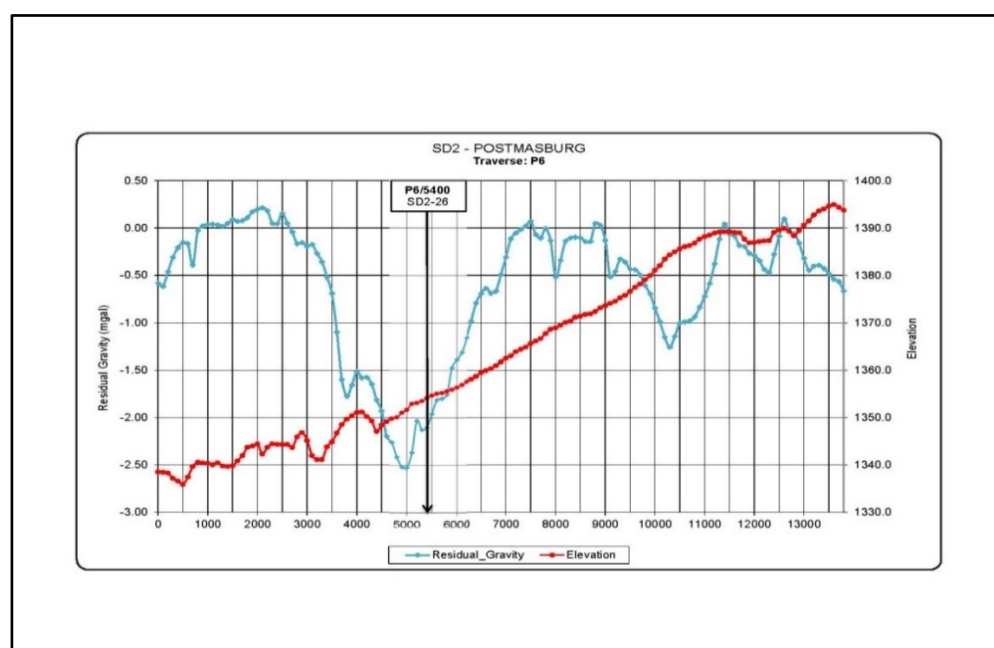


Figure 62: Drill Site P6 – Borehole SD2-26

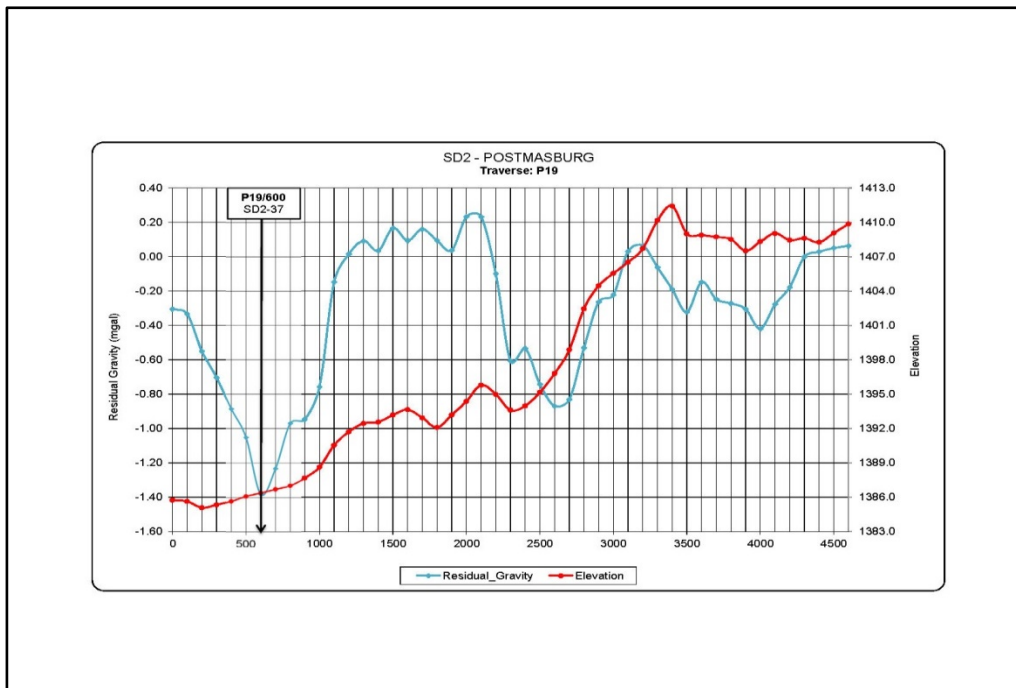


Figure 63: Drill Site P19 – Borehole SD2-37

2.3.3 SD2 Hydrogeological Investigation

2.3.3.1 Desk Study

A desk study and information review were conducted prior to field investigations. The following information was reviewed during desk study:

- 1:250 000 geological map series,
- 1:8 500 000 Groundwater Harvest Potential map of RSA (DWAf 1995),
- 1:2 500 000 Groundwater Resources map of RSA –Sheet 1 (WRC.DWAf 1995),
- 1:4 000 000 Groundwater Resources map of RSA – Sheet 2 (WRC.DWAf 1995),
- 1: 500 000 Hydrogeological Map Series of RSA (1996),
- Existing borehole information were obtained from the following database:
 - Department of Water Affairs (DWAf) National Groundwater Database (NGDB),
 - Borehole information from Golder's in-house database (Aquabase), and
 - Monitoring data from the DWAf Kimberley office.
- Previous hydrogeological reports consisting out of resource assessment, development, and monitoring studies from DWAf and hydrogeological consulting firms, and
- Reconciliation strategy for Sedibeng Water's Vaal Gamagara pipeline scheme and Water Master Plan compiled by Golder Associates Africa in 2010.

2.3.3.2 Remote Sensing

A GIS mapping exercise was conducted, using satellite imagery to map linear structures (dykes, faults or lineaments). These linear structures mostly represent intrusive dykes, which are generally near vertical (85 to 90 degrees) and have strike lengths in excess of 100 km. The general strike directions are WSW – ENE, SSW – NNE, and ESE – WNW.

2.3.3.3 Landowner Engagement

The Department of Water Affairs and Sedibeng Water requested early commencement with stakeholder communication during the assessment phase through pro-active and transparent landowner engagement, rather than *ad-hoc* and reactionary engagement, or relying only on the regulatory public consultation that is being triggered by the environmental authorisation processes.

The Communication and Stakeholder Engagement Strategy involved:

- Confirmation of land ownership in the SD2 area. This was done by means of title deeds searches, verification and confirmation of details of landowners, surface rights permit holders and lawful occupiers of land through a process of networking and referral (e.g., liaising with the local agricultural union's chairperson,
- Identification of the relevant authorities with jurisdiction in the proposed demarcated project area,
- Created community and landowner awareness as follows:
 - Compilation and distribution of a background information letter accompanied by a full-colour map of the proposed project area and comment sheet to the relevant authorities (national, regional and local) and directly affected landowners within the SD2 area.
- Golder convened small focus group meetings, as follows:
 - District Municipalities with jurisdiction in the proposed demarcated project areas (SD2),
 - Local Municipalities with jurisdiction in the proposed demarcated project areas (SD2),
 - Agricultural Union and water bodies (e.g., water board, WUA – Tshping Water),
 - Relevant national and provincial government department(s).
- Golder convened group consultations with directly affected landowners/lawful occupiers of land for SD2.

2.3.3.4 Hydrocensus

The hydrocensus was conducted during 2012 and 2013. A total of 142 boreholes were surveyed in the SD2 study area with the co-operation of the landowners.

On some private land areas farmers did not allow access, which was not forced to maintain good relationships with landowners as alternative exploration options were available. The survey also included groundwater users with high abstraction rates, namely Postmasburg municipality boreholes and Jen Haven community production boreholes.

The hydrocensus borehole information is summarised in Appendix D and borehole position are indicated on Figure 64.

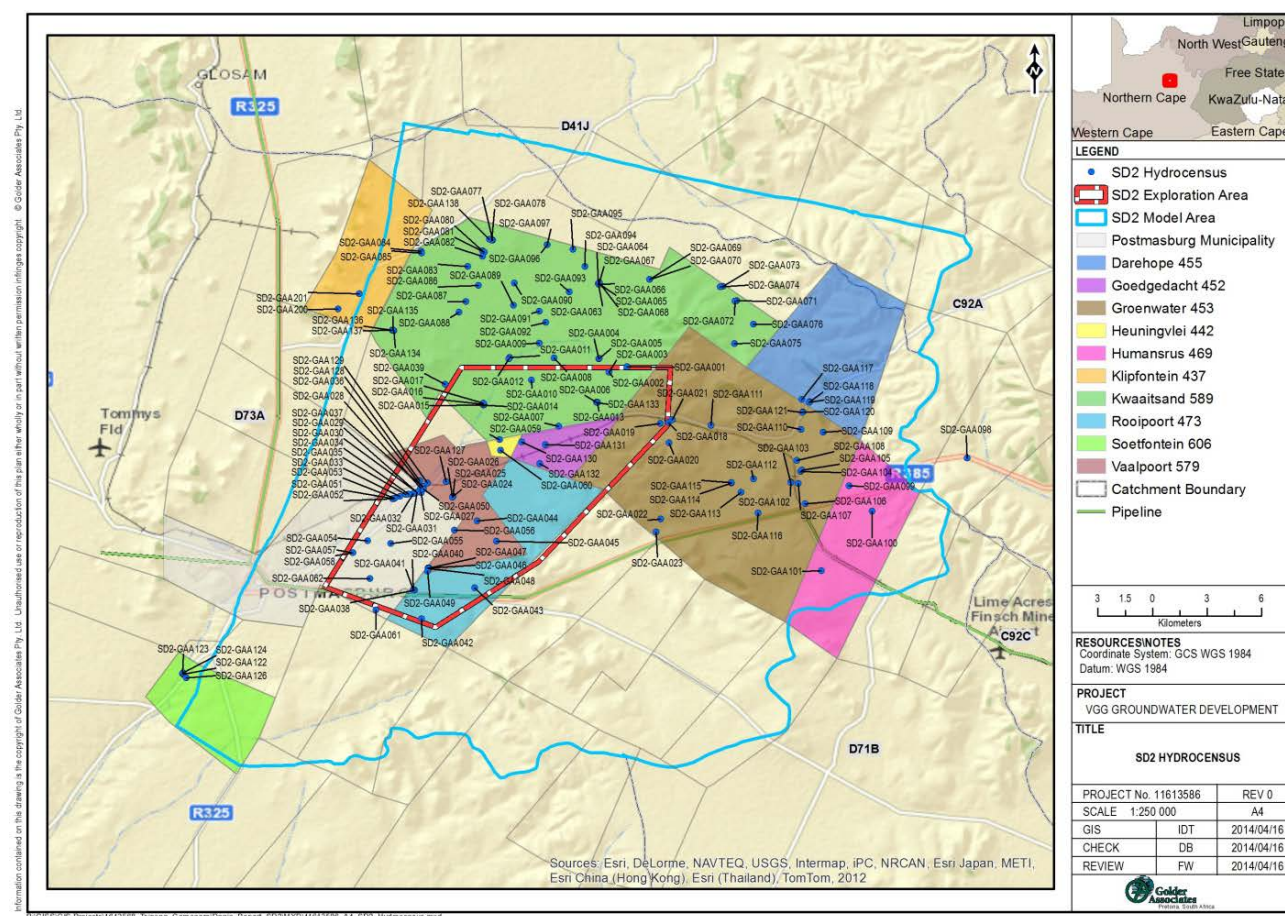


Figure 64: SD2 Hydrocensus Borehole Positions

Existing borehole information obtained revealed the following:

- Recorded borehole depths vary between 2.8m and 176m with an average depth of 67.3m,
- 111 water levels measurements were obtained, which range between 0.32m and 64.12m, with an average water level of 20.12mbgl,
- Reported borehole discharge rates range between 0.37l/s to 30l/s (SD2-GAA200 Sedibeng mine), with an average discharge rate of 4.4l/s,
- The reported groundwater use are mainly domestic all purpose (DA) and stock watering (AS).

Field parameters including pH and EC were measured in the field, these measurements indicate:

- The pH field values range between 6.4 and 9.4 with an average of 7.8(alkaline). The measured pH values are within the accepted quality range of 5 to 10 and is typical of the host formations comprising out of dolomite, BIF and calcrete of the investigation area, and
- The measured EC values range between 9.0 and 362mS/m with an average of 85.1mS/m. Only SD2-GAA015 and SD2-019 exceeds the DWAF 1998 Class 1 drinking water limit of 150mg/l. The elevated EC concentration are probably related to local point source pollution.

A total of 37 water samples were collected at existing boreholes during the hydrocensus and test pumping of existing boreholes to determine the baseline water quality of the existing groundwater users. The samples were sampled as per Golder standards and were submitted to UIS Analytical Services in Centurion for analysis.

Only one fountain SD2-GAA083 was confirmed within the SD2 investigation area.

2.3.3.5 Exploration Drilling

The drilling programme was completed on 8 March 2014, with a total of 47 boreholes drilled as indicated on Figure 65.

The objective of the exploration drilling was to quantify the sustainable groundwater of the source development area and to determine the feasibility of the source to contribute to the VGG pipeline.

Borehole drilling sites were selected to investigate geological structure and lithology, determine aquifer characteristics, measurement of groundwater levels to determine groundwater flow directions, and to establish potential production and monitoring boreholes.

The boreholes were drilled according to a sustainable yield approach, where boreholes were drilled over the entire major karstification zone of SD2 to minimize draw down of the water level.

Drilling depths of exploration boreholes were controlled by geology, water strike depths and yields. Exploration boreholes with air-lift yields ($>10\text{ l/s}$) were constructed as possible production boreholes.

The boreholes were drilled according to a sustainable yield approach, where boreholes were drilled over the entire major karstification zone of SD2, to minimize draw-down of the water level. This approach is contradictory to a mining approach of de-watering, where deep ($>100\text{ m}$) production boreholes are concentrated in an area in order to lower/dewater the water table.

The drilling approach entails specialized drilling (large diameter percussion) and construction of exploration boreholes in areas underlain by dolomite, banded iron formation and Kalahari sediments. The drilling diameters started at 381mm diameter as a maximum and reducing to 305, 254, 203 and 165mm as minimum pending on the geology and water strikes intersected.

The exploration boreholes were cased with steel casings (4mm and 6mm thickness). High yielding boreholes were developed as potential production boreholes and low yielding boreholes monitoring boreholes.

Gravel packs were installed in the annulus between the sides of the borehole and the casing of the borehole to stabilise the geological formation and allow groundwater inflow into the borehole. Bentonite seals of 3m to 5m were installed above the gravel pack at surface.

One monitoring borehole (SD2-16M) was drilled within 20m distance from high yielding borehole SD2-16. The purposes of this monitoring borehole apart from a monitoring facility was to determine the hydraulic parameters of the major karstification zone during long term test pumping. This monitoring borehole was marked using the after-fix "M" after the borehole number (SD2-16M).

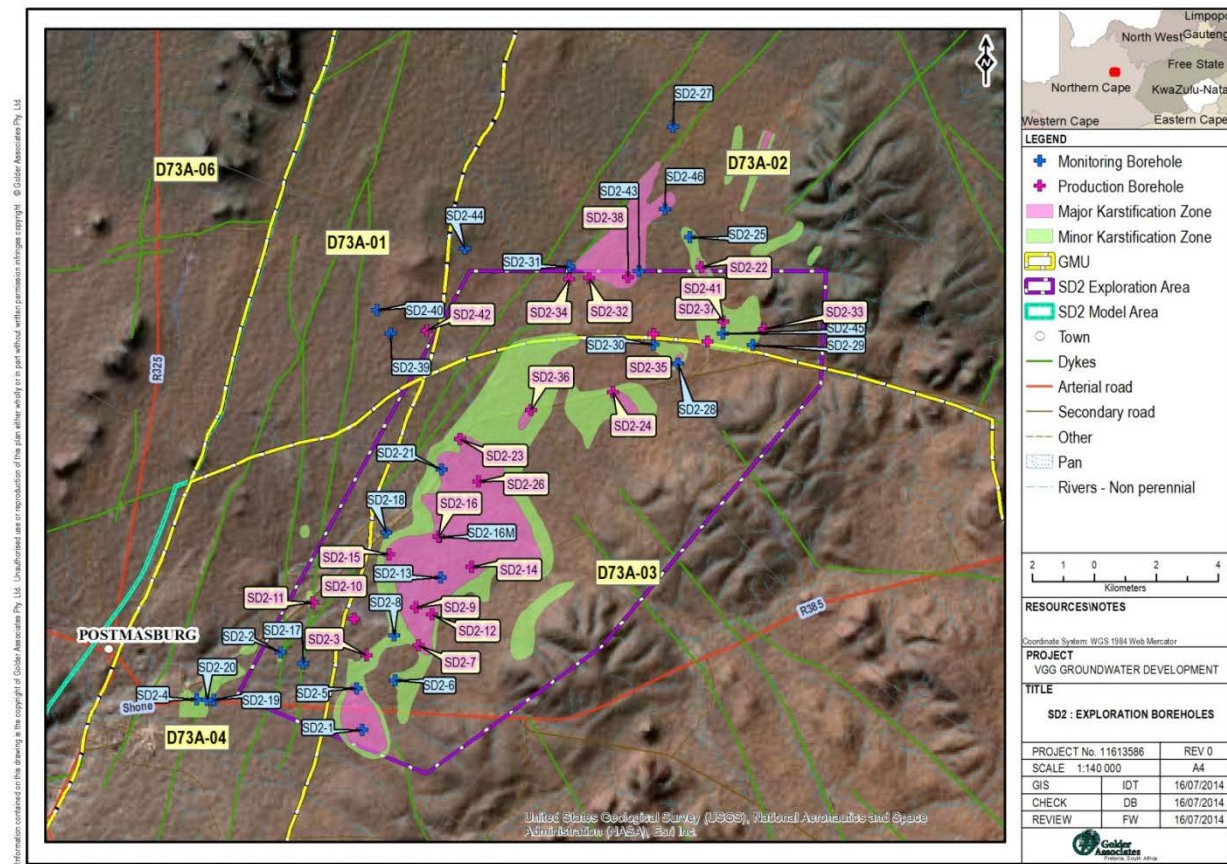


Figure 65: SD2 Exploration Borehole Positions

Drilling Results

A total of 47 exploration boreholes were drilled, from which 28 boreholes were constructed as potential production status and 19 as monitoring status. The drilling results are summarised in Appendix E with details of water strike depths, strike yields and main geology intersected. Borehole altitudes were surveyed to an accuracy within <20mm amsl. The drilling results for SD2 are summarised as follows:

- Drilling depths range between 34m and 130m, with an average depth of 81m,
- Intersected groundwater strike depths range between 13m and 119m with an average of 57m,
- Final blow yields range between 0.1l/s and 40l/s (SD2-26) with an average blow yield of 13.7l/s, and
- Recorded water level depths range between 5 (SD2-42) and 60m (SD2-33) with an average of 28m.

The combined air-lift yield from the 28 potential production boreholes is 100l/s. The final blow yield ranges, as a percentage of the number of exploration boreholes drilled are as follows:

- Seepage intersected: 10 exploration boreholes – 21%,
- Yields <10l/s: 14 exploration boreholes – 30%,
- Yields 10l/s to 20 l/s: 14 exploration boreholes – 30%, and
- Yields >20l/s: 9 exploration boreholes – 19%.

2.3.3.6 Delineation of Kalahari Sediment Thickness

The boreholes logs of the SD2 exploration boreholes and the SkyTEM resistivity map for four depth horizons (10m –shown in Figure 66, 20m, 30m and 40m) were used to delineate and contour the thickness of the Kalahari sediments (calcrete and clay) as indicated on Figure 67.

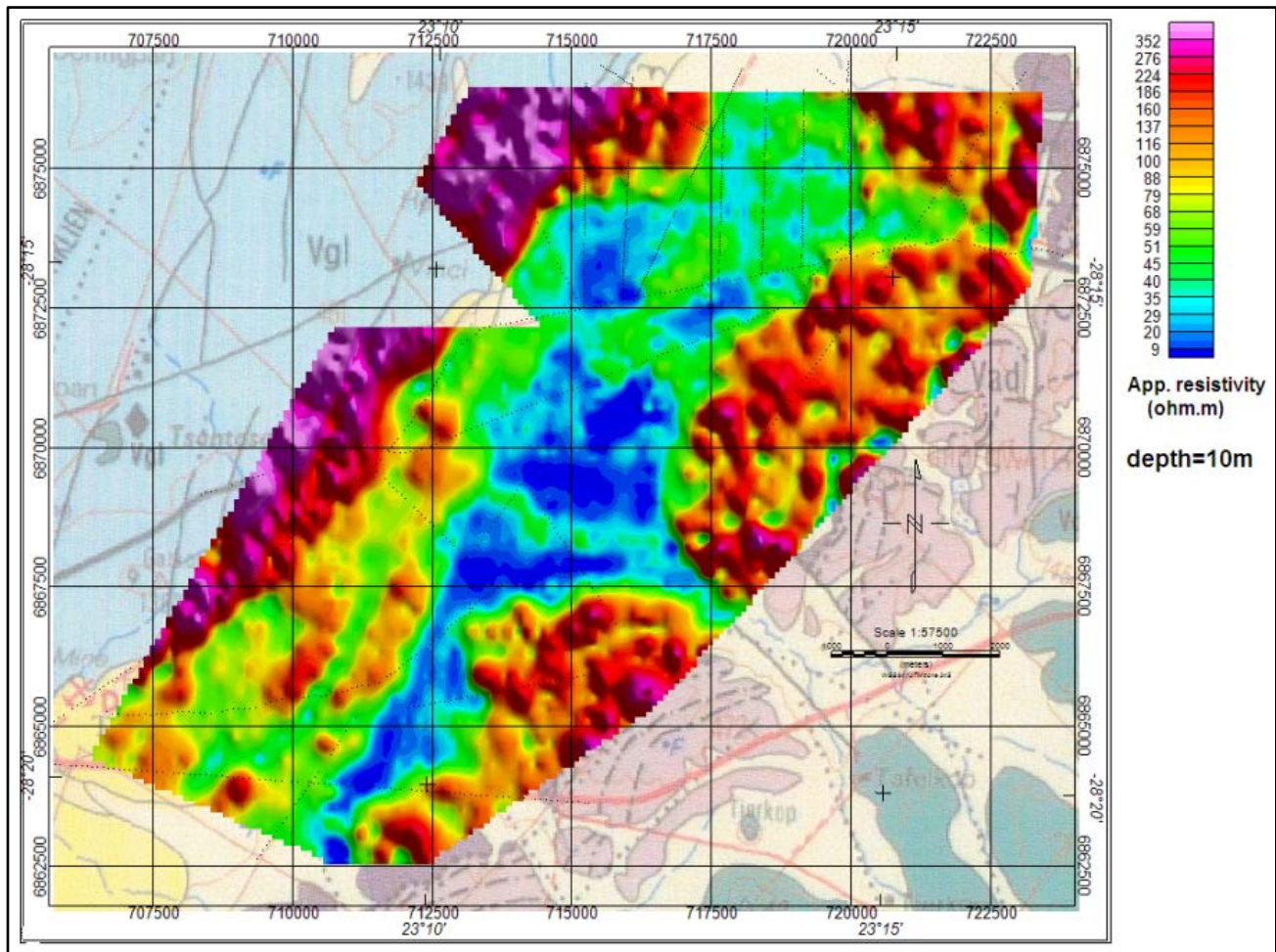


Figure 66: Resistivity distribution at 10m depth

These inferred Kalahari sediments thickness exceeds 60mbgl in certain areas, have a low permeability, restrict groundwater movement and acts as storage unit. At exploration borehole SD2-1 Kalahari sediments and clay were encountered up to 106m below surface. These delineated Kalahari sediment thicknesses correlate well with the residual gravity values outlining areas of low formation density.

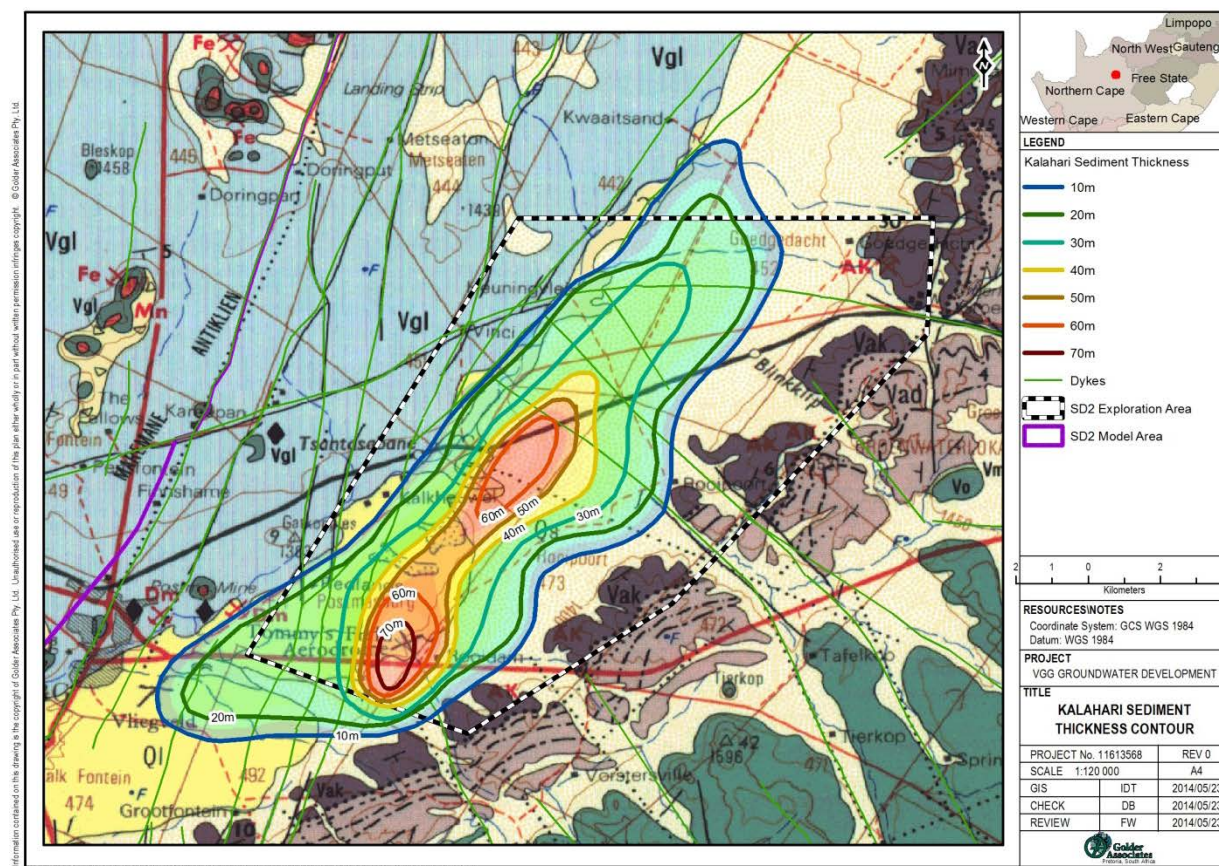


Figure 67: Kalahari Sediment Thickness

2.3.3.7 Aquifer Testing

Aquifer testing was performed on 20 existing boreholes (Figure 68) and 34 newly drilled exploration boreholes (Figure 69). The testing programme in SD2 area was completed 16 March 2014.

The aquifer testing programme consists out of a step drawdown/discharge test (SDT) followed by a constant discharge test (CDT), and a water level recovery test. Each SDT comprised three to four 60-minute steps at increasing pumping rates. The aim of the SDT is to assess the performance of the borehole under different pumping yields and determine the pumping rate for the CDT.

The CDT is conducted to determine the hydraulic parameters of the aquifer and identify possible aquifer boundaries. The CDT at the exploration boreholes were conducted for periods of between 12 and 72 hours, after which the water level recovery was measured. The CDT pumping rates were set at yields determined from the SDT to be sustainable for the planned duration of the test. Water levels were monitored in adjacent boreholes during the CDT to determine if there is connectivity between the boreholes.

Pumping rates varied from 0.1 l/s to 30.0 l/s. Water-level recovery measurements were taken for the same period as pumping during the SDT and CDT or to 100% recovery of the original water level. The recovery of the boreholes provides an independent measure of the Transmissivity of the aquifer. In the case of existing boreholes only SDT was conducted for yield determinations.

Five high yielding exploration boreholes (SD2-9, SD2-12, SD2-15, SD2-34 and SD2-35) were subjected to second long term 72hour CDT.

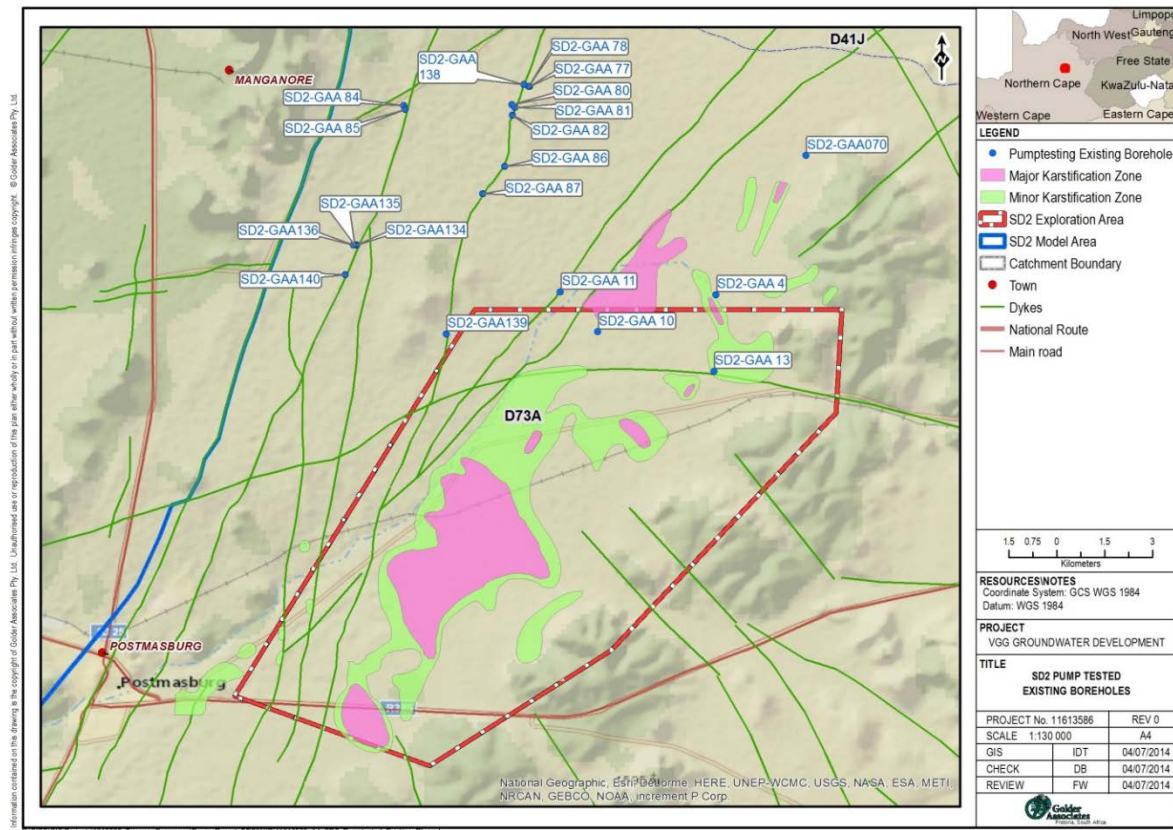


Figure 68: Position of Existing Boreholes Test Pumped

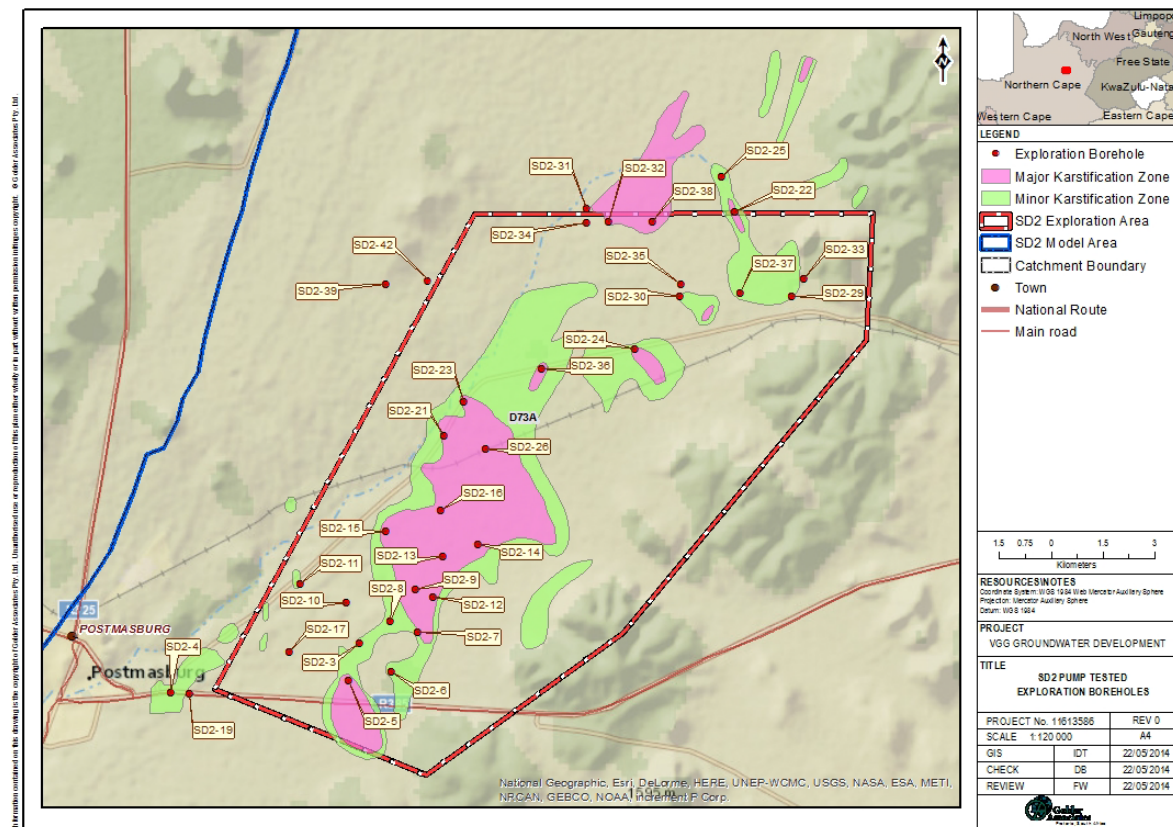


Figure 69: Position of Exploration Boreholes Test Pumped

The aquifer testing programme of the existing boreholes are summarised in Table 22 and of the exploration boreholes in Figure 69.

Table 22: SD2 Existing Boreholes Pump Tested

Borehole Number	Borehole Depth (m)	Static Water level (mbgl)	No of SDT's	Final Yield (l/s)	DD (m)	PI Yield (l/s)
SD2-GAA 4	88.55	44.25	3	20.4	0.68	No PI
SD2-GAA 10	69.1	31.75	3	4.03	13.92	No PI
SD2-GAA 11	69	14.13	2	1.02	47.82	0.44
SD2-GAA 13	88.2	49.05	1	0.84	27.05	No PI
SD2-GAA070	146	56.51	1	0.5	36.83	0.34
SD2-GAA 77	138.38	11.94	2	1.01	85.17	No PI reached
SD2-GAA 78	81.76	16.13	2	0.74	57.10	No PI
SD2-GAA 80	39.7	31.17	1	0.4	6.28	-
SD2-GAA 81	76.8	32.07	4	4.03	36.65	3.30
SD2-GAA 82	68.56	5.38	2	1.24	57.14	0.70
SD2-GAA 84	28.8	9.8	4	4.46	5.10	No PI
SD2-GAA 85	59.63	13.56	2	0.92	37.40	0.63
SD2-GAA 86	78.68	8.28	1	0.52	54.34	No PI
SD2-GAA 87	45.9	9.16	2	1.06	29.53	0.70
SD2-GAA134	28.6	13.75	2	0.71	13.0	0.41
SD2-GAA135	54.6	12.88	2	1.06	37.88	0.40
SD2-GAA136	36.8	11.14	4	4	0.92	No PI
SD2-GAA 138	119.8	6.5	1	0.62	86.0	0.21
SD2-GAA139	90.6	12.24	3	1.5	68.97	1.00
SD2-GAA140	58.2	14	1	0.5	36.82 (SDT)	0.30

Test Pumping Results

Test pumping results were interpreted by means of WHI Aquifer Test version 3 software, by Waterloo Hydrogeologic Inc. and the FC Method developed by the Institute for Groundwater Studies at Free State University, Bloemfontein.

The test pumping results of existing boreholes interpreted from test pumping software are summarised in Table 24.

Storativity (S) values calculated for existing and new exploration boreholes are summarised in Table 23.

Table 23: SD2 Storativity Values

Borehole Number	Date Tested	Borehole Depth (m)	Static Water level (mbgl)	Monitor Borehole	Monitor borehole Aquifer Test - T (m ² /day)	Draw Down (m)	Storativity (S)	Storativity (S)
SD2 Exploration Boreholes								
SD2-11	20/09/2013	34	11.52	SD2-	4750	0.77	1.58 X 10-	0.0000015
SD2-16	27/10/2013	97	19.64	SD2-16M	1910	0.58	1.57 X 10-	0.000157
SD2-35	23/02/2013	98.85	50.12	SD2-30	1240	0.1	7.38 X 10-	0.000738
SD2-42	13/03/2014	38.70	5.21	SD2-39	600	0.11	3.48 X 10-	0.0000348
Mean								0.00031
Median								0.00016

The drilling and test pumping results confirm the presence of a semi-confined aquifer system in the dolomite and BIF formations, as an aquifer that is partly confined by layers of lower permeability (calcrete) material through which recharge and discharge may occur.

Table 24: Calculated Transmissivity Values of SD2 Exploration Boreholes

Borehole Number	Borehole Depth (m)	Static Water level (mbgl)	Constant Draw Down Test			Recovery		Transmissivity (T)		Borehole Diameter (mm)	Primary aquifer/ Geology	Boreholes Status
			Duration (Min)	Yield (l/s)	Drawdown (m)			CJ Method (m²/day)	Aquifer Test (m²/day)			
						(Min)	%					
SD2-3	118	19.47	2880	20.1	18.68	480	100	898	591	165	Dolomite	Production
SD2-7	52.4	20.83	2880	30.22	8.42	10	100	500	431	203	Dolomite	Production
SD2-9	66.3	19.23	1440	20.64	0.52	90	100	965	998	165	Dolomite	Production
SD2-9(2)	66.44	18.19	4320	20.08	0.28	2	100	6180	-	165	Dolomite	Production
SD2-10	70.5	12.35	1440	15.0	9.43	40	100	3788	756	165	Dolomite	Production
SD2-11	34	11.52	2880	30.1	1.68	1440	100	834	946	203	Dolomite	Production
SD2-12	74.4	21.10	1440	20.1	4.63	300	100	683	-	165	Dolomite	Production
SD2-12(2)	74.06	20.38	4320	20.12	4.8	1	100	4120	-	165	Dolomite	Production
SD2-13	52.6	19.75	2880	20.0	16.58	2880	91	570	-	203	Gravel	Production
SD2-14	100.0	23.94	1440	15.2	12.16	90	100	472	-	165	Dolomite	Production
SD2-15	81.8	16.11	1440	20.0	3.36	30	100	476	-	165	Dolomite	Production
SD2-15(2)	80.44	16.4	4320	20.08	3.58	720	100	12360	-	165	Dolomite	Production
SD2-16	97.0	19.64	4320	20	5.84	3	100	892	1020	165	Dolomite	Production
SD2-17	59.6	13.24	1440	15.0	9.43	960	100	191	-	165	Dolomite	Production
SD2-21	94.0	19.81	4320	13.0	24.24	2	100	203	-	165	Dolomite	Production

Borehole Number	Borehole Depth (m)	Static Water level (mbgl)	Constant Draw Down Test			Recovery		Transmissivity (T)		Borehole Diameter (mm)	Primary aquifer/ Geology	Boreholes Status
			Duration (Min)	Yield (l/s)	Drawdown (m)			CJ Method (m²/day)	Aquifer Test (m²/day)			
						(Min)	%					
SD2-22	73.0	45.8	2880	13.0	9.32	1200	100	80.0	-	165	Dolomite	Production
SD2-23	73.0	21.79	1440	15.0	6.78	3	100	1338	-	203	Dolomite	Production
SD2-24	119.0	48.01	1440	15.0	8.64	2880	97	220	-	165	Dolomite	Production
SD2-26	75.0	23.3	4320	20.0	13.56	720	100	1500	-	203	BIF/Dolomite	Production
SD2-30	98.0	52.52	1440	10.03	15.25	210	100	184	-	165	Dolomite	Production
SD2-31	85.0	11.38	1440	7.0	2.34	600	100	438	-	203	Dolomite	Monitoring
SD2-32	90.0	31.63	1440	8.0	32.70	180	100	61	-	203	Dolomite	Production
SD2-33	101.96	59.3	2880	9	12.89	840	100	119	-	165	BIF	Production
SD2-34	34.0	12.31	1440	20.0	1.4	1440	97	872	-	203	Dolomite	Production
SD2-34(2)	34.46	12.31	4320	30.04	2.77	1440	100	842	-	203	Dolomite	Production
SD2-35	100.48	50.36	1440	25	0.28	15	100	1342	-	203	Dolomite	Production
SD2-35(2)	98.85	50.12	4320	30.02	0.43	1200	100	4635	8530	203	Dolomite	Production
SD2-36	97.5	33.92	1440	15	1.54	480	100	1013	-	203	Dolomite	Production
SD2-37	83.86	59.8	2880	20.17	0.77	10	100	2528	-	165	Dolomite	Production
SD2-38	88.75	38.08	3240	15	27.43	20	100	63	-	165	Dolomite	Production
SD2-42	39	5.21	4320	20.0	4.62	360	100	269	265	165	Dolomite	Production

2.3.4 SD2 Groundwater Resource Assessment

2.3.4.1 Groundwater Use

Existing Groundwater Users

The existing groundwater use for the SD2 was calculated from data and abstraction rates required during the hydrocensus and groundwater database. The groundwater use and abstraction rates are summarised in Table 25.

The existing groundwater users are divided into two main use categories namely municipality/community use and private use with a combined abstraction rate of 1 721 186.56m³/Month.

Private used boreholes where no yields were reported were calculated based on an average of:

- Windmill 0.3l/s for 8 hours/day,
- Solar pump 0.2l/s for 6 hours/day,
- Hand pump 0.1l/s for 8 hours/day,
- Fountains 0.5l/s for 24 hours/day, and
- Motorized pumps at 0.5l/s for 8 hours/day.

Table 25: SD2 Existing Groundwater Use and Abstraction Rates - 2013

Groundwater use	Borehole number	Abstraction Rate m ³ /Month	Abstraction Rate m ³ /Year
Postmasburg Municipality	SD2-GAA036; SD2-GAA037 and calculated average of existing production BH's	46 673	560 079
Municipality Jen Haven Community	SD2-GAA002; SD2-GAA004	10 368	124 416
Groenwater Community	Boreholes in use (12)	3 957	47 485
Private	226 Boreholes and fountains	111 188	1 334 258
Total Use		172 186	2 066 238

SD2 WARMS Registered Groundwater Users

11 groundwater users were located within the SD2 modelling area that is registered with the Water Authorization and Registration Management System (WARMS) and are indicated on Figure 70 and summarised in Table 26.

Table 26: WARMS Registered Groundwater Users

Groundwater user Name	No. on Map	Latitude	Longitude	Licence number	Use	Drainage Region	WARMS Mm3/Year
AREEMENG MMOGO PRIMARY	W3	- 28.303500	23.305833	25058650	AGRICULTURE: WATERING LIVESTOCK	D73A	3421
SOLANDRA INVESTMENT 506	W5	- 28.316278	23.102722	25059070	MINING	D73A	2600

Groundwater user Name	No. on Map	Latitude	Longitude	Licence number	Use	Drainage Region	WARMS Mm3/Year
MF CLAASSENS	W6	- 28.200000	23.133333	25002238	AGRICULTURE: IRRIGATION	D41J	24300
PEJ DUVENHAGE	W8	- 28.183333	23.200000	25003237	AGRICULTURE: IRRIGATION	D41J	27250
T COETZEE	W9	- 28.383333	23.216667	25003512	AGRICULTURE: IRRIGATION	D73A	98768
A DUNWOODY	W11	- 28.250000	23.389247	25017525	MINING	C92A	7200
JJ COETZEE	W16	- 28.200000	23.133333	25002540	AGRICULTURE: IRRIGATION	D41J	9590
CC CLAASSENS	W17	- 28.183333	23.133333	25002602	AGRICULTURE: IRRIGATION	D41J	9730
LJ JANSE VAN RENSBURG	W18	- 28.183333	23.133333	25004487	AGRICULTURE: IRRIGATION	D41J	6463
JH BOSHOF	W20	- 28.200000	23.150000	25005048	AGRICULTURE: IRRIGATION	D41J	5450
42 BOERDERY	W21	- 28.200000	23.133333	25009133	AGRICULTURE: IRRIGATION	D41J	39000
Total							1 431 450

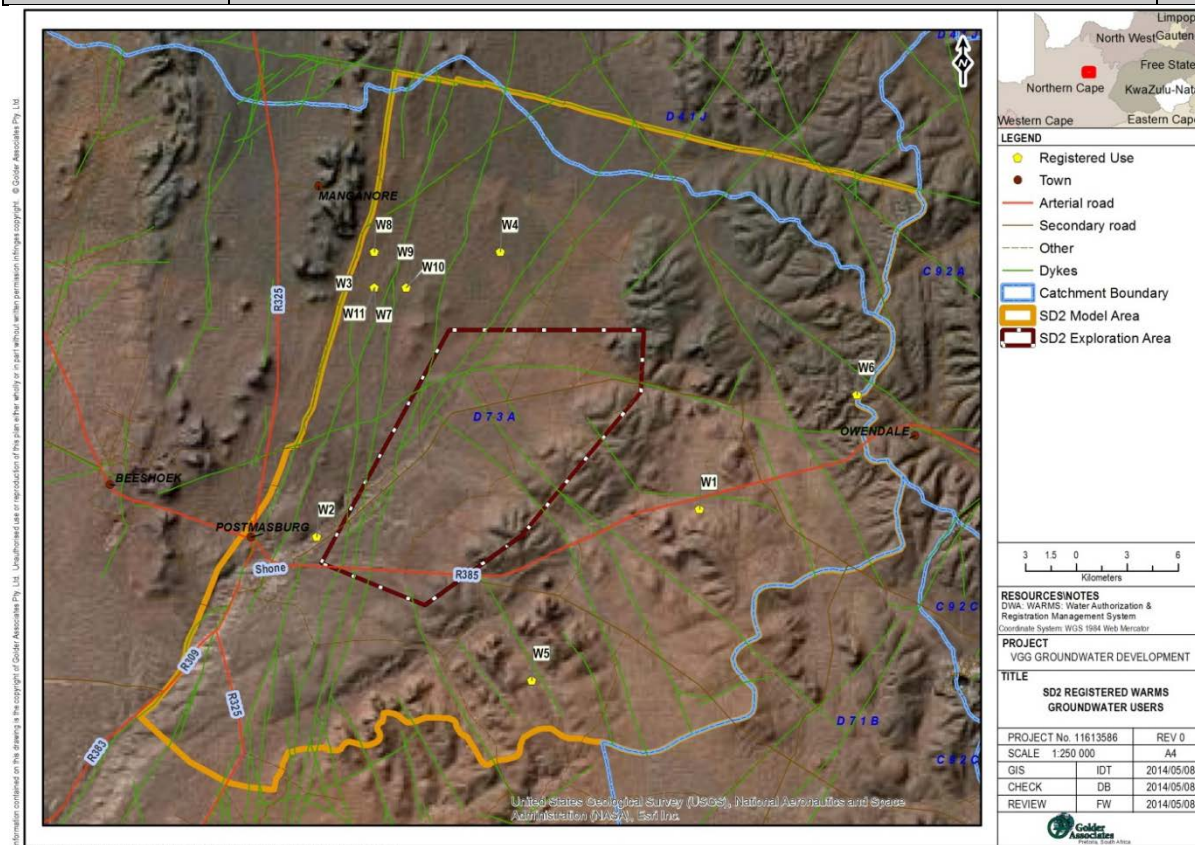


Figure 70: SD2 Registered WARMS Groundwater Users

Fountains

Six fountains were located from the groundwater data base which falls within the SD2 modelling area. These fountains positions are indicated on Figure 71 and are summarised in Table 27. However only fountain SD2-GAA083, falling within the designated hydrocensus area position was confirmed during the hydrocensus. Some existing fountains are non-perennial in the modelling area and may start flowing during high rainfall seasons.

Table 27: SD2 Fountains

Fountain/Farm	Map Number	Latitude	Longitude	Altitude (mamsl)	Equipment	Estimated Flow (l/s)	Estimated Flow M ³ /Month	Estimated Flow M ³ /Year
Groenwater	GR13	-28.255580	23.326970	1451.2	-	1.01	2617.9	31415.0
Knoffelfontein	PEN6	-28.293680	23.078620	1352.2	N	12.62	32711.0	392532.5
Farm 492 ptn. Grootfontein	Grootfontein	-28.368960	23.101390	1330.1	N	0.5	1296.0	15552.0
Olyn fontein ptn. Olienfontein	OLN9	-28.349370	23.051997	1289.2	-	0.5	1296.0	15552.0
Ploegfontein	PLOEG01	-28.372470	23.036240	1269.8	N	0.5	1296.0	15552.0
Seretse sencho ptn. Sion	SD2- GAA083	-28.170450	23.175170	1403.1	N	0.2	518.4	6220.8
Total						15.3	39 735.3	476 824.3

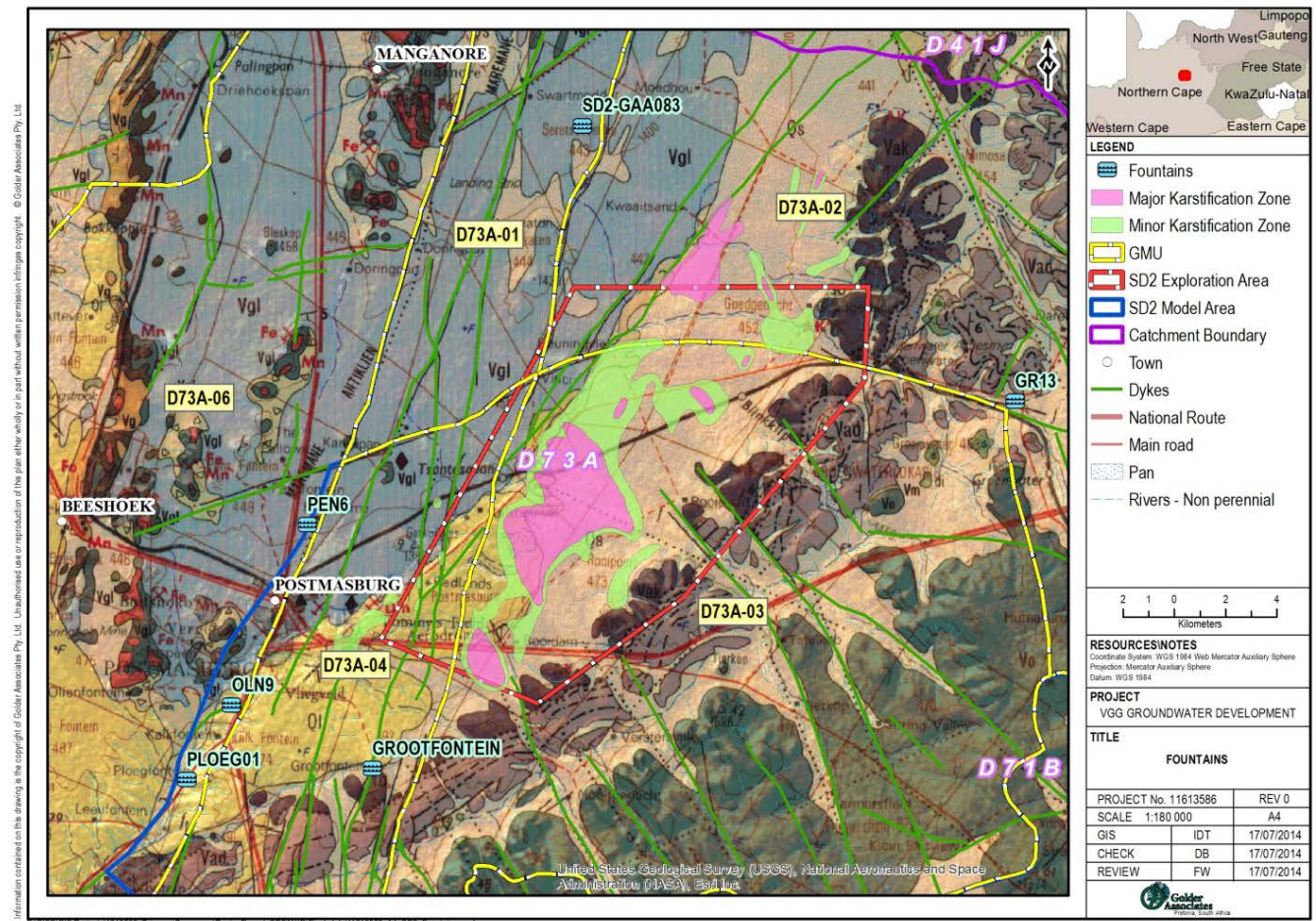


Figure 71: SD2 Fountain Positions

2.3.4.2 Groundwater Levels and Flow directions

Manual derived groundwater piezometric contours were compiled at 10 metre intervals for the SD2 study area. The contours are based on 298 water level elevation data points, sourced from the Golder in-house database. The manual compiled contours were all digitized. These digitized contours were used as input values and contoured on Surfer software, to compile the final groundwater piezometric contours, at 10 meter intervals, as depicted in Figure 72.

The regional groundwater flow direction for the SD2 study area is south west towards Postmasburg. Groundwater piezometric contours mimic the surface topography, and regional the groundwater flow is from higher lying ground toward lower lying valleys, where groundwater accumulates in the alluvial deposits and contributes to baseflow.

Groundwater piezometric contours within the central parts the model domain shows a low hydraulic gradient (Figure 72) due to the high aquifer transmissivity within the dolomitic compartments. The region is bounded by dykes which are associated with major steps in hydraulic heads, where water levels on the one side of a dyke are substantially lower. Piezometric levels north and northwest of the model domain show steeper gradients, indicating lower transmissivities in the BIF hard rock aquifer. The depth to the groundwater table ranges from 1 to 123 mbgl, with an (arithmetic) average depth to groundwater of 20.5 mbgl.

Groundwater piezometric contour levels ranges from 1550mamsl in the east to 1260mamsl in the south west, representing a maximum head of 290 metres for the study area.

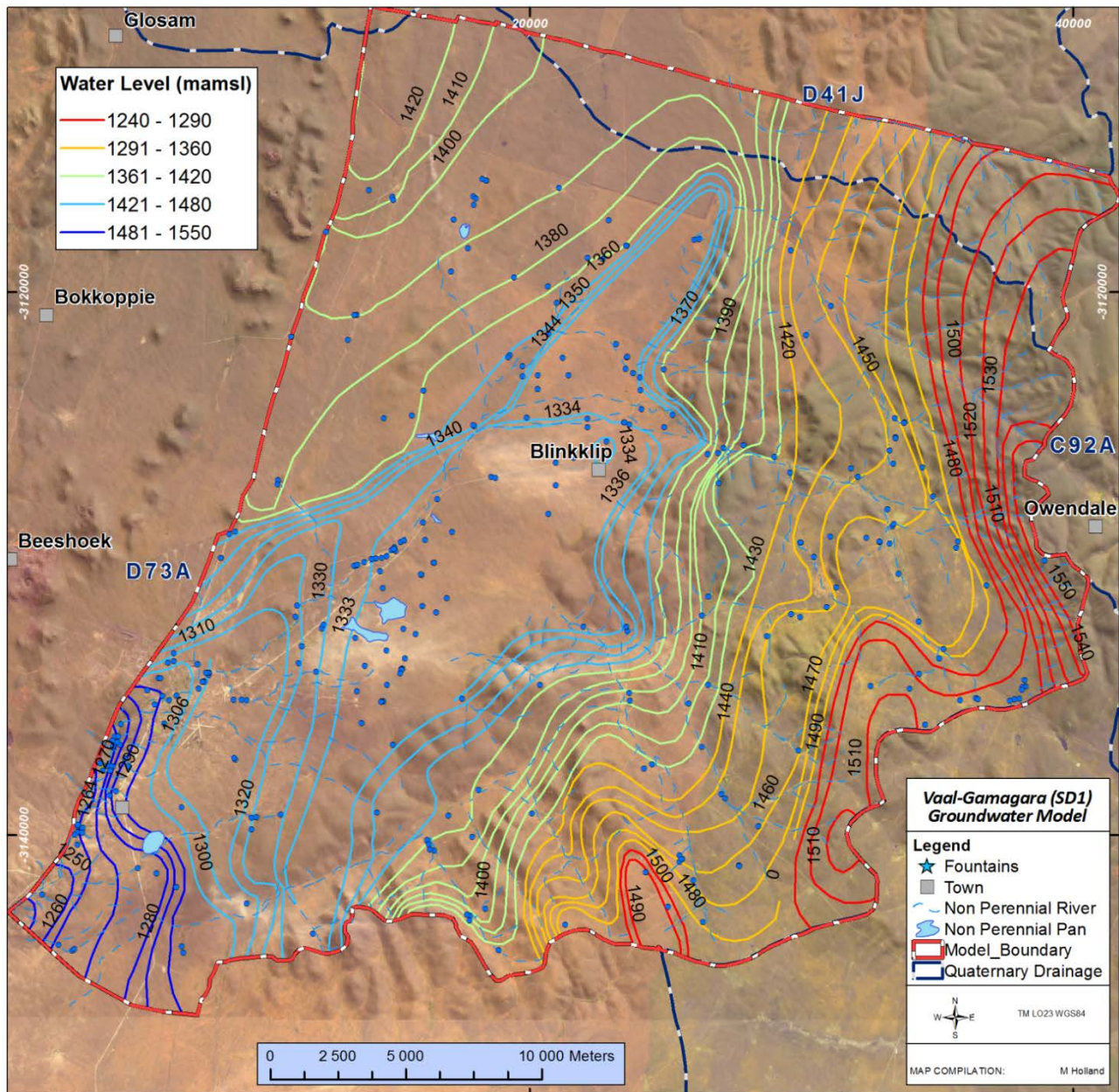


Figure 72: SD2 Groundwater Piezometric Contour Map

2.3.4.3 Groundwater Management Units

Groundwater Management Unit (GMU) is a groundwater system that is hydraulically connected which is recognised by territory or state agencies (Richardson, 2008).

The geological formations, structural information, piezometric surface and water quality indicators were used to delineate groundwater management units. This enabled assessment of groundwater recharge at local scale, to assess how much water is locally available for use, at what quality and at which location.

A total of six Groundwater Management Units (GMU's) were delineated for the entire SD2 modelling area shown in Figure 73 in order to quantify available water resources, estimate recharge volumes and calculate water balances on a sub-catchment scale.

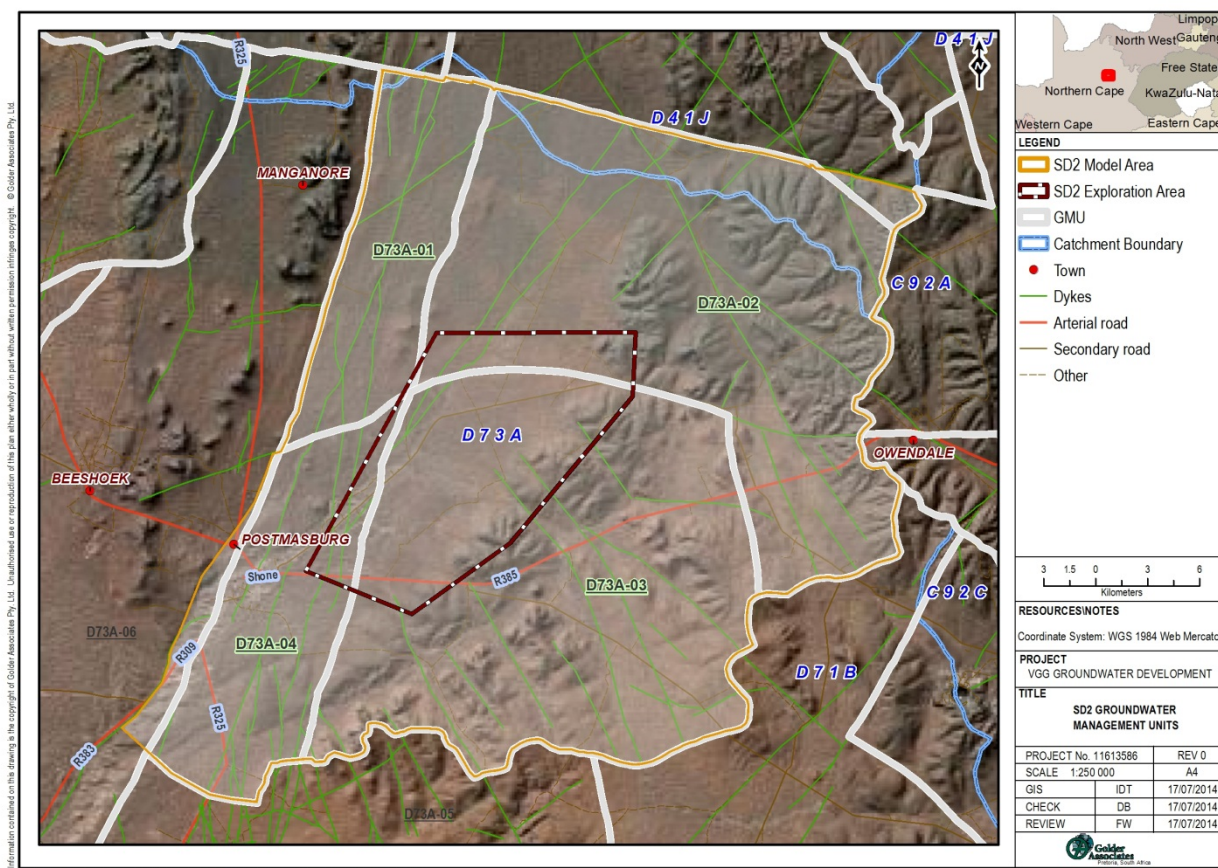


Figure 73: SD2 Groundwater Management Units

2.3.4.4 Aquifer Recharge Estimates

The quantity of rainfall and intensity of rainfall (monthly rainfall) are the major drivers of aquifer recharge in the study area. Groundwater recharge (excluding lateral inflows) is sustained by direct rainfall on the surface area and the evaluation thereof is dependent on various factors:

- Volume of rain during a rainfall season as well as the rainfall intensity. Larger rainfall intensity effects surface runoff with increased recharge occurring in areas comprising surface depressions,
- Type of surface cover. Aquifer recharge increases in areas with outcropping BIF and dolomite geological formations, gravel, and sand cover. Limited to no recharge occurs where Kalahari Group Sediment thicknesses exceed 15 metres,
- Depth to groundwater level. Shallow groundwater level areas or areas with relative lower water level depths may represent areas with increased recharge from rainfall,
- Groundwater quality. The relative electrical conductivity and chloride content of water can be used to identify areas with increased recharge from rainfall, and
- Local surface depressions also represent areas with increased recharge potential due to the accumulation of surface run-off water.

The published hydrogeological maps (DWA 1996) indicate the average recharge for the study area as 5mm to 10 mm per annum.

The Chloride Ratio Method was used for this study as the method works well for areas underlain by dolomite and BIF formations.

Chloride is a conservative tracer and enters an aquifer by the rainfall recharging the aquifer. The percentage rainfall, representing average annual recharge, can be derived from the ratio of the chloride concentration in rainfall relative to that of groundwater, (Bredenkamp et al, 1995). A specific requirement is that no chloride was added by dissolution of aquifer material, from salts contained within the aquifer matrix, or has entered the aquifer via pollution.

If the specific requirement above is not valid, it should be noted that the chloride ratio method will result in an underestimate of rainfall recharge and not an overestimate. Once the mean annual rainfall is determined for a local area, the mean annual recharge can be estimated by means of the chloride ratio method.

The mean annual recharge is the long-term maximum recharge expressed as a long-term average. Rainfall variability and intensity (depth) as well as extended droughts are important aspects which determine the sustainability of a resource. Recharge often occurs during episodic recharge events and aquifer storage is important for sustainable abstraction to bridge extended drought periods. The median recharge is the minimum recharge that is available for 5 out of 10 years and considered the volume of water which is available for sustainable use.

SD2 modelling area was delineated into 8 recharge zones based on related chloride values (Figure 74 and geology). These recharge estimate zones were delineated using chloride values from higher yielding boreholes and boreholes considered uncontaminated (lower chloride values). In areas with sparse or no chloride values, values from similar geological and rainfall terrains were used. These values were used to determine the % recharge from mean annual precipitation (MAP)

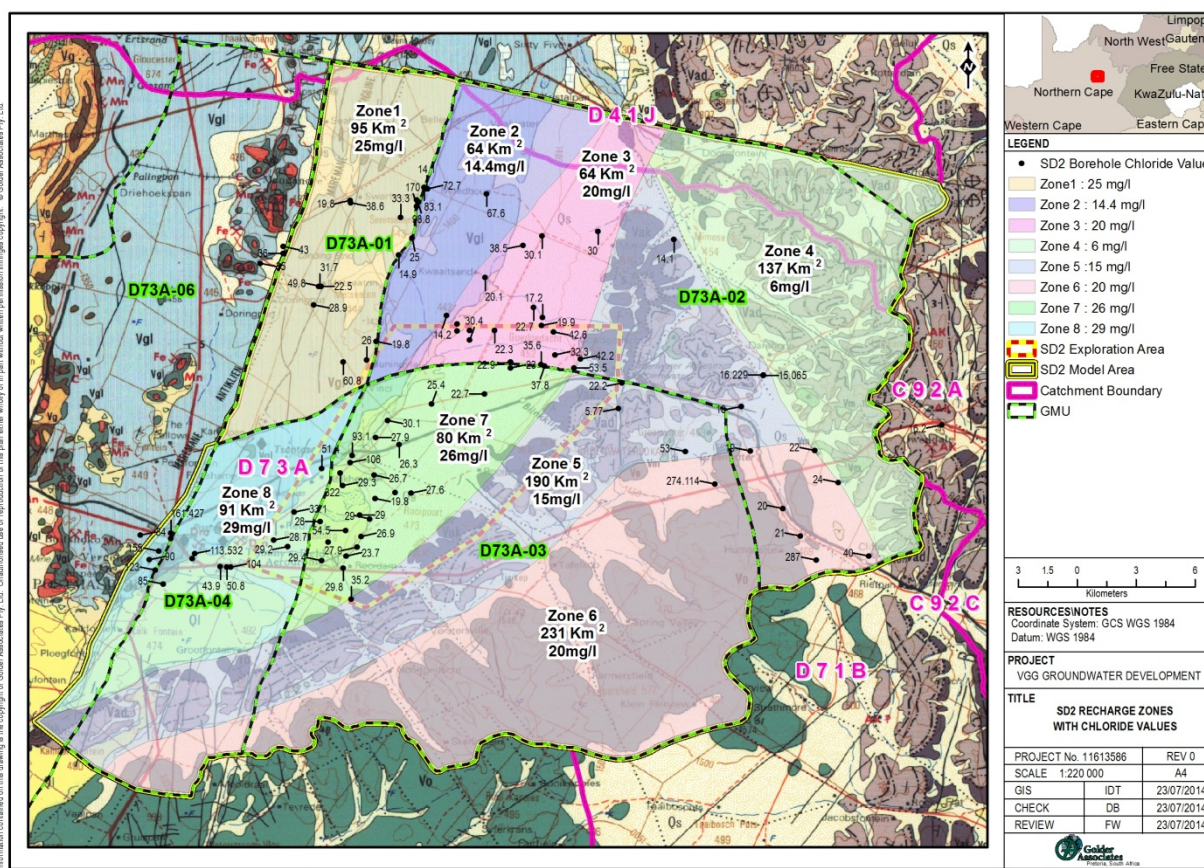


Figure 74: SD2 Recharge Zones - Cl Values

The mean and median annual recharge for the SD2 modelling area recharge zones is presented in Table 28

The exploitable groundwater resource (median recharge) for the SD2, D73A catchment for all GMU's as presented in Table 8 amounts 9.0 million m³/a.

Table 28: Summarised Recharges Estimates for SD2 Recharge Zones Based on the Chloride Ratio Method

Recharge Zone	Representative Cl (mg/l)	% Recharge	Area km ²	Mean (mm/a)	Median (mm/a)	Mean (Million m ³ /a)	Median (Million m ³ /a)	Quaternary Catchment Area	GMU Number
1	25	2.4	95	7.8	5.3	0.7	0.5	D73A	D73A-01
2	14.4	4.2	64	13.8	9.4	0.9	0.6	D73A	D73A-02
3	20	3	64	9.8	6.7	0.6	0.4	D73A	D73A-02
4	6	10	137	32.8	22.3	4.5	3.1	D73A	D73A-02
5	15	4	190	13.1	8.9	2.5	1.7	D73A	D73A-02
									D73A-03
									D73A-04
6	20	3	231	9.8	6.7	2.3	1.5	D73A	D73A-02
									D73A-03
									D73A-04
7	26	4	80	13.1	8.9	1.0	0.7	D73A	D73A-03
									D73A-04
8	29	2.1	91	6.9	4.7	0.6	0.4	D73A	D73A-04
Total			952	-	-	13.2	9.0	8	-

2.3.4.5 Groundwater Reserve

The Africa Geo-Environmental Services (AGES) conducted an intermediate groundwater reserve study in 2008 for the Lower Vaal Water Management Area (WMA). The intermediate groundwater reserve determination was done with using a Groundwater Yield Model for the Reserve (GYMR) and compared with the existing Groundwater Resource Directed Measures (GRDM) method using different scenarios.

Comparing scenario 1 (GYMR – Present Day) and scenario 5 (GRDM – Present Day) of the study, variances are observed in the groundwater balance as shown in Table 29.

Table 29: Comparison of Scenario 1 and 5 Present Day Water Balances in SD1 – C92A (DWA, 2009)

Scenarios	Surface Area (km ²)	Total Inflow (Mm ³ /a)	Total Outflow before losses (sinks) Mm ³ /a	Total abstraction (WARMS) + calculated (Mm ³ /a)	Evapotranspiration flow loss along streams (Mm ³ /a)	Net Base Flow (Mm ³ /a)	Net Base Flow EWR (Mm ³ /a)	Usable GW Component from base flow (Mm ³ /a)	GRDM status Category
GYMR Present Day	3234	18.57	-7.07	-0.56	-6.39	-5.10	-1.53	3.57	C
GRDM Present Day	3234	33.91	-1.82	-0.56	0	-32.08	-9.62	22.46	A

Using the GRDM (Present day scenario for 2008) as a representative value for total inflow (recharge) and net base flow, there is a groundwater balance of 22.46 million m³/a available for use in the D73A quaternary catchment.

2.3.4.6 Groundwater Quality

Groundwater samples were collected from 37 existing boreholes during the hydrocensus and aquifer testing programme. Groundwater samples were furthermore collected from 39 exploration boreholes during the aquifer testing programme.

These samples were collected as per Golder's standard sampling procedures during CDT or with disposable bailers at low yielding boreholes. The objective of the groundwater sampling was to assess and determine a representative baseline groundwater quality of the existing groundwater users and new monitoring/production boreholes.

Baseline Groundwater Quality

The baseline groundwater quality of SD2 exploration boreholes is based on macro chemistry analyses of the sampled boreholes. The concentrations are compared to the SANS 241:2011 water quality standard and the baseline quality are represented by the Median of the concentrations. The baseline water quality of the new exploration boreholes is summarised in Table 30 below.

Table 30: SD2 Baseline Groundwater Quality

Item	Physical Parameters			Macro Determinants (Major Ions and Trace Metals)								Minor Determinant		
	pH	EC mS/m	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	SO ₄ mg/l	NO ₃ mg/l	MALC Mg/l	F mg/l	Fe mg/l	Mn mg/l
No. of Records	39	39	39	39	39	39	39	39	39	39	39	39	39	33
10 % Percentile	7.24	43.2	308	42.5	22.6	12.1	2.27	20.3	13.4	1.93	166	0.1	0.05	0.05
Median Baseline water Quality	7.70	43.20	308.00	42.50	22.60	12.10	3.34	20.30	13.40	4.05	166.00	0.21	0.06	0.16
Average	7.70	58.29	414.54	65.14	37.09	22.02	3.34	39.89	22.06	4.05	258.82	0.21	0.06	0.16
90% Percentile	8.13	75.6	512	87.3	53.1	35	5.47	54.5	32.3	7.26	347	0.351	0.05	0.47
Max. Allowable Limit (SANS 241:2011)	<5 >9	<170	<1200	<300	<100	<200	<100	<300	<500	<11	-	<1.5	<0.3	<0.5

The aquifer systems at SD2 consist out of sedimentary rocks which chemical composition contributes to the chemical character of the groundwater quality:

- Dolomite is a calcium, magnesium carbonate CaMg(CO₃)₂ formation and highly soluble;
- BIF is a sedimentary rock consisting out of layers of iron oxides, either magnetite (Fe₃O₄) or hematite (Fe₂O₃), alternating with bands of iron-poor shale's, and chert and is often red in color; and
- Calcrete is a hardened sedimentary rock natural of calcium carbonate binding other materials such as gravel, sand, clay, and silt.

Point Source Pollution

From the analytical results existing point source pollution was reported in 10 of the existing boreholes and three newly drilled exploration boreholes. Point source pollution is from well-defined and specific sources e.g. animal farming and stockades. The boreholes impacted by point source pollution which exceeds the DWAF (1998) Class 1 drinking water quality standard are listed in Table 31 and indicated on Figure 75.

Table 31: SD2 Existing Point Source Pollution

Borehole No.	Farm/Locality	Chemical Determinants Exceeding DWAF drinking Water Standard Class I	Water Quality Class
SD2-GAA027	Postmasburg Municipality Land	NO3	II
SD2-GAA042	Rooibosfontein ntn. Rooibosdam	NO3	II
SD2-GAA080	Seretsesencho ptn. Sion	TDS; NO3	II
SD2-GAA081	Seretsesencho ptn. Sion	NO3	II
SD2-GAA082	Seretsesencho ptn. Sion	EC, TDS, Mg, NO3	IV
SD2-GAA085	Seretsesencho ptn. Swartmodder	NO3	II
SD2-GAA097	Farm 440 ptn. Moedhou	NO3	II
SD2-GAA134	Metseaten	NO3	III
SD2-GAA135	Metseaten	NO3	II
SD2-GAA138	Seretsesencho ptn. Sion	NO3	II
SD2-8	Postmasburg Municipality Land	NO3	II
SD2 -19	Postmasburg Municipality Land	NO3	II
SD2-39	Jen Haven	NO3	III

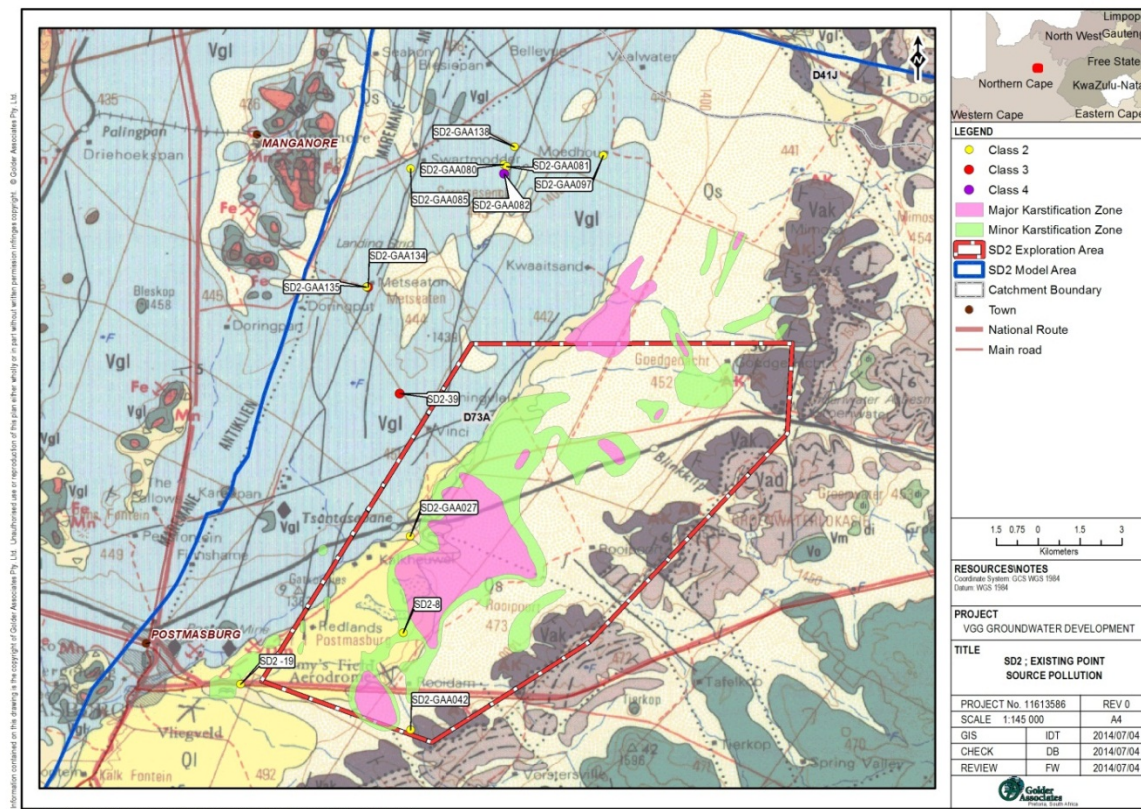


Figure 75: SD2 Existing Point Source Pollution

2.3.4.7 Hydrogeological Conceptualizing

The hydrogeological conceptualizing for SD2 was developed from data gathered during the exploration phase. The conceptualizing forms the basis for the understanding of the groundwater occurrence and flow mechanisms of the study area and is used as basis for the numerical groundwater model.

Because of the extent of the investigation area the hydrogeology is conceptualise and represented as five hydrogeological sections, the positions of sections are indicated on Figure 76:

- Cross Section A – B;
- Cross Section C – D;
- Cross Section E – F;
- Cross Section G – H and
- Cross Section I – J.

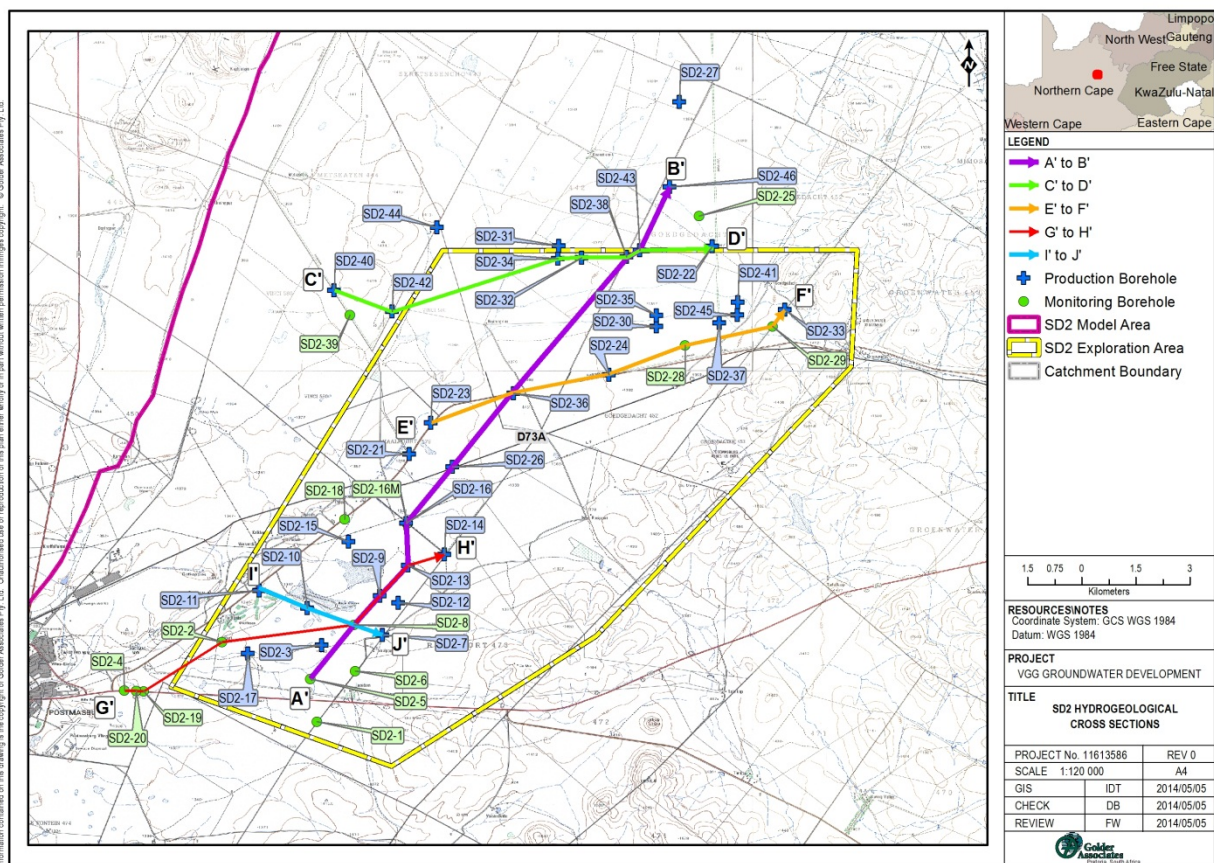


Figure 76: Position of Hydrogeological Cross Sections

Hydrogeological Cross Section A – B

A hydrological cross section was done in a south-west – north-east direction to illustrate the geological and hydrogeological information associated with the main dolomite karst zone and the water level step of 10m between two major dolomite compartments (Figure 77)

The cross-section shows the presence of a calcrete layer at surface of approximately 20 to 30m thickness with a low permeability. Gravel deposits comprising out of BIF fragments, jasper and chert are represented below the calcrete horizon, underlain by dolomite with major karstification. Semi conciliated BIF is present to the northeast at surface also underlain of the dolomite, though less karstification zones.

These karstification zones which developed in the dolomite and along dolerite dyke contacts are highly permeable with blow yields intersected as high as 40l/s (SD2-26).

The groundwater flow direction is largely towards Postmasburg in the southwest, with transmissivity values ranging from 38 to 1013 (SD2-36).

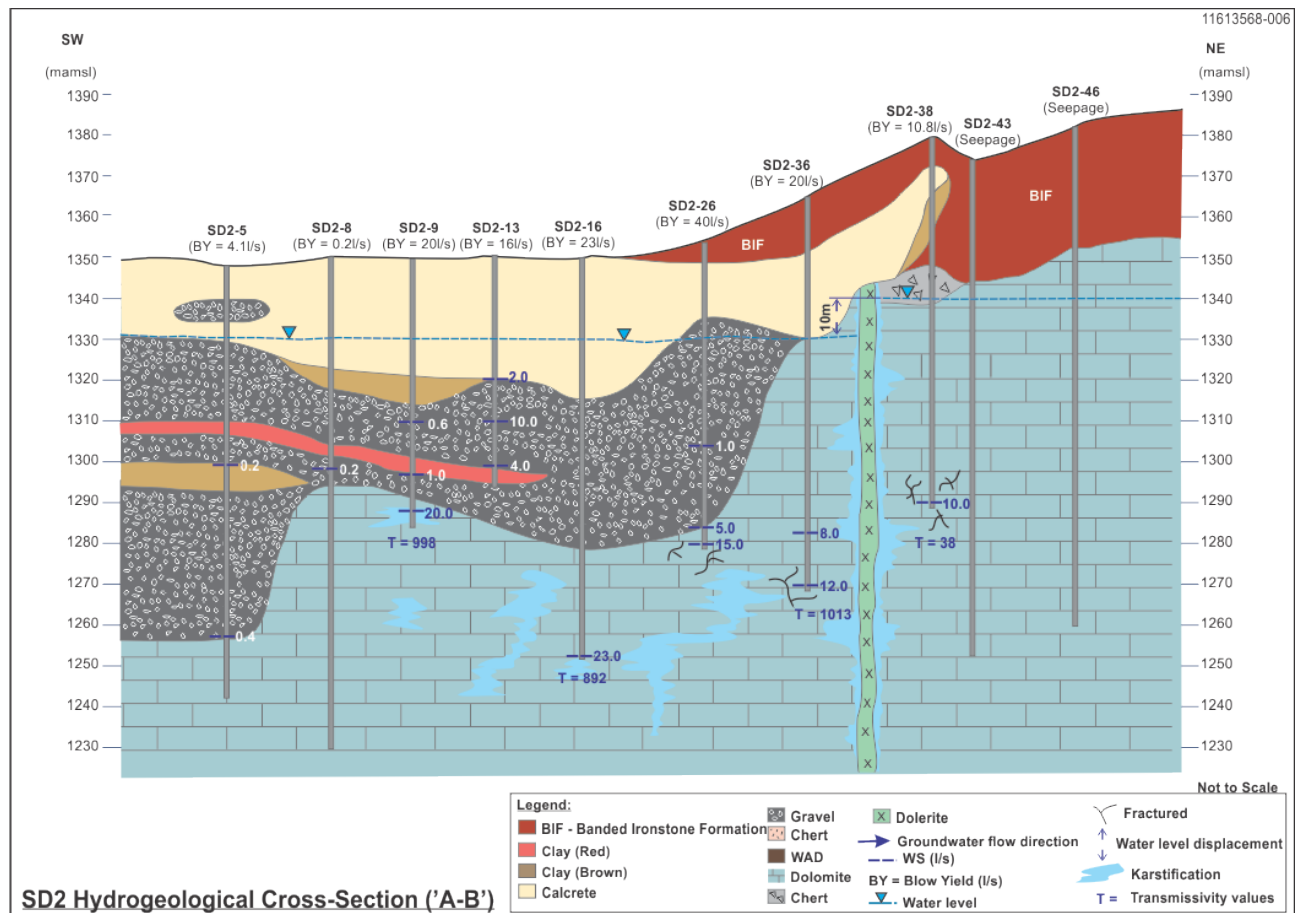


Figure 77: Hydrogeological Cross Section A - B

Hydrogeological Cross Section C – D

A hydrological cross section was done from west to east direction to illustrate the geological and hydrogeological information obtained from the exploration drilling and is illustrated in Figure 78. The water level displacements of 14m and 13m respectively between different dolomitic compartments by dolerite dykes are shown in Figure 78.

The cross-section shows the presence of chert rich dolomite at surface in the west and BIF formation at the surface in the east, dipping 5 to 6 degrees southeast. The BIF is underlain by dolomite with major karstification.

These karstification zones which developed in the dolomite and along dolerite dyke contact are highly permeable with blow yield intersected ranging from 4.3 to 26 l/s.

The groundwater flow direction largely towards Postmasburg in the southwest, with transmissivity values ranging from 36 to 842 (SD2-34).

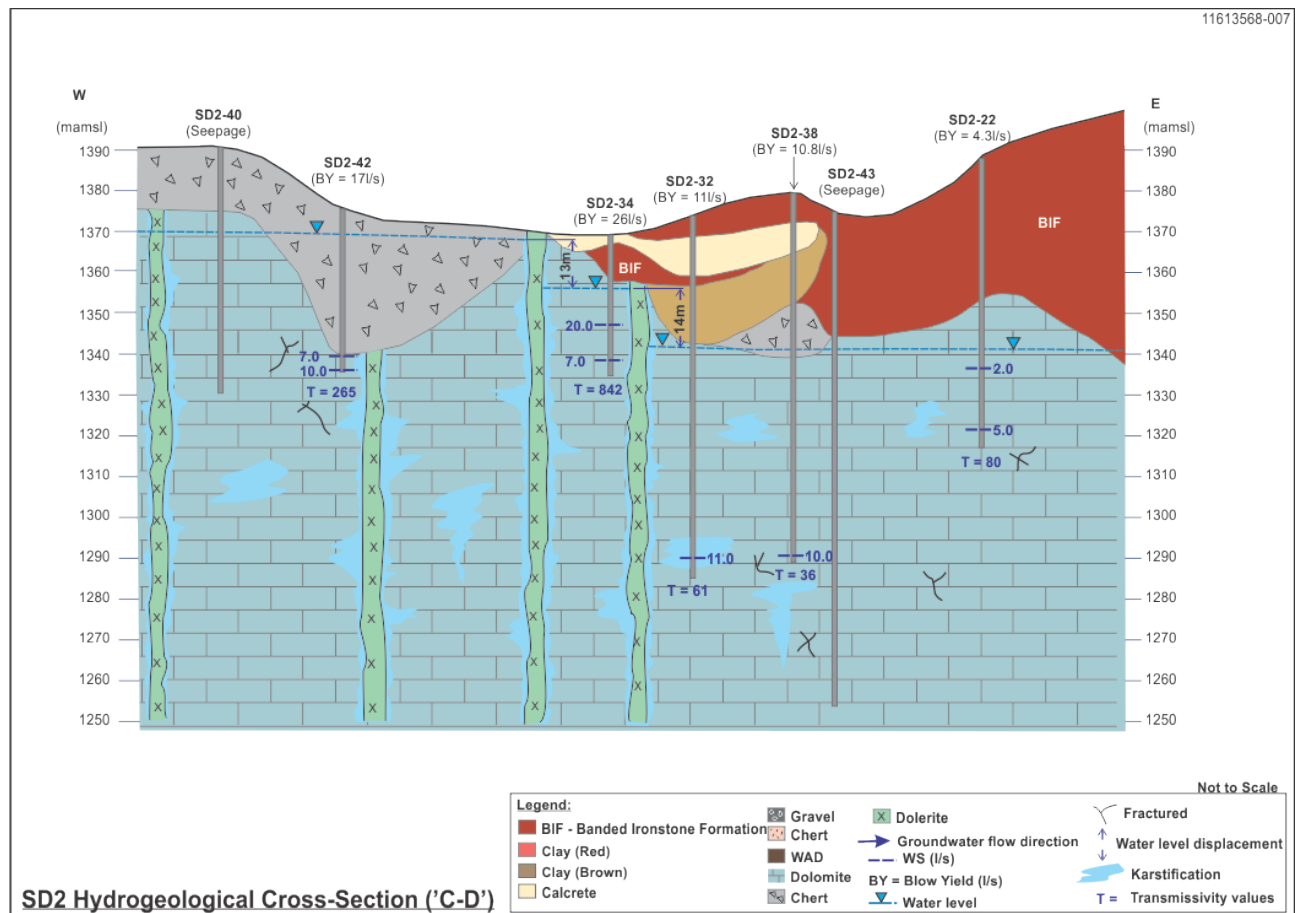


Figure 78: Hydrogeological Cross Section C - D

Hydrogeological Cross Section E - F

Hydrological cross section E'-F' was done from west to east to illustrate the geological and hydrogeological conditions in this region as illustrated in Figure 79. The water level displacements of 10m between different dolomitic compartments by dolerite dykes are shown in Figure 79.

The cross-section shows the occurrence of semi conciliated BIF formation at the surface, underlain by dolomite with major karstification zones.

These karstification zones which developed in the dolomite and along dolerite dyke contact are highly permeable with blow yield intersected ranging from 0.2 to 20l/s.

The groundwater flow direction largely towards Postmasburg in the southwest, with transmissivity values ranging from 119 to 1338 (SD2-23).

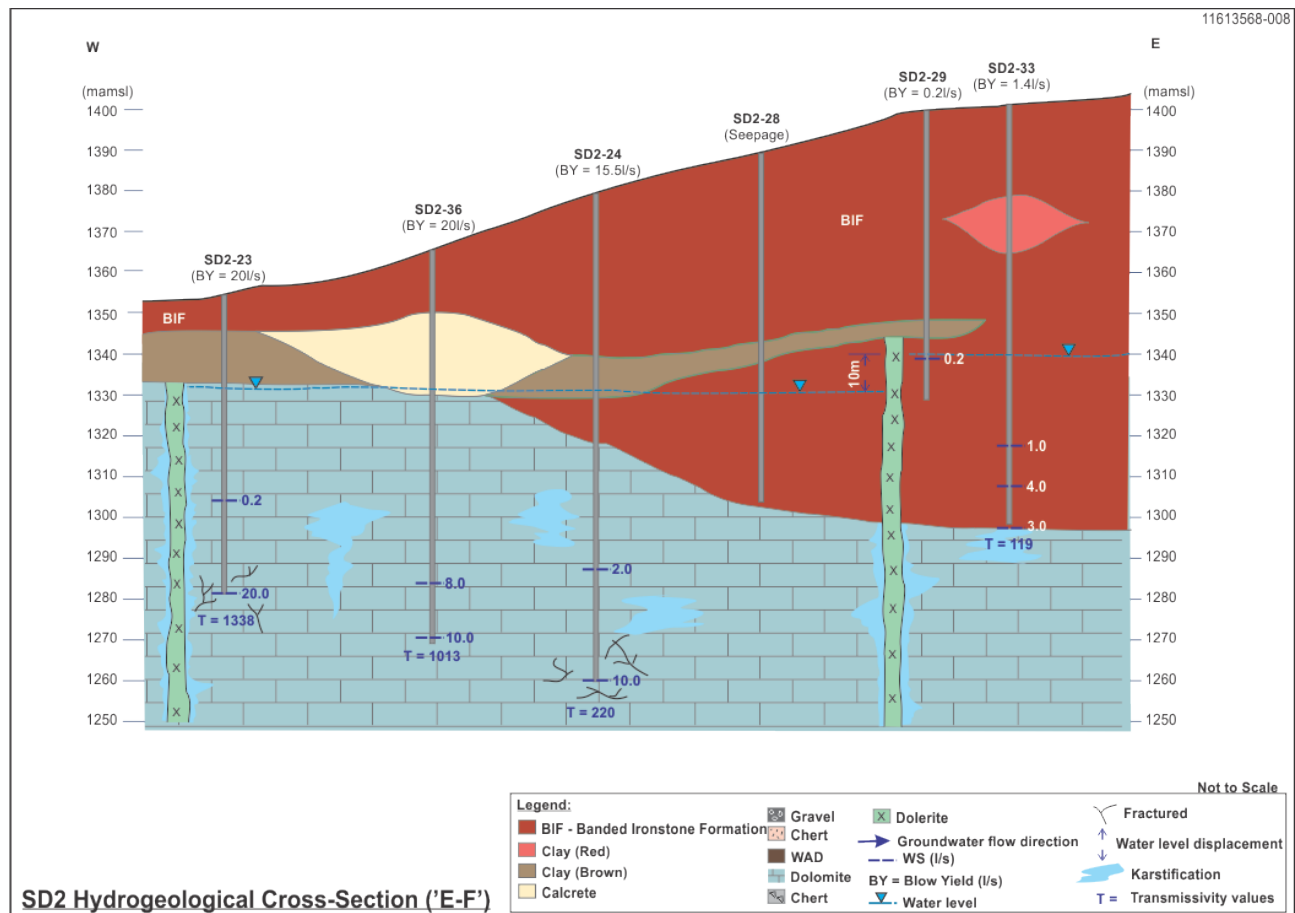


Figure 79: Hydrogeological Cross Section E - F

Hydrogeological Cross Section G – H

Hydrological cross section G-H was done in a southwest – northeast direction to illustrate the geological and hydrogeological information associated with the main karstification zone and the displacement of the water table between the two proposed well field dolomitic compartments (Figure 80). The water level displacements of 14m and 12m respectively between different dolomitic compartments by dolerite dykes are shown in Figure 80.

The cross-section shows the presence of a calcrete layer at surface of approximately 25m thickness with a low permeability. Clay and gravel deposits comprising out of BIF fragments, jasper and chert are represented below the calcrete horizon, underlain by dolomite with major karstification.

These karstification zones which developed in the dolomite and along dolerite dyke contacts are highly permeable with blow yields intersected as high as 20l/s (SD2-9).

The groundwater flow direction is mainly towards Postmasburg in the southwest, with transmissivity values ranging from 472 to 965 (SD2-9).

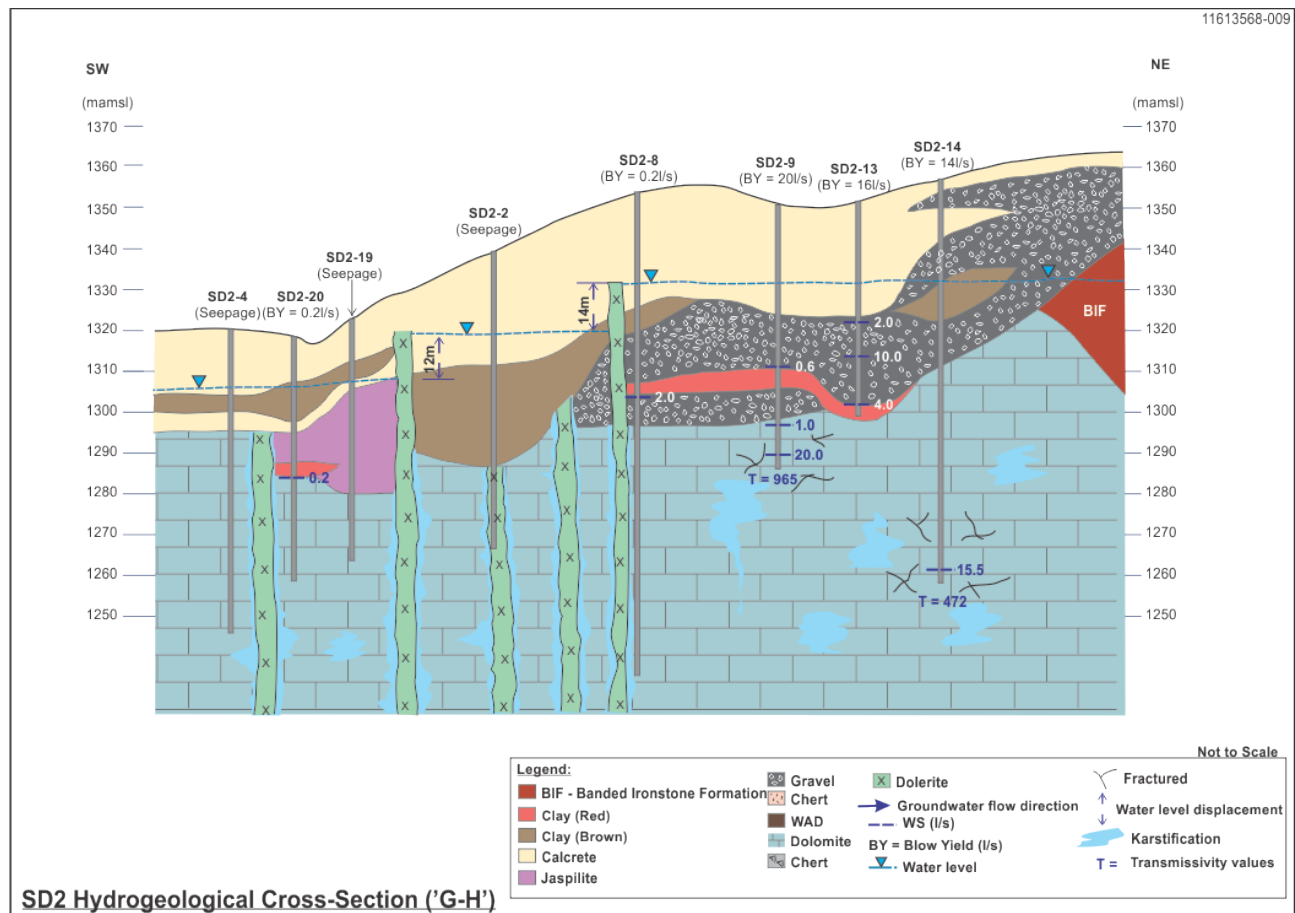


Figure 80: Hydrogeological Cross Section G – H

Hydrogeological Cross Section I – J

Hydrological cross section I-J was done from west to east to illustrate the geological and hydrogeological conditions encountered in this region. Water level displacements of 14m and 12m respectively between different dolomitic compartments by dolerite dykes are shown in Figure 81.

The cross-section shows the occurrence of a calcrete layer at surface of approximately 25m thickness with a low permeability. Clay and gravel deposits comprising out of BIF fragments, jasper and chert are present below the calcrete horizon, underlain by dolomite with major karstification. Semi conciliated BIF is present at surface in the east, dipping 5 to 6 degrees east.

These karstification zones which developed in the dolomite and along dolerite dyke contacts are highly permeable with blow yields intersected as high as 33 l/s (SD2-11).

The groundwater flow direction largely towards Postmasburg in the southwest, with transmissivity values ranging from 500 to 3788 (SD2-10).

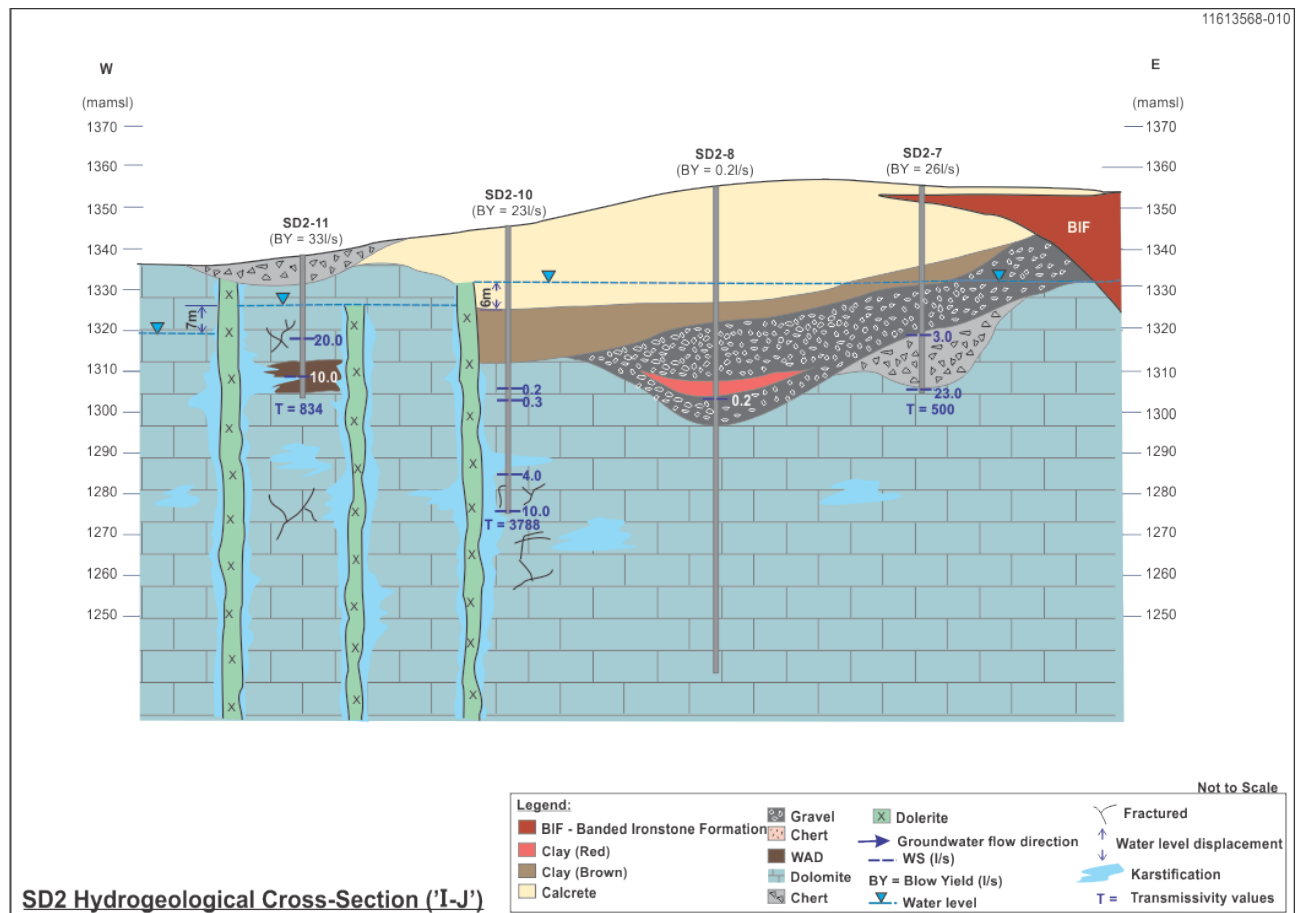


Figure 81: Hydrogeological Cross Section I - J

SD2 Aquifer Zones

From the available drilling and test pumping data of SD2, three aquifer systems were identified in the different geological formations:

- Upper Kalahari Sediments - intergranular unconfined aquifer system comprising mainly out of calcrete, gravel and clay. This aquifer zone has a low permeability retards and restrict water movement and acts as storage unit,
- Fractured and weathered semi consolidated Banded Ironstone Formation (BIF), semi confined aquifer system, and
- Dolomite karst aquifer system, unconfined to semi confined aquifer system, compartmentalised by dolerite dykes and highly permeable.

The hydraulic parameters of the three defined aquifer zones are summarized in Table 32.

Table 32: Summarised Hydraulic Parameters

Aquifer zone	No. of BH'S	Storativity S	Average S	T (m ² /d)	Median T (m ² /d)	Average T (m ² /d)
Exploration Boreholes						
Upper Kalahari Calcrete and Gravel	2	-	-	570.0 to 892.0	838.0	731.0
Fractured and Weathered semi consolidated BIF	2	-	-	119 to 1500.0	810.0	810.0
Karstification in Dolomite	29	1.58 X 10 ⁻⁶ to 7.38 X 10 ⁻⁴	0.00023	265.0 to 8530.0	838.0	1817.0

2.3.5 SD2 Groundwater Modelling

A comprehensive 3D numerical groundwater flow model was constructed at quaternary catchment scale to assess the impact of the proposed SD1well field on the regional groundwater flow, aquifer storage and discharge.

The software code chosen for the numerical finite-element modelling work was the 3D groundwater flow model SPRING. The program was first published in 1970, and since then has undergone several revisions and is widely accepted by environmental scientists and associated professionals. SPRING uses the finite-element approximation to solve the groundwater flow equation. This means that the model area or domain is represented by several nodes and elements. Hydraulic properties are assigned to these nodes and elements and an equation is developed for each node, based on the surrounding nodes. A series of iterations are then run to solve the resulting matrix problem utilising a pre-conditioning conjugate gradient (PCG) matrix solver for the current model. The model is said to have “converged” when errors reduce to within an acceptable range. SPRING can simulate steady and non-steady flow, in aquifers of irregular dimensions

2.3.5.1 Groundwater Model Construction

Model Domain

The model domain boundaries were established during the conceptualisation phase and were chosen along mapped dykes, often coinciding with the upper quaternary catchment (D73A) boundaries, to ensure a dependable water balance for the model with recharge being the main driver of groundwater flow. Several head dependant boundary conditions were assigned along:

- The northern boundary, representing shallow inflows along the non-perennial drainage system towards quaternary catchment D41J; and
- The south-western edge of the model domain, representing potential groundwater outflow towards downstream aquifer systems (Figure 82).

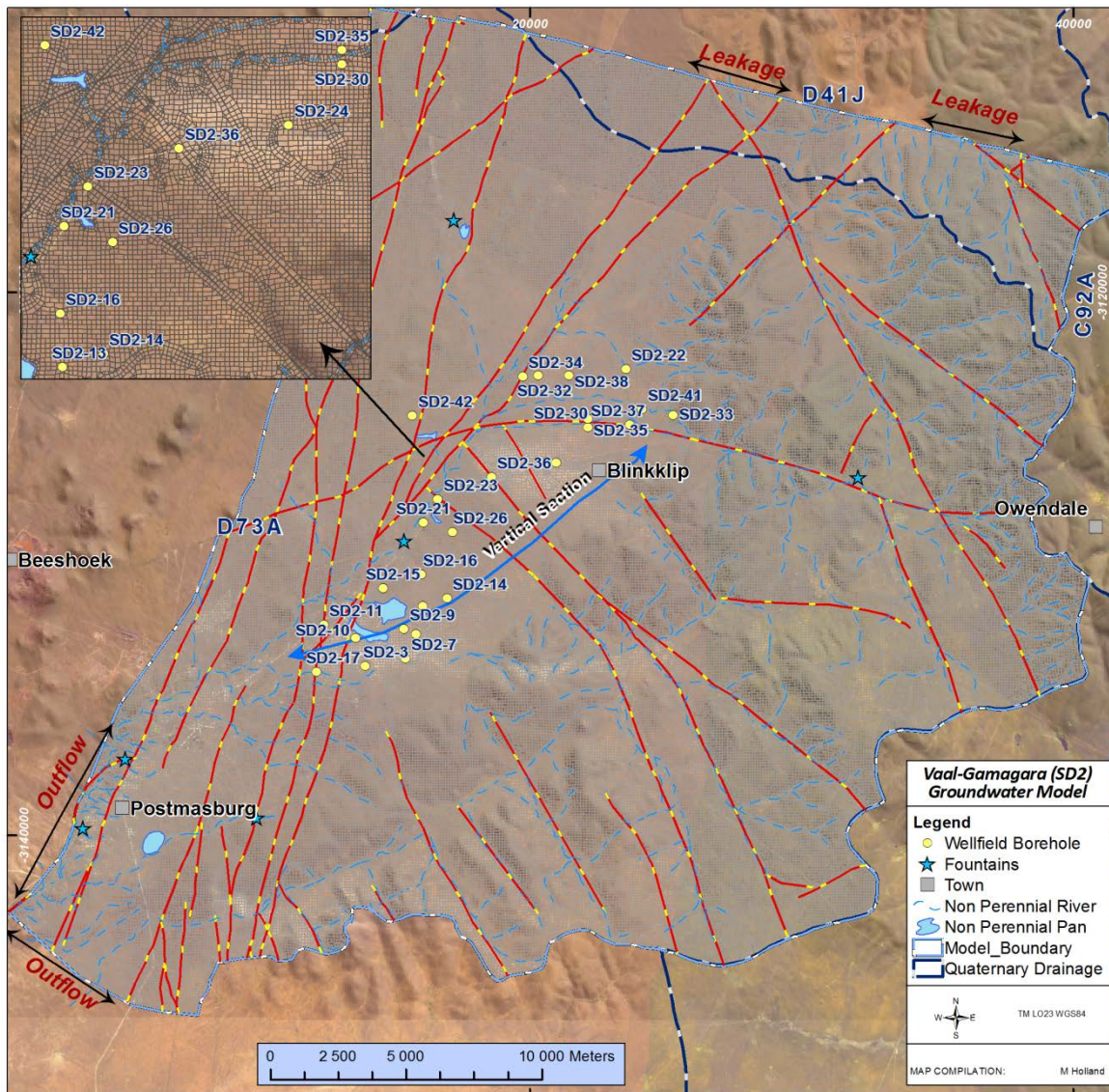


Figure 82: SD2 Finite-Element mesh and Model Domain (also showing cross-section reference)

The total model domain covers an area of 951 km². The horizontal element size (side length) varies from a minimum of 30 to 50 m (average) along surface drainages and mapped dykes and faults, to a maximum side length of 200 m further away from the area of interest or steep gradients. The chosen model discretisation allows a sufficiently accurate representation of discrete physical features (dykes, fault zones and drainages) in a regional groundwater flow model, employed to ensure a justifiable water balance and natural upstream boundaries of the flow system for the area of interest.

Groundwater Model Layers

The finite-element model was conceptually set-up as a three-dimensional four (element) layer groundwater flow model. The vertical model discretisation respectively model layer coincides with the conceptual hydrogeological model. However, to increase the numerical accuracy of the unsaturated flow calculations, various model layers have been further sub-divided (Table 33). The numerical model is therefore spatially discretised into 127 684 nodes on 9 node layers, which make up 8 element layers with 145 056 elements (triangles and quadrangles) per layer, to account for the various hydrogeological units underlying the proposed well fields.

The SRTM elevation data were lowered by 2.4m to fit ortho-heights obtained from local trig beacon and compared to gravity survey data and surveyed boreholes elevations.

The thickness of the Kalahari Group layer (split into four model layers) was based on the isopach's interpolated by the client. The Banded Ironstone Formation and Ventersdorp lava's, where present in the model domain, were represented as two model layers with an inferred thickness ranging from 15 to 170m. The dolomitic units are discretised into 4 model layers, representing both the highly karstified dolomites as well as the deeper dolomitic bedrock. The bottom elevation of the active groundwater flow system was set at approximately 120 m below the current groundwater level, resulting in a model thickness ranging from 145 to 335 m. The layer arrangement is summarised in Table 33 and shown in a cross-section in **Figure 83**. The vertical section was chosen across the main well field area (**Figure 83**) and shows the detailed vertical representation and discretisation of the conceptual model.

Table 33: Layer Arrangement for the SD2 Groundwater Model

Conceptual Model Layer	Element layers	Map Colour	Aquifer feature	Data used for interpolation
I, top	I, top		Surface elevation	SRTM 90 m Digital Elevation Model (DEM)
I, bottom	1-4		Kalahari Group	Divide Layer 1 into 4 (Equal proportion) - Kalahari Group Isopach
II, bottom	1-2		Banded Ironstone Formation/Ventersdorp Lava	Thickness ~ 15 to 170 m
III, bottom	5-6		Weathered- and Karst Aquifer	Fixed offset from Layer 2
IV, bottom	7-8		Karst Aquifer	120 m below initial water level

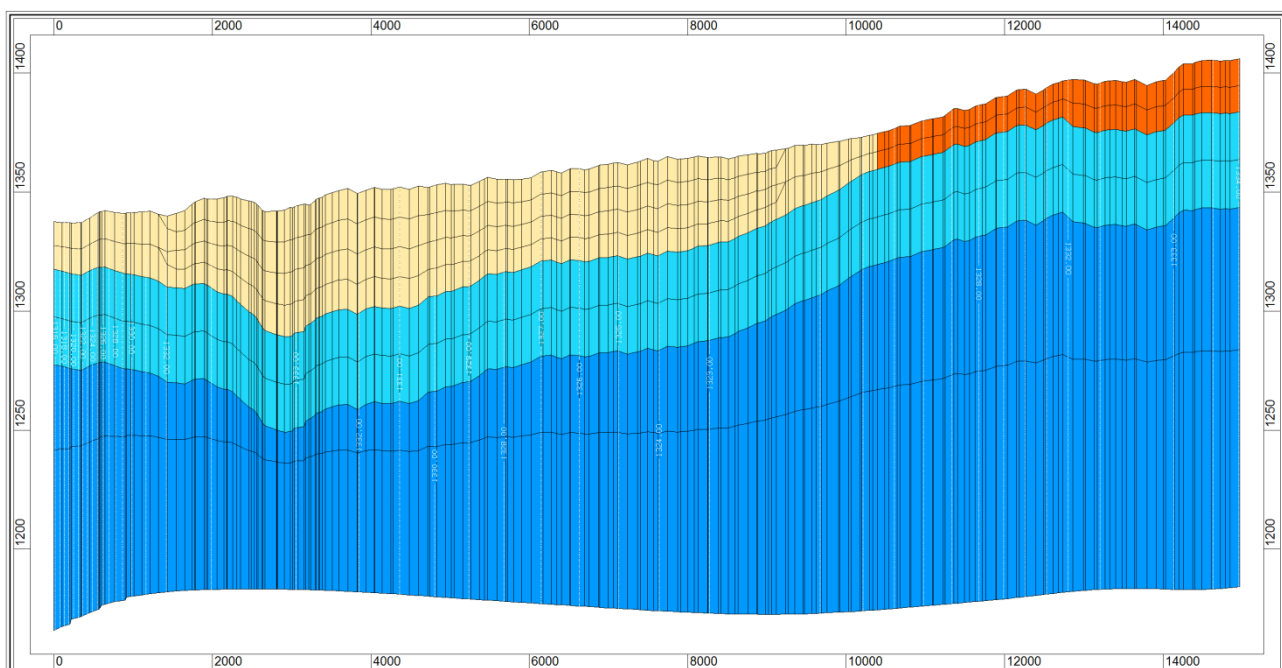


Figure 83: SD2 Vertical Grid Layout Example

Groundwater Recharge

The spatial distribution of the recharge rates adapted from the conceptual model is shown in Figure 84. Groundwater enters the model domain as direct recharge from rainfall. It was implied that certain areas may

have greater recharge potential and may thus contribute a larger proportion of recharge towards the aquifer systems. The median annual recharge values range between 1 and 20 mm per year for the SD2 groundwater system (Figure 34).

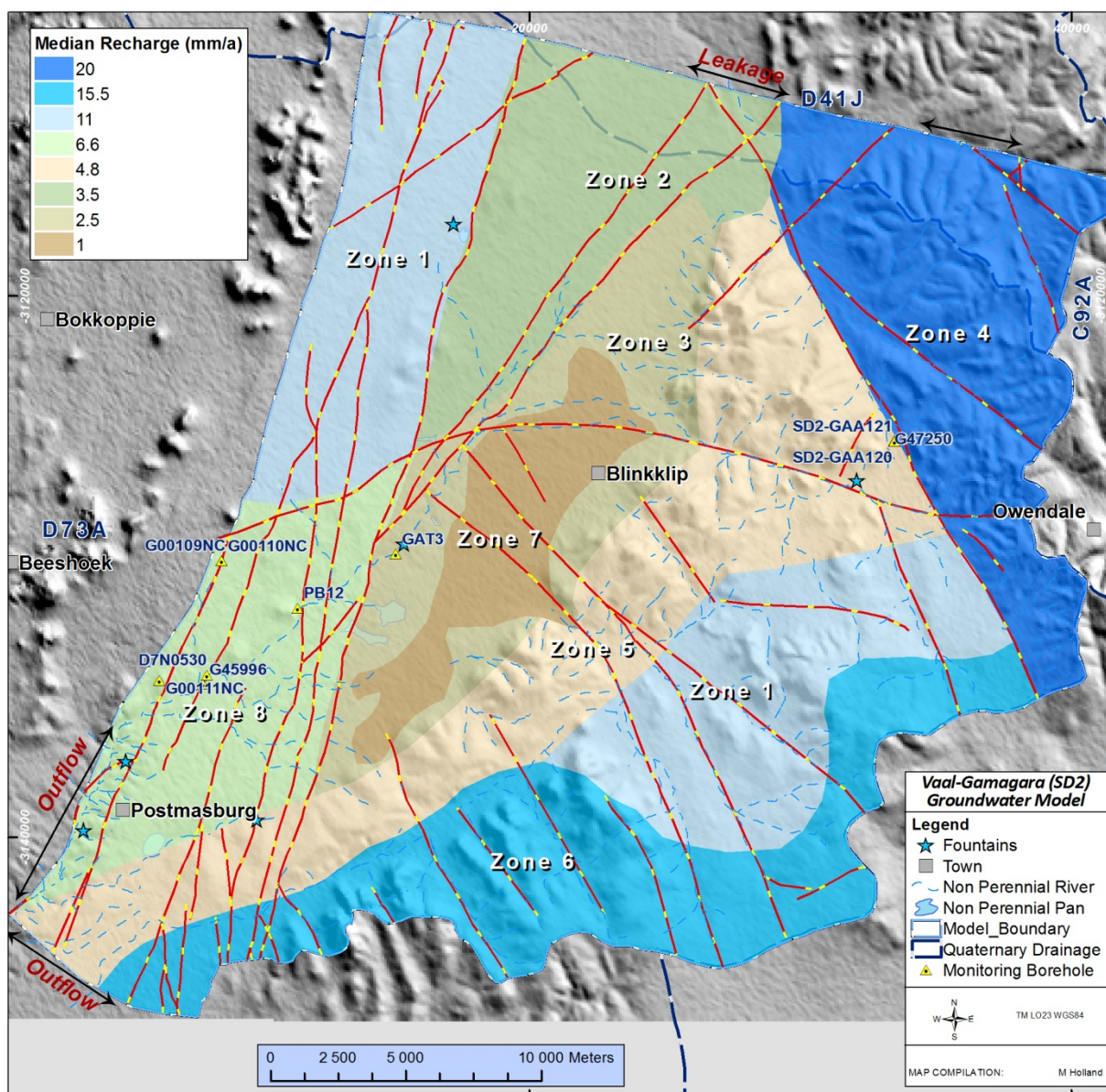


Figure 84: Recharge Rates (and zones) Assigned in the SD2 Groundwater Model

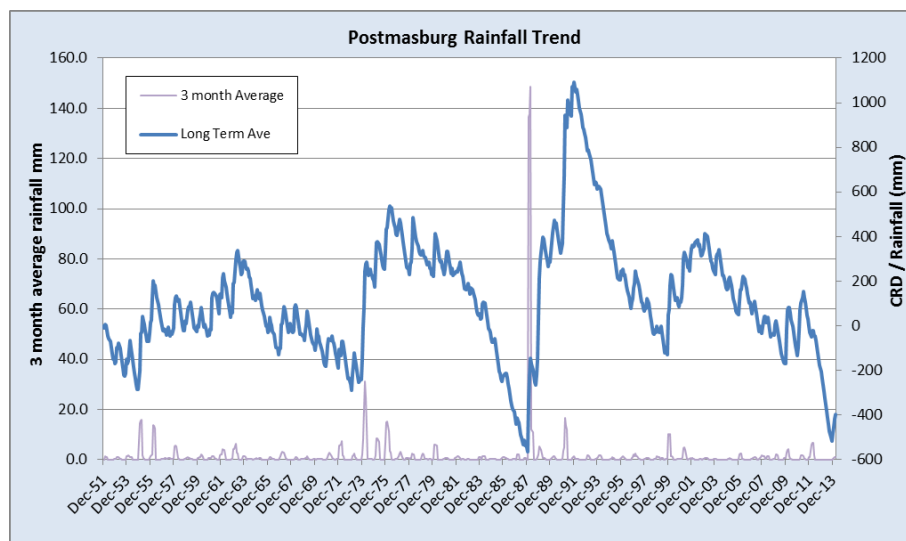
Generally groundwater level monitoring data show a good relationship between the Cumulative Rainfall Departures (CRD) from the mean rainfall and observed water level fluctuations in the dolomitic aquifer, indicating dynamic recharge (Figure 85). The Postmasburg rainfall station data was used as the input for the variable monthly recharge calculations for the transient model runs and calibrated against the existing groundwater monitoring boreholes shown in Figure 84..

The eight steady state recharge zones were combined into three variable recharge areas for the transient model runs. The median recharge rates over a 17 year period from (March 1997 to March 2014) for the delineated zones are given in Table 34.

The available groundwater monitoring data are limited and not all boreholes have complete records of water levels over time or represent in some cases water levels during pumping conditions and not static (rest) water levels. The longest record of water level measurements extends back to November 1999.

Table 34: Median Recharge Rates for the Variable Recharge Areas

Variable Recharge	Km ²	Median Recharge (17 year) (mm/a)	Combined Zones
Area 1	242.7	14	Zone 4 and 6
Area 2	350.97	9	Zone 1 and 8
Area 3	357.58	3.5	Zone 2,3, 5 and 7

**Figure 85: Groundwater Level versus the Cumulative Rainfall Departure**

Groundwater Abstraction

Both steady state and transient borehole abstractions from the model domain were simulated using a well (flux) boundary condition. Outflow rates were assigned to single nodes (at the appropriate elevation) within the model mesh. For fully penetrating wells, equal heads were prescribed for all applicable nodes above the well node and the inflows for each node (or across each model layer) automatically calculated by the software. The monthly abstraction rates applied to the steady state model amount to a total groundwater withdrawal of 124 441 m³/month.

River Courses and Springs

Groundwater within the study area was assumed to originate as spatially distributed rainfall recharge within the model domain. It is thought that a portion of the seasonal groundwater recharge occurring within the model domain discharges internally to surface drainage systems via springs or as discharge to the river drainage systems (baseflow).

The interaction between groundwater and surface water courses was simulated under the assumption of continuous gaining river systems (i.e. groundwater is only allowed to discharge into them and not vice versa). These drainages were therefore described within the model using SPRING's 'river package', with no exfiltration of surface water allowed. The stage of each river node was carefully aligned with the height of the Digital Elevation Model (DEM) at that point and an incision the river bottom of 2 m below topography assumed. A river-bed conductance of 1E-7 m/s was assumed. Known springs (Figure 82) within the SD2 area were incorporated as free seepage boundaries at the specific node of the spring location.

2.3.5.2 Model Calibration

Steady State Calibration

Once a reasonable fit of the piezometric contours respectively their gradients was established using the gradient method within the SPRING software package, the measured groundwater levels (in metres above mean sea level) observed in 298 boreholes were used as targets for the manual calibration. The regional water level measurements spread over decades and represent therefore by no means a single snapshot of water levels taken under the same climatic conditions and land uses or average conditions. The project team biased therefore the steady state calibration towards a reasonable fit of the most recent water levels respectively abstraction and recharge conditions.

Since the modelled groundwater levels are directly related to the assigned recharge rates and hydraulic conductivities, an independent estimate of one or the other parameter is required to arrive at a potentially unique solution of the model calibration. The estimated recharge rates were therefore considered fixed for the steady state calibration and only hydraulic conductivities considered variable, i.e. adjusted within reasonable boundaries (Table 35) to represent the observed flow system.

Table 35: Average Transmissivity and Hydraulic Conductivity Values for the SD2 Region

Stat.	T-Value (m ² /d)	Hydraulic Conductivity	
		(m/d)	(m/s)
Arithmetic mean	1568	10.5	1.2E-4
Median	834	5.6	6.4E-5
Geometric mean	276	4.4	2.1E-05

The spatial distribution of the calibrated conductivity values for layer 5 is shown in Figure 86 and a cross-section along the well field is shown in Figure 87. The values for all model layers summarised in Table 14.

Table 36: Calibrated Hydraulic Conductivity Ranges for SD2 Groundwater Model

Layer	Aquifer	Hydraulic conductivity [m/s]	
		Min	max
I-IX	Dyke (Barriers to Flow)	1E-9	1E-7
I-IV	Kalahari	8E-7	4E-6
I-VI	Weathered- and Karst Aquifers	1E-6	3.6E-4
	BIF and Lava	5E-8	5E-6
VII-IX	Deep Karst Aquifer	5E-7	6E-5

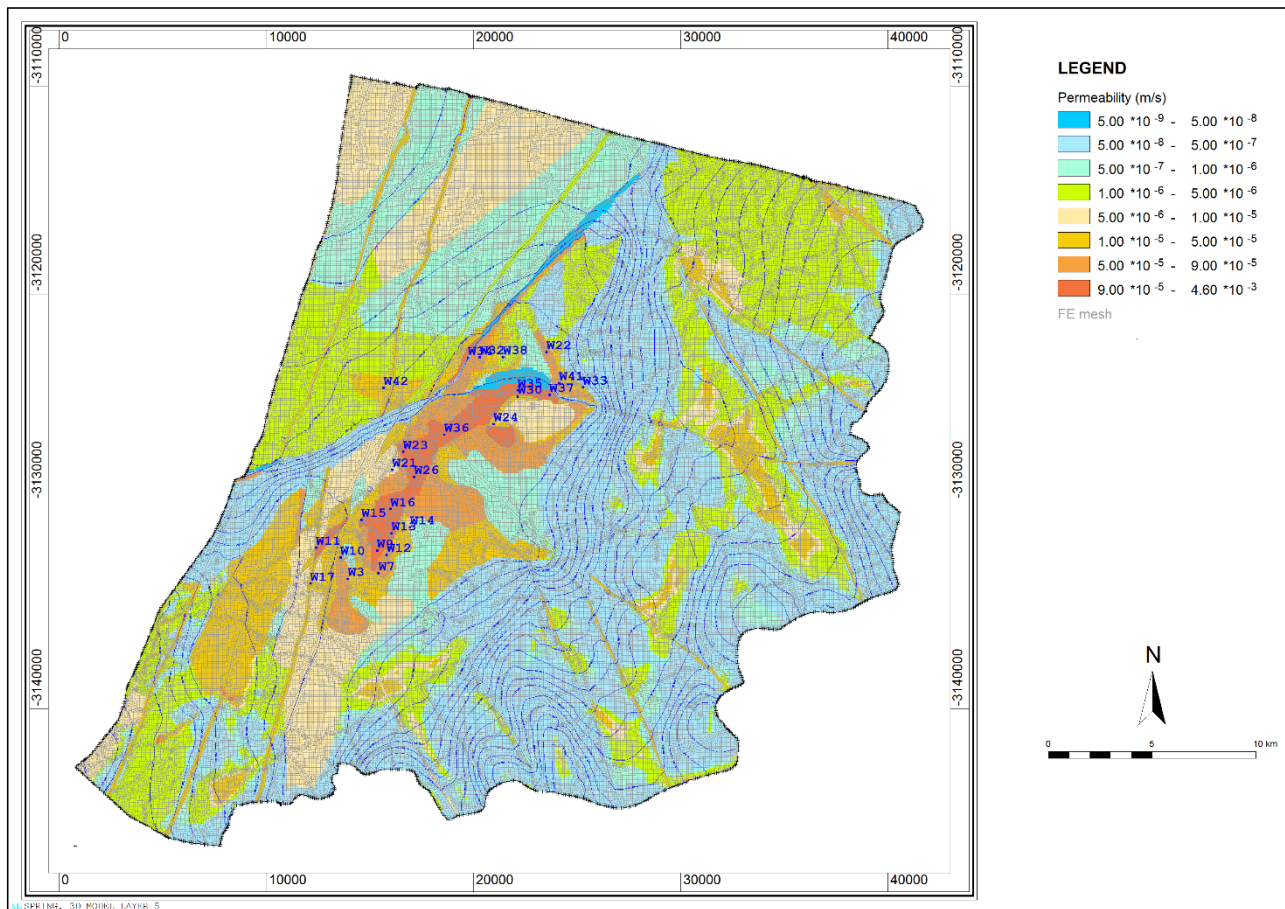


Figure 86: Lateral Distribution of Permeability's (layer 5) and Simulated Steady State Heads (10 m contour interval)

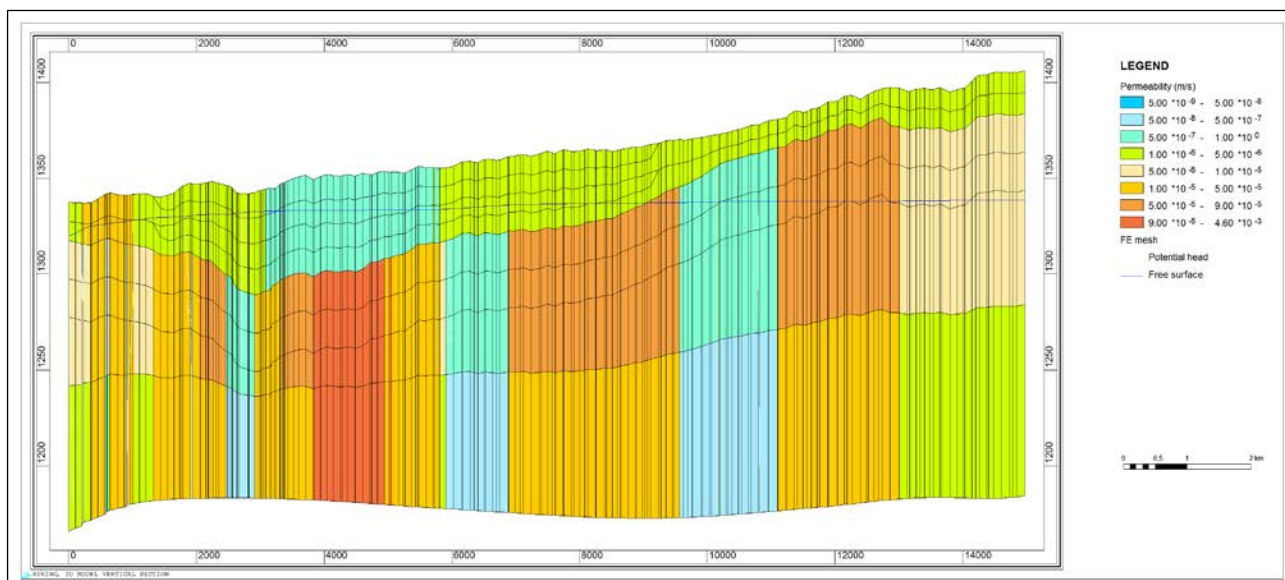


Figure 87: Vertical Distribution of Permeability's and Simulated Steady State Heads (potentiometric surface)

Transient Calibration

In order to simulate the temporal responses of the aquifers to variable rainfall recharge and external stresses (abstractions), a transient calibration of the steady-state model is required. Although transient calibration introduces another uncertain fitting parameter, namely the storage coefficient S (as a sum of specific

storativity and yield for unconfined aquifers), it partially eliminates the non-uniqueness of the steady-state calibration parameters and provides additional insight into the appropriateness of the conceptual model.

Transient simulations require the definition of stress periods, during which boundary conditions remain constant, and time steps, for which model calculations are made. Since the frequency of the rainfall measurements were provided on a monthly basis, the water balance of the model was also calculated on a monthly time-step. Stress periods assigned in the present model can be divided into two components:

- The first component covers the transient calibration phase from 1999 to 2014 and entailed 183 stress periods (months) with variable monthly recharge rates.
- The second component entails stress periods assigned for the predictive model runs considering various aquifer management scenarios for the period 2013 to 2031 (205 stress periods or months).

The model was further optimised by calibrating the simulated heads to observed pumping test drawdown data for selected SD2 production boreholes. The pumping tests ranged from 24 to 72 hours and the transient model comprised of 73 one-hour time steps. A summary of the calibration targets is shown in Table 37. The pumping tests do not represent the entire the model domain and the refined model calibration was therefore limited to the SD2 well field region only.

Table 37: Exploration Boreholes (with pumping test data) used as Transient Calibration Targets

BH ID	Model Node	L/S	m ³ /hour	Time (Minutes)
SD2-09	1692	20	72	4320
SD2-11	1694	30	108	2880
SD2-12	1695	20	72	4320
SD2-14	1697	15	54	1440
SD2-15	1698	20	72	4320
SD2-16	1699	20	72	4320
SD2-21	1705	13	46.8	4320
SD2-34	1718	30	108	4320
SD2-35	1719	30	108	4320
SD2-38	1722	13	46.8	3360
SD2-42	1726	20	72	4320

For the transient calibration the available long-term water level monitoring and 10 (SD2) pumping test datasets were used as calibration. The main aim of the calibration was to match the “signature” or behaviour of temporal water table fluctuations observed, rather than the actual head itself.

Figure 88 shows a comparison of simulated vs. observed heads for several representative boreholes. Good quality records of water level measurements were limited with a number of probably inaccurate and/or incomplete records.

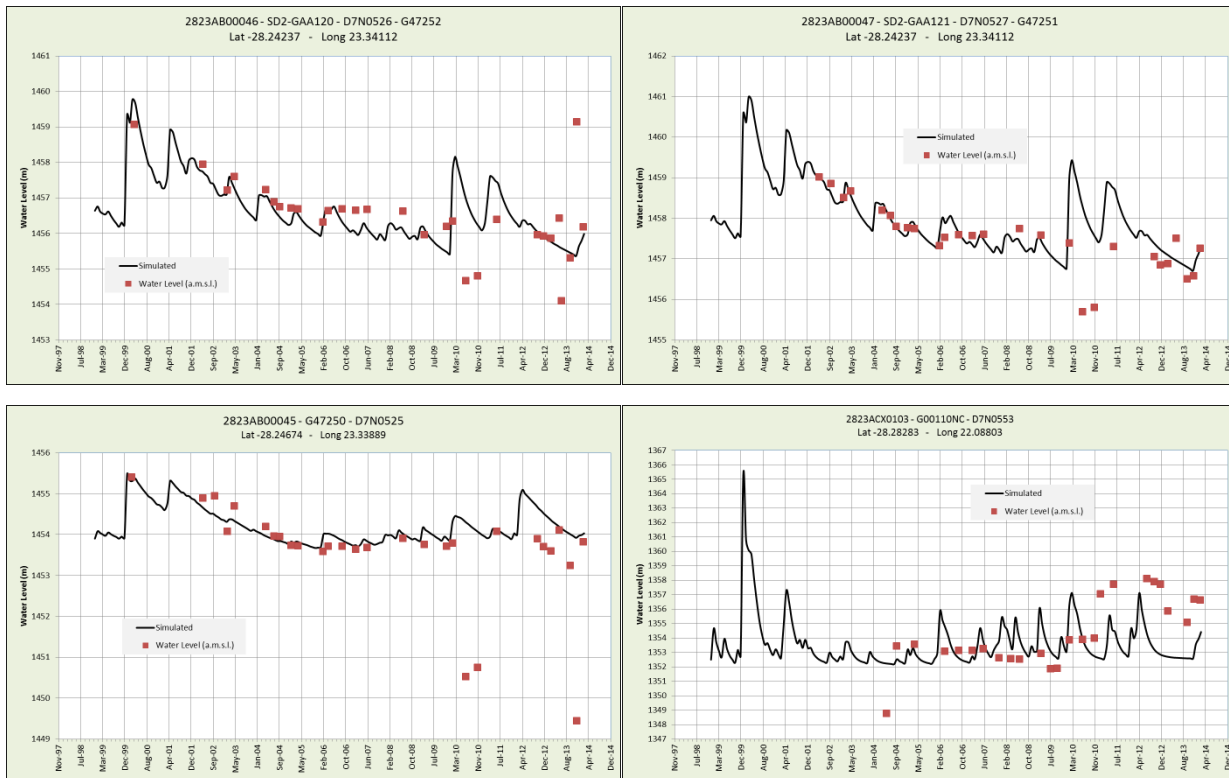


Figure 88: Transient Simulated versus Observed Groundwater Levels

Based on the results, it is evident that in most cases the “signature” of the temporal water level fluctuations is sufficiently well represented by the model. The “off-set” between observed and simulated heads for some boreholes appears to be a result of the assigned steady state starting water levels, which reflect average and not actual historical water levels at a given point in time. In all cases, this “off-set” is acceptable (within 2 meters) and within the seasonal range of water level fluctuations.

The transient calibration of pumping test datasets refines and verifies the steady-state calibration by matching transient hydraulic-head trends which reflect the stresses of pumping from the production boreholes (Figure 89). The transient model calibration was used to optimize the spatial variability of storage coefficients.

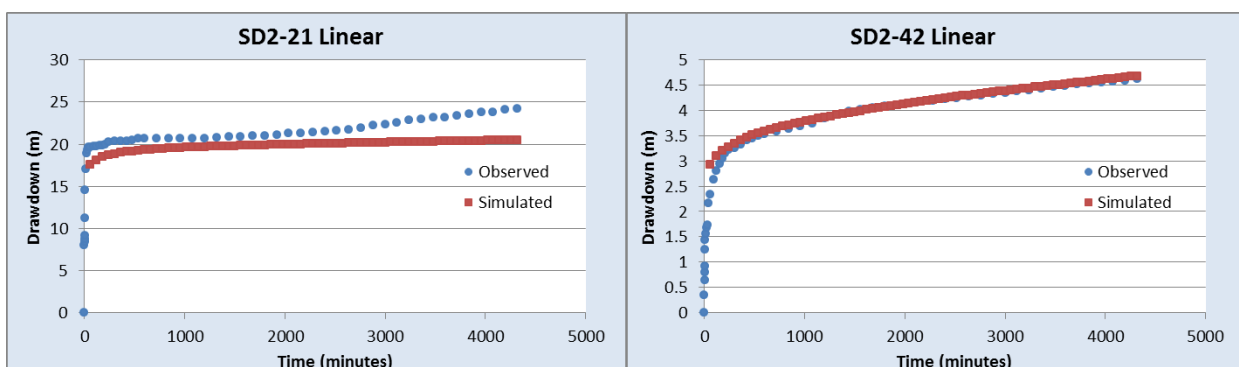


Figure 89: Transient Model Calibration using Drawdown from initial Static Water Level

An acceptable fit is observed for most pumping test boreholes. It is evident that in some cases the drawdown behaviour cannot be accurately represented due to the heterogeneity of fracture distributions and subsequent hydraulic discontinuities proximal to the pumping well.

2.3.5.3 Predictive Simulations

Water Balance

A summary of the steady state water balance is provided in Table 38.. The steady-state water balance (Table 38) shows that the vast majority of recharge (which is the only model inflow) contributes to baseflow in drainages (including evapotranspiration losses along these drainages and pans) and spring discharges within the model domain or is abstracted, and that only around 14 % of the inflow (recharge) reports to the head dependent outflow boundaries, i.e. towards downstream catchments. Total (steady-state) groundwater abstractions consume in comparison (for the steady-state scenario) around 18 % of the total recharge for the area. The detailed water balances for the 4 delineated Groundwater Management Units (GMU) is shown in Table 39. It is important to note that the water balance exclude the GMU immediately east of Postmasburg (D73A-06).

Table 38: SD2 Regional Steady State Water Balance

Inflow	m ³ /month	m ³ /annum
Recharge	683 202	8 198 424
Outflow	m ³ /month	m ³ /annum
Shallow seepages to pans and spring discharge	-150 742	-1 808 899
Boreholes Abstraction	-124 442	-1 493 303
Contribution to Drainages and potential evapotranspiration	-309 523	-3 714 278
South-western Outflow	-78 825	-945 894
Leakage across Northern Boundary	-19 670	-236 045
Total Outflow	-683 202	-8 198 420

Table 39: Steady-state Water Balance for each of the 4 Delineated GMUs (in m³/month)

Inflow	D73A-01	D73A-02	D73A-03	D73A-04
Recharge	81 191	329 045	243 456	24 293
Inflow from D73A-01		51 581		13 049
Inflow from D73A-02			85 255	
Inflow from D73A-03				120 554
Total Inflow	81 191	380 626	328 711	157 896
Outflow				
Shallow seepages to pans and spring discharge	-7 391	-107 919	-22 099	-12 618
Boreholes Abstraction	-5 788	-28 166	-75 003	-7 908
Contribution to Drainages and potential evapotranspiration	-3 381	-139 616	-111 055	-53 421

Inflow	D73A-01	D73A-02	D73A-03	D73A-04
Leakage across Northern Boundary		-19 670		
Internal Outflow to D73A-02	-51 581			
Internal Outflow to D73A-03		-85 255		
Internal Outflow to D73A-04	-13 049		-120 554	
Internal Outflow to D73A-06				-83 950
Total Outflow	-81 191	-380 626	-328 711	-157 896

Applied Rainfall Variability (2014 to 2031)

The calibrated transient model was subsequently used to simulate the impact of proposed abstractions from the SD2 well field on the water levels and water balance of the regional aquifer system. The predictive scenario was simulated based on historically observed rainfall variability. The rainfall/recharge data from 1997 to 2014, which is regarded to be a conservative approach, was used to simulate the recharge in the predictive scenario.

Applied Abstraction Scenarios (2014 to 2031)

The forward simulations of the proposed SD2 well field considered four abstraction scenarios, namely:

- Scenario 0 – Base or reference case with no abstractions, i.e. the well field project no-go option.
- Scenario 1 – 26 production boreholes:
 - Upper limit of abstraction with a combined yield of 729 270 m³/month (8.75 Mm³/annum).
- Scenario 2 – 21 production boreholes of which 4 is regarded as short-term:
 - Optimised long-term abstractions with a combined yield of 462 528 m³/month (5.5 Mm³/annum) with a peak yield (for 4 months a year) of 538 740 m³/month (6.5 Mm³/annum).
- Scenario 3 – 21 production boreholes of which 8 is regarded as peak supply:
 - Optimised long- and short-term abstractions with a combined yield of 307,476 m³/month (3.7 Mm³/annum) for the SD2 production boreholes with a peak yield (for 4 months a year) of 458 148 m³/month (5.5 Mm³/annum).

The various abstraction scenarios are detailed in (Table 40), while the position of the SD2 well fields and associated (upper limit Scenario 1) abstraction rates are shown spatially in Figure 90.

Table 40: SD2 Abstraction Rates for the Forward Scenario's 1, 2 and 3 (in m³/month)

BH no.	Scenario 1	Scenario 2	Scenario 3
SD2-3	21 900	0	0
SD2-7	39 420	26 280	26 280
SD2-9	39 420	39 420	26 280
SD2-10	39 420	31 536	26 280
SD2-11	32 850	26 280*	21 900*

SD2-12	39 420	26 280	26 280*
SD2-13	21 900	0	0
SD2-14	26 280	18 396*	18 396*
SD2-15	39 420	26 280	26 280
SD2-16	39 420	26 280	26 280
SD2-17	10 950	0	0
SD2-21	13 140	0	0
SD2-22	13 140	13 140	13 140
SD2-23	39 420	31 536	26 280
SD2-24	13 140	13 140*	13 140*
SD2-26	39 420	31 536	31 536
SD2-30	10 950	0	0
SD2-32	13 140	13 140	13 140*
SD2-33	13 140	13 140	13 140
SD2-34	52 560	39 420	26 280*
SD2-35	39 420	39 420	26 280
SD2-36	39 420	39 420	26 280
SD2-37	39 420	39 420	26 280
SD2-38	26 280	18 396*	18 396*
SD2-41	13 140	13 140	13 140*
SD2-42	13 140	13 140	13 140
Total	729 270	538 740	458 148

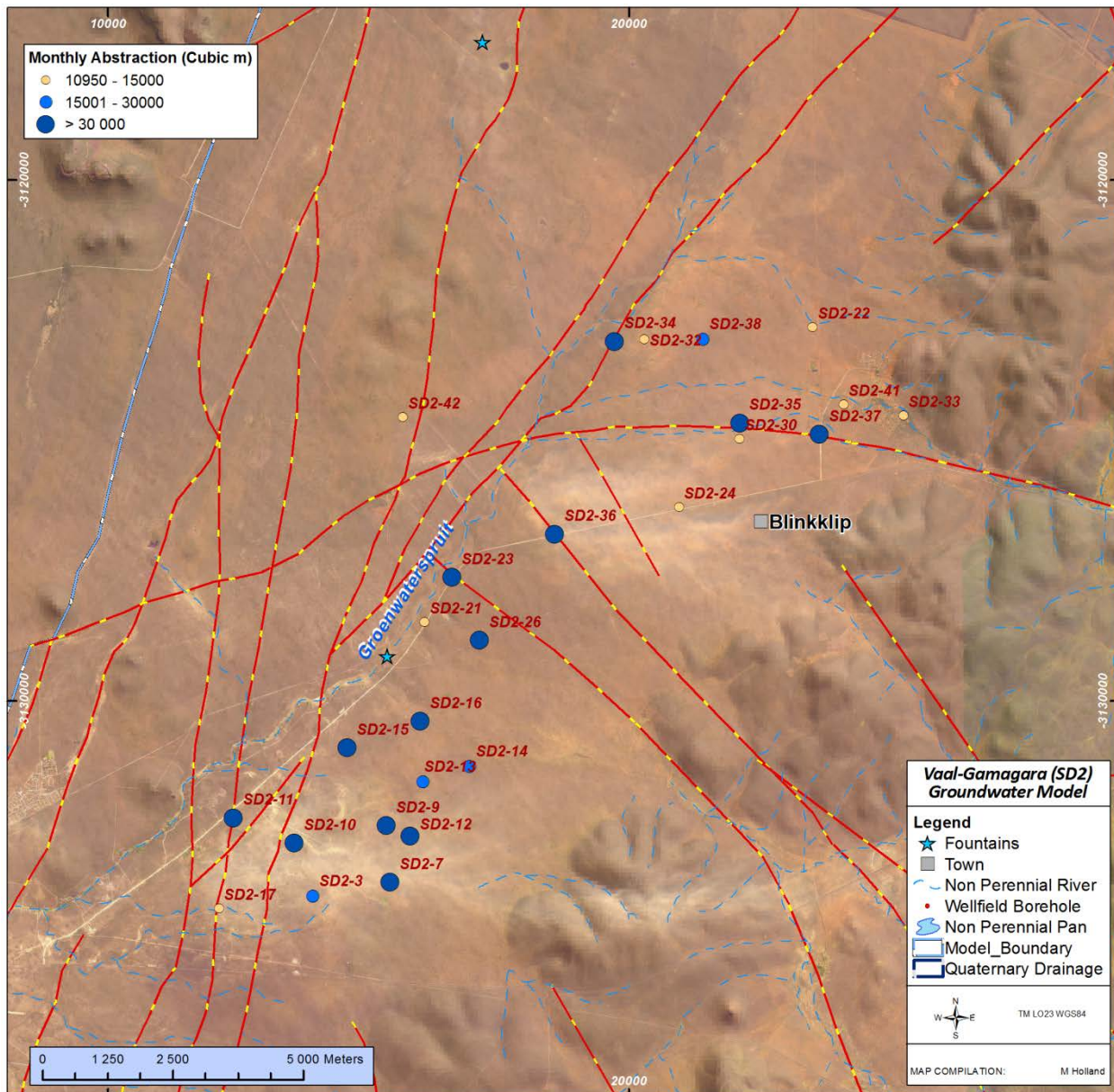


Figure 90: Locality of SD2Well Fields (Scenario 1)

SD2 Well Field Scenario 1

Scenario 1 can be considered as a worst-case scenario with abstraction rates close to the upper limit of the recommended yields obtained through the local pumping test analysis. As a result, the predictive simulation run reveals a wide-ranging cone of depression, extending approximately 25 x 18 km (considering a 2 m cut-off value), due to the distribution of the well fields as shown in Figure 91. The clearly anisotropic zones of influence or groundwater drawdown are due to the presence of dykes with lower permeabilities resulting in the compartmentalisation of the aquifer system.

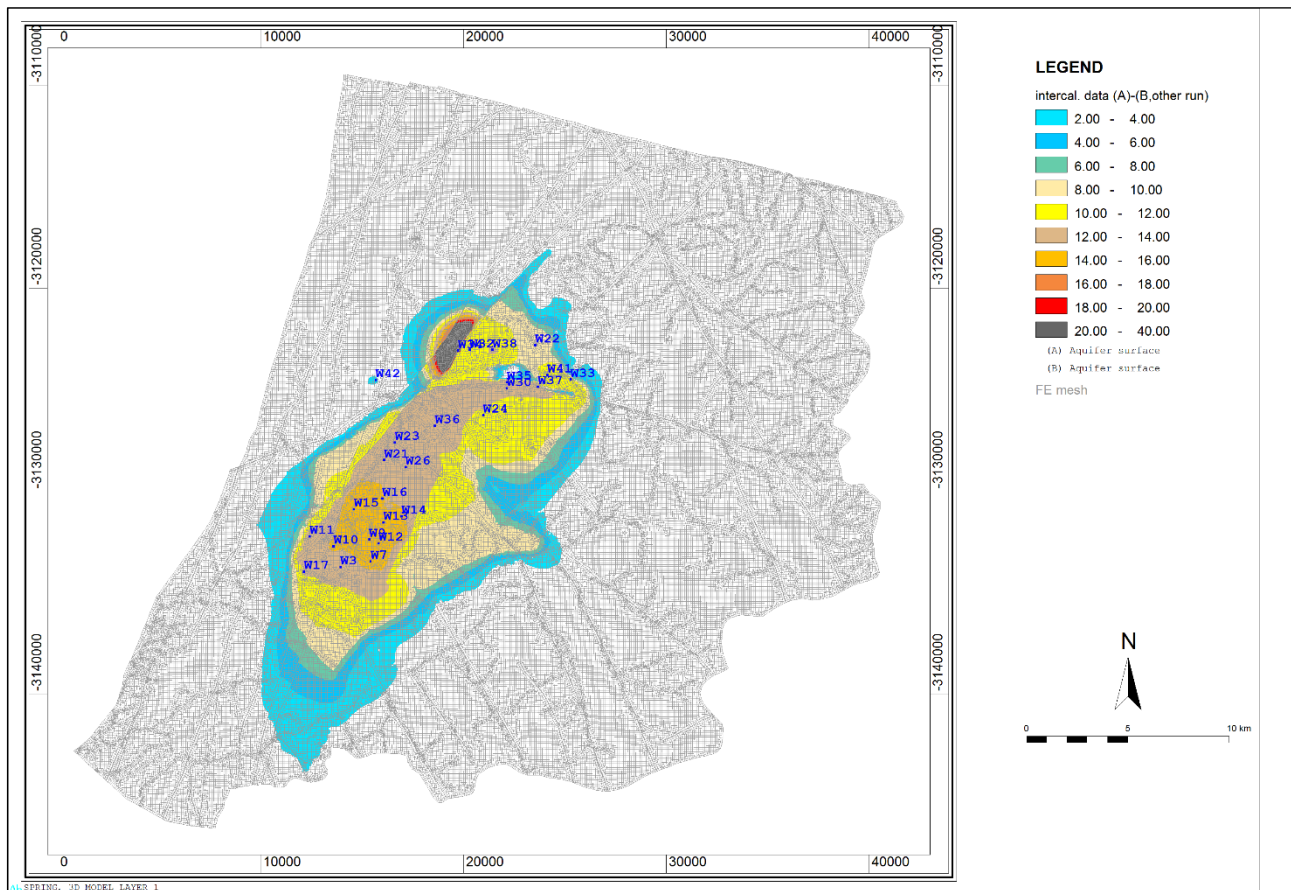


Figure 91: Scenario 1-Cone of Dewatering (m)

SD2 Well Field Scenario 2

The drawdown cone in the optimised Scenario (2) is smaller in extent and depth (Figure 92). The cone of dewatering is expectedly more pronounced within the central part where numerous production boreholes are within proximity to each other (i.e. SD2-7, SD2- 9, SD2- 10, SD2-14 and SD2-16).

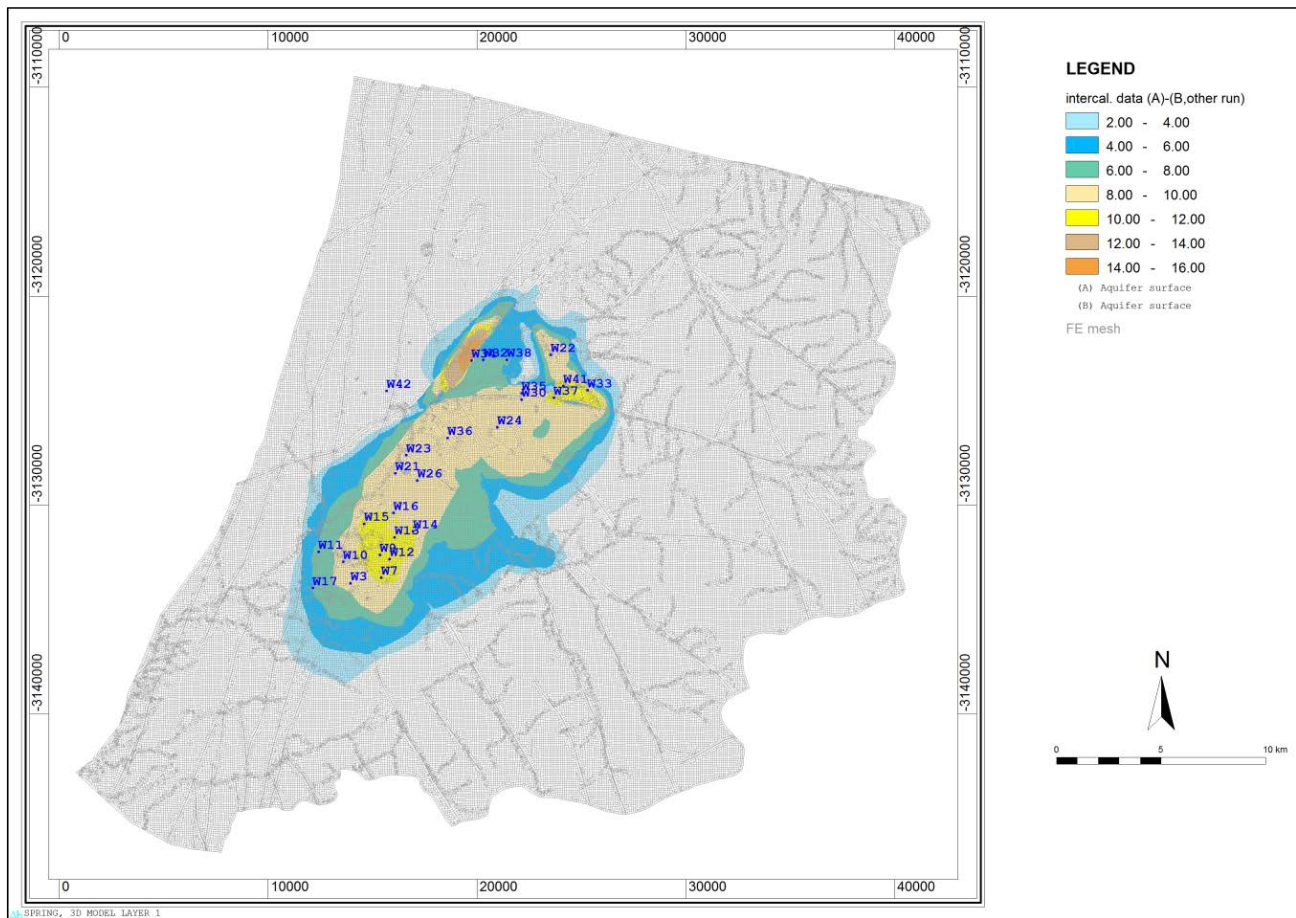


Figure 92: Scenario 2 - Cone of Dewatering (m)

SD2 Well Field Scenario 3

The final dewatering cone of Scenario (3) (Figure 93) extends approximately 19 x 10 km (considering a 2 m cut-off value) with drawdown ranging predominately between 6 and 8 m.

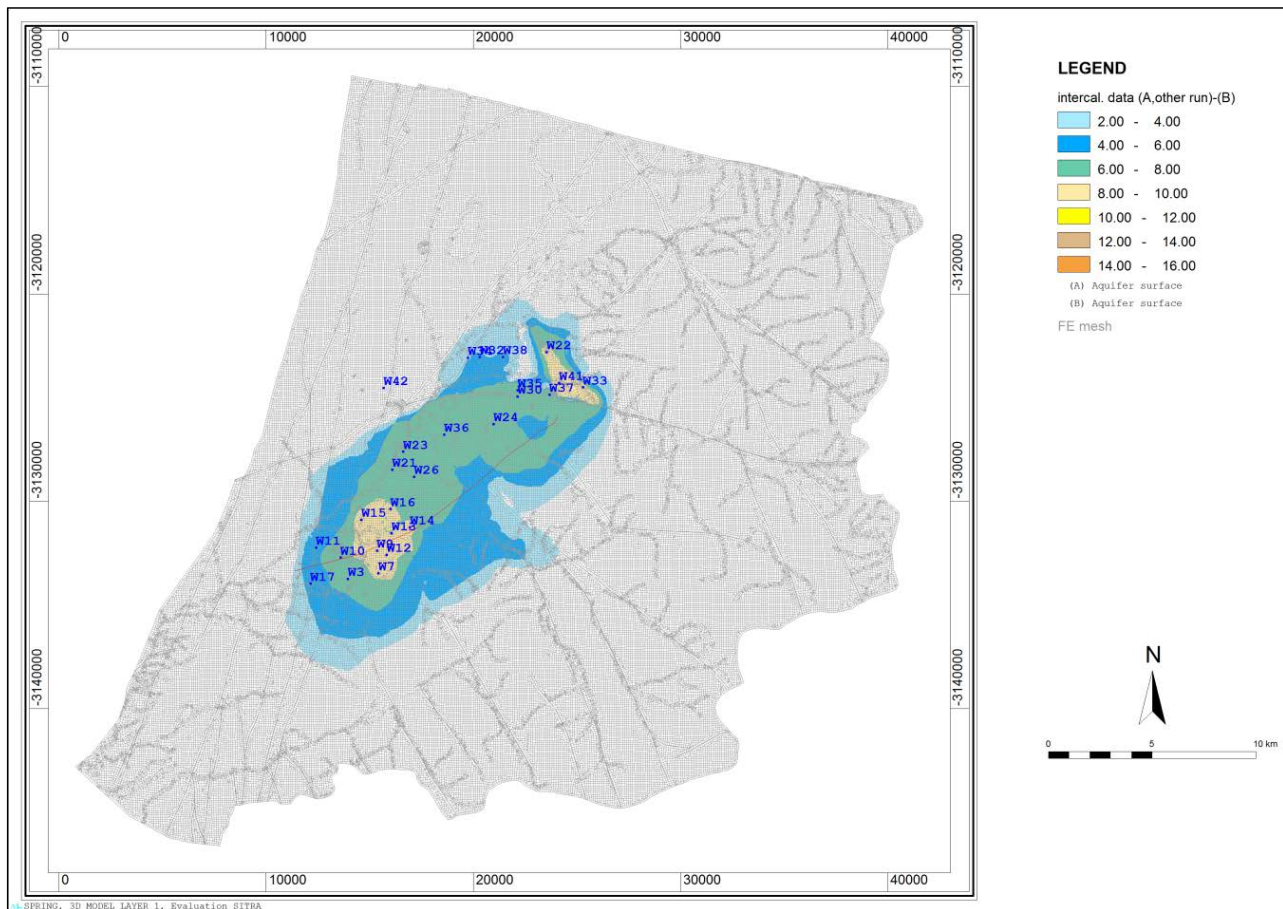


Figure 93: Scenario 3 - Cone of Dewatering (m).

Predicted Impact on Water Balance

The change in the predicted water balance compared to the base case (no well field abstractions) for scenario 3 is shown in Table 41.

Table 41: Simulated Water Balance (Transient State – 2031 – Scenario 3)

Regional Water Balance	Scenario 3	Base Case	Diff. From Base Case
Inflow	m³/month	m³/month	m³/month
Recharge	1 603 282	1 603 282	
Outflow	m³/month	m³/month	m³/month
Shallow seepages to pans and spring discharge	-153 200	-175 388	-22 187
Boreholes Abstraction	-582 590	-124 442	458 148
Contribution to Drainages and potential evapotranspiration	-332 891	-342 063	-9 173
Outflow Boundaries	-109 949	-110 019	-70
Sub-Total Outflow	-1 178 630	-751 912	
Change In Storage	-424 653	-851 370	-426 718
Total Outflow	-1 603 282	-1 603 282	

Predicted Change in Storage

The abstractions from the SD2 well fields result in a change of storage together with a small reduction in groundwater contributions to drainages and pans and a minimal reduction in flows across the outflow boundaries (to downstream catchments). If the outflows (abstractions) are consistently greater than the

inflows, water will be taken from storage, and this manifests itself as an overall decline in groundwater levels. The in- and outflows for the simulation period is shown in Figure 93, while the net change in storage for the base case (no well field abstractions) compared to Scenario 3 is shown Figure 94. The total abstraction from the model domain amounts to approximately 53 % of the average recharge of 870 885 m³/month (10.45 Mm³/annum) for the simulation period.

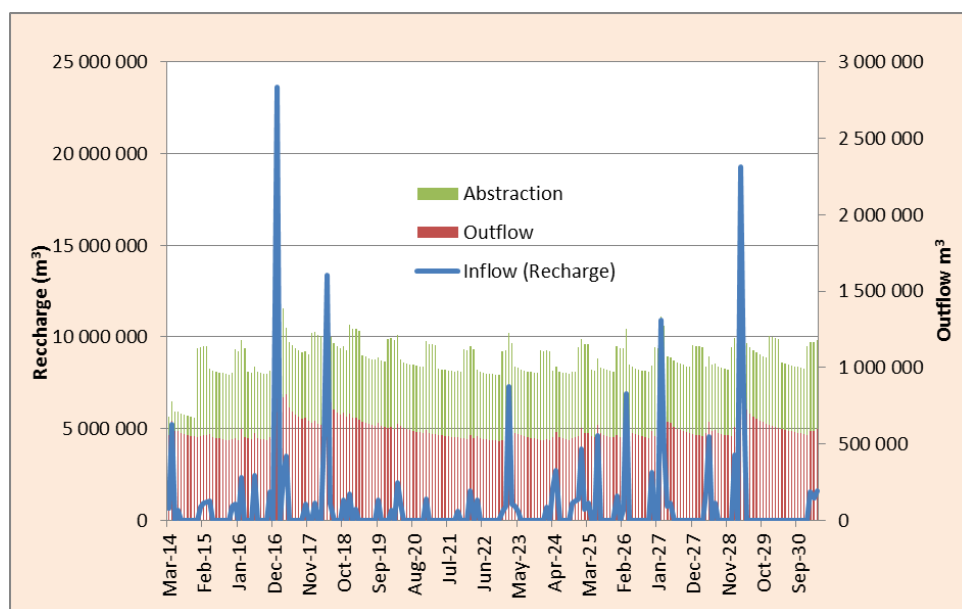


Figure 94: Simulated In- and Outflows for the Modelled Scenario 3

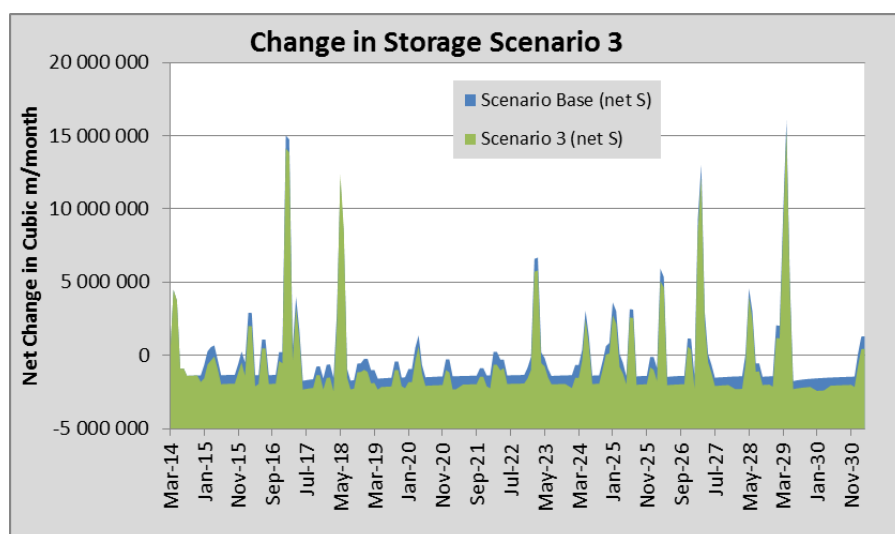


Figure 95: Net change in Storage for Scenario 3 compared to the Base Case

Impact on Outflow Boundary

The SD2 well fields (Scenario 3) will have almost no influence on the groundwater outflow (boundaries) based on the resulting predictions. The total cumulative loss of outflows (for the simulation period end 2030) compared to the base case is 3 173 m³.

Impact on Drainages (Groundwater Baseflow) and Seepages (Pans and Springs)

Conceptually (and based on the simulated water balances), groundwater pumped from the well field initially comes from storage in the vicinity of the well fields, but after sufficient time has elapsed, the cone of depression will eventually reach a new dynamic equilibrium. However, in order to maintain this equilibrium,

groundwater abstractions must be balanced by increased recharge (increase in the amount of water entering the system by e.g. reduction in evapotranspiration losses (or artificial recharge,) or reduced discharge (reducing the amount of water leaving the system). The total cumulative reduction in groundwater flow towards surface water drainages and springs and pans (Figure 96) due to the proposed well field abstraction (for the simulation period of 17 years) compared to the base case is approximately 889 180 m³ and 2 673 945 m³ respectively.

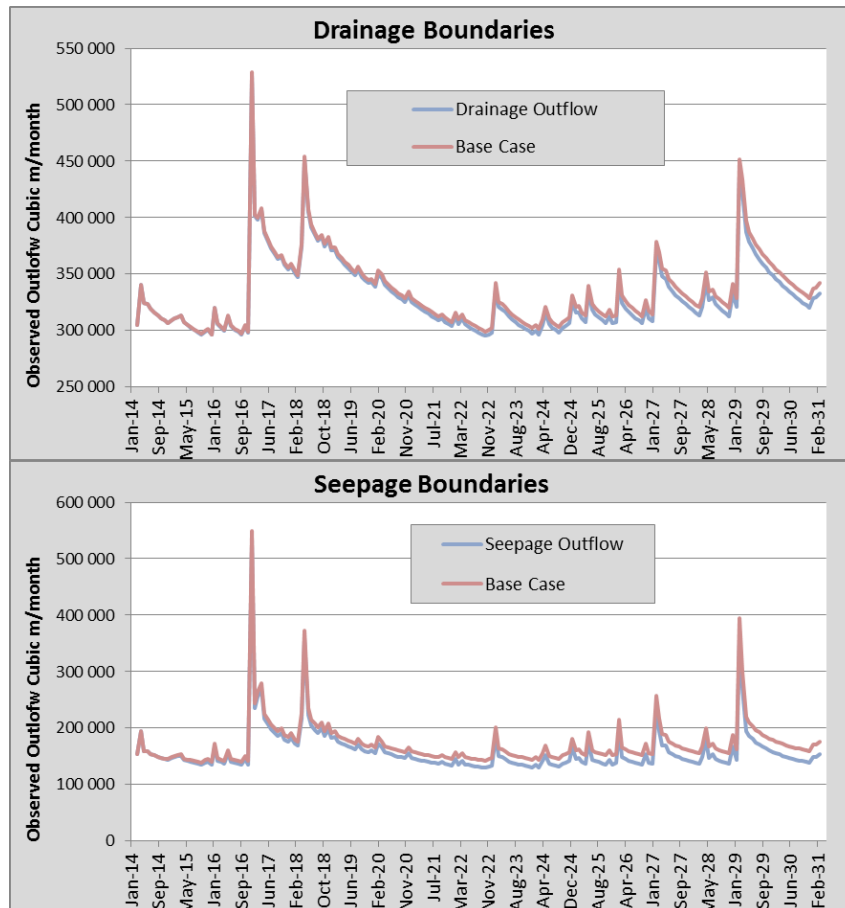


Figure 96: Cumulative change in Storage for Scenario 3 compared to the Base Case

Impact on Ecological Groundwater Reserve (EWR)

The groundwater component of the Reserve is the part of the groundwater resource that sustains basic human needs (BHN) and in some instances contributes to EWR. To be able to quantify the groundwater component of the Reserve, the volume of groundwater needed for BHN and contributing to EWR needs to be quantified. The EWRs of the Resource in question must consider the following:

- Groundwater contribution to baseflow in rivers.
- Groundwater contribution to wetlands.
- Groundwater contribution to springs and other Groundwater Dependant Ecosystems.

The groundwater component of the Reserve is defined by the following relationship:

$$\text{Reserve}(\%) = \frac{\text{EWR}_{\text{gw}} + \text{BHN}_{\text{gw}}}{\text{Re}} \times 100$$

Where:

$Re = \text{recharge} + (\text{inflow} - \text{outflow})$

BHN_{gw} = basic human needs derived from groundwater (not regarded in this case)

EWR_{gw} = groundwater contribution to EWR

The potential impact on the Reserve (considered in this case as the ecological component only) is shown in Table 42 and is based on the recharge and baseflow from the model simulation. The ecological Reserve range is from 8 to 57 %. It is evident that the development of the SD2 well field has an insignificant impact on the low flows contributing to the Reserve.

Table 42: Groundwater Reserve Summary for the four Delineated GMUs

GMU	Area Km ²	Recharge* (Mm ³ /a)	Baseflow (Mm ³ /a)	Low Flow (Pre- Well field) (Mm ³ /a)	Reserve	Low Flow (Post- Well field) (Mm ³ /a)	Reserve
D73A-01	96	0.51	0.05	0.04	8%	0.04	8%
D73A-02	351	4.56	1.86	1.67	37%	1.66	36%
D73A-03	363	3.43	1.48	1.33	39%	1.32	39%
D73A-04	121	0.92	0.58	0.52	57%	0.52	56%

* - Total Inflow [Recharge – (Inflow – Outflow)]

Impact on Water Levels

Well-field Boreholes

The simulated impacts of the groundwater abstraction from the SD2 well field on the regional groundwater levels are shown as contour maps of water table drawdown by comparing the water levels simulated for the last stress period of the base case (no well field abstractions) (in 2031) simulation against the lowered water levels due to abstraction from the SD2 well field (in 2031).

No drawdown values below 2 meters are visualised to account for the inaccuracy in the model calibration, which is however within the expected seasonal variability of water table elevations. It is likely that any drawdown below 2 meters is within the range of natural water table fluctuations and therefore any potentially affected groundwater dependent ecosystem therefore adapted to it. Similarly, potential groundwater users are unlikely to recognise such drawdown as borehole yields are typically not significantly impacted by such seasonal fluctuations. Scenario 1 can be considered as a worst-case scenario with abstraction rates close to the upper limit of the recommended yields obtained through the local pumping test analysis. As a result, the predictive simulation run reveals a wide-ranging cone of depression, extending approximately 25 x 18 km (considering a 2 m cut-off value), due to the distribution of the well fields as shown in Figure 91. The clearly anisotropic zones of influence or groundwater drawdown are due to the presence of dykes with lower permeabilities resulting in the compartmentalisation of the aquifer system.

The drawdown cone in the optimised Scenario (2) is smaller in extent and depth (Figure 92). The cone of dewatering is expectedly more pronounced within the central part where numerous production boreholes are within proximity to each other (i.e. SD2-7, SD2- 9, SD2- 10, SD2-14 and SD2-16). The final dewatering cone of Scenario (3) (Figure 46) extends approximately 19 x 10 km (considering a 2 m cut-off value) with drawdown ranging predominately between 6 and 8 m.

The simulated drawdown behaviour for each well field borehole (Scenario 3) is given Table 43.

Table 43: Summary of Simulated Drawdown at the end of the Predictive Period for the Three Simulated Scenarios

BH no.	Scenario 1 Drawdown (m)	Scenario 2 Drawdown (m)	Scenario 3 Drawdown (m)
SD2-3	13.5	7.4	5.8
SD2-7	15.3	10.8	8.8
SD2-9	14.5	10.0	7.7
SD2-10	14.7	10.3	8.1
SD2-11	12.6	6.8	5.3
SD2-12	15.7	11.0	8.9
SD2-13	14.3	9.3	7.3
SD2-14	15.0	13.5	11.5
SD2-15	15.6	9.6	7.7
SD2-16	13.9	9.9	8.0
SD2-17	11.9	5.0	3.7
SD2-21	16.5	8.4	6.6
SD2-22	9.3	8.8	7.6
SD2-23	13.1	9.1	7.0
SD2-24	11.3	9.0	6.8
SD2-26	13.3	9.1	7.2
SD2-30	12.3	8.9	6.4
SD2-32	11.4	6.0	3.8
SD2-33	11.4	11.3	9.5
SD2-34	20.4	14.8	3.1
SD2-35	12.5	9.0	6.4
SD2-36	12.5	8.8	6.6
SD2-37	12.6	9.7	6.8
SD2-38	20.3	16.8	14.7
SD2-41	9.9	9.6	8.0
SD2-42	5.5	2.1	2.0
Average	13.4	9.4	7.1

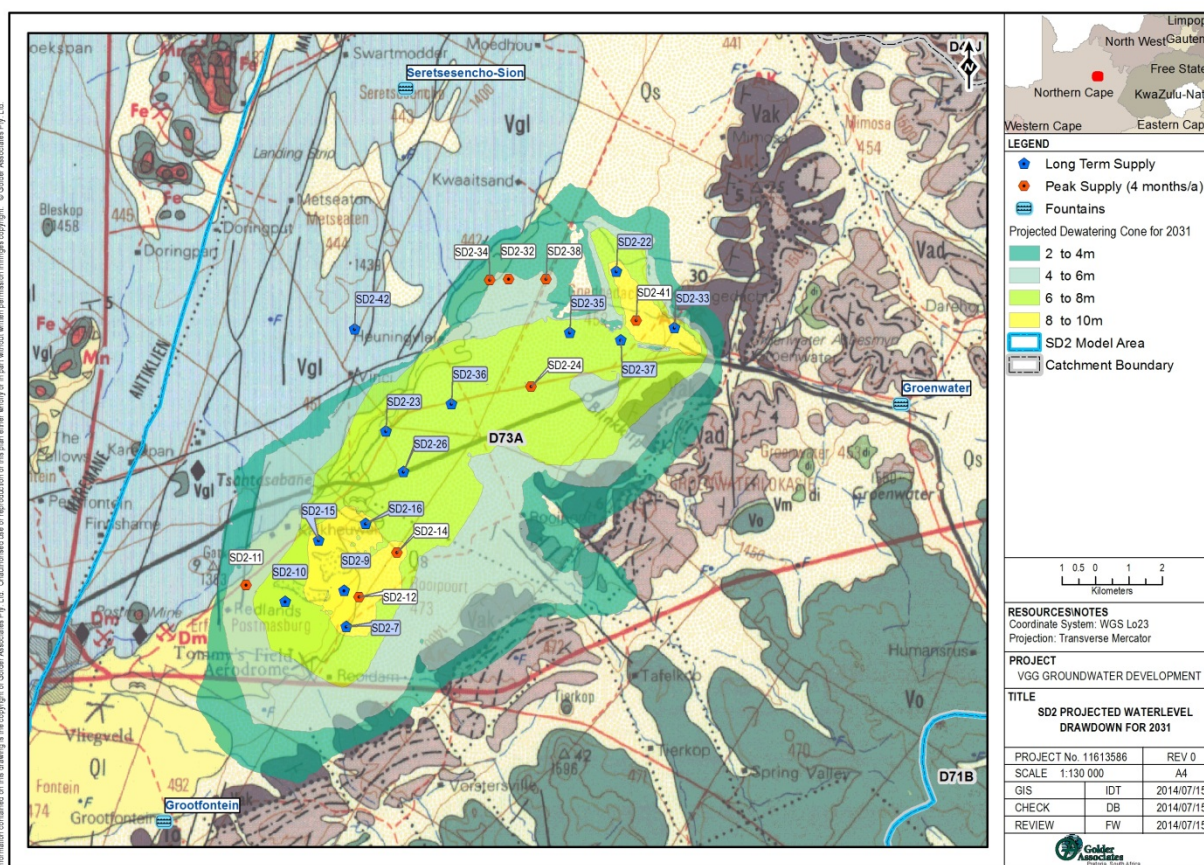


Figure 97: SD2 Projected Water Level Draw Down – 2031

2.3.6 Recommended wellfield abstractions

The individual borehole pumping rates for scenario 2B (22 production boreholes), were optimised through three groundwater model simulations (scenario 1, 2A and 2B) to limit water level drawdowns on the regional dolomite aquifer to within 4 to 6m, to limit the risk of sinkhole occurrences.

The 2014 recommended abstraction rates for the proposed SD2 area wellfield are listed in **Table 44** and indicated on Figure 98. The recommended well field abstraction conditions up to 2030 was as follows:

- 13 Boreholes can be implemented for long term abstraction (2030) use at a combined monthly peak rate of 307 476 m³/month,
- 8 Boreholes can be implemented for peak supply (4 months/a) use at a combined rate of 150 627 m³/month,
- A WULA should be submitted to implement the 21 production boreholes (scenario B) to abstract **3 689 712 m³/a** on a sustainable basis over the long term and **1 808 064 m³/a** over a short term / peak supply for four months/a (**5 497 776 m³/a** combined peak supply) to augment water supply to the VGWSS – this represents an average annual abstraction of **4 292 400 m³/a**,
- Critical water levels have been established for the aquifer conditions as per this point in time, however, an update of them would be required in once implementation of the scheme is planned. These levels should not be exceeded – once levels are approached, abstraction rates or duration should be reduced.

Table 44: SD2 Recommended Well Field Abstraction Rates

Well field	Borehole No.	Latitude	Longitude	Depth(m)	Diam (mm)	WL (mamsl)	WL (mbgl)	Discharge (l/s)	T (m²/d)	Pumping Hours Per day	Daily Abstraction m³/day	Monthly Abstraction m³/month	Long Term m³/month	Peak Supply m³/month	Water Quality Class
South	SD2-7	-28.3161	23.1572	52.4	203	1332.75	20.63	10	500	24	1296	39420	26280	-	0
South	SD2-9	-28.3063	23.15652	66.3	165	1332.74	18.19	10	965	24	1296	39420	26280	-	0
South	SD2-10	-28.3093	23.1385	70.5	165	1332.85	12.60	10	3788	24	1296	39420	26280	-	0
South	SD2-12	-28.3081	23.1612	74.06	165	1332.49	20.23	10	4120	24	1296	39420	-	26280	0
South	SD2-14	-28.296	23.17275	100	165	1332.91	23.96	7	472	24	864	26280	-	18396	0
South	SD2-15	-28.2928	23.14875	80.44	165	1332.82	16.4	10	12360	24	1296	39420	26280	-	0
South	SD2-16	-28.2882	23.1631	97	165	1332.7	19.40	10	892	24	1296	39420	26280	-	0
South	SD2-23	-28.2632	23.16925	73	203	1332.88	21.34	10	1338	24	1296	39420	26280	-	I
South	SD2-24	-28.2511	23.21368	119	165	1333.45	47.61	10	220	12	432	13140	-	13140	0
South	SD2-26	-28.2741	23.1747	75	203	1333.1	22.73	12	1500	24	1296	39420	31536	-	0
South	SD2-35	-28.2364	23.22553	100.48	203	1333.87	50.12	10	1342	24	1296	39420	26280	-	0
South	SD2-36	-28.2557	23.1894	97.5	203	1333.08	33.92	10	1013	24	1296	39420	26280	-	0
South-West	SD2-11	-28.305	23.12651	34	203	1326.66	10.47	10	834	20	1080	32850	-	21900	I
North	SD2-22	-28.2198	23.23976	73	165	1342.96	45.20	5	203	24	432	13140	13140	-	0
North	SD2-32	-28.222	23.20683	90	203	1343.12	31.63	5	61	24	432	13140	-	13140	0
North	SD2-33	-28.2351	23.25756	101.96	165	1343.1	59.43	5	119	24	432	13140	13140	-	I
North	SD2-37	-28.2383	23.24114	83.86	165	1336.55	59.9	10	2528	24	1296	39420	26280	-	0
North	SD2-38	-28.222	23.21828	88.75	165	1343.49	38.08	7	33	24	864	26280	-	18396	0
North	SD2-41	-28.2332	23.24583	72	203	1343.28	51.54	5	-	24	432	13140	-	13140	0
North-West	SD2-34	-28.2223	23.20101	34	203	1357.23	11.68	10	872	24	1728	52560	-	26280	I
North-West	SD2-42	-28.2355	23.15964	39	165	1370.55	5.95	5	269	24	432	13140	13140	-	I
Total											15062.4	458148	307476	150672	
		Long Term m3/Month										307476			
		Peak Supply m3/Month										150672			
		Long Term m3/annum										3 689 712			
		Peak Supply m3/annum										1 808 064			
		Long + Peak Supply m3/annum										5 497 776			

Subsequent to the simulated groundwater impacts (Scenario 3), of the 28 boreholes drilled and constructed as potential production boreholes, 21 (75%) were proposed as wellfield boreholes and illustrated in Figure 98.

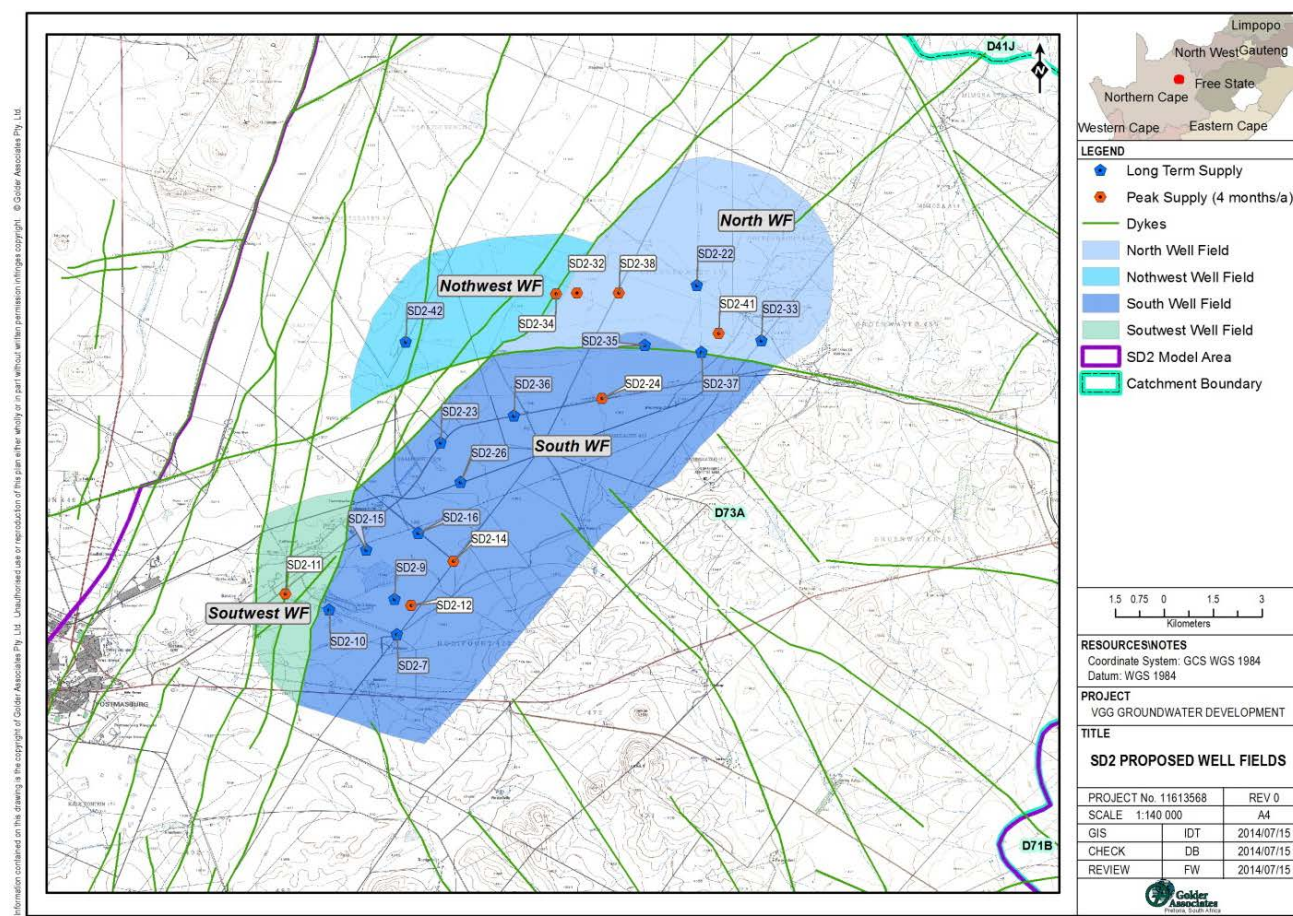


Figure 98: SD2 Production Wellfields and Abstraction Boreholes

The recommended abstractions for the four SD2 well fields are summarised in Table 45 below:

Table 45: Recommended abstraction rates for the SD2 Area wellfields

Well Field	Number of BH's	Yield l/s	Long Term m ³ /m	Long Term m ³ /a	Peak Supply m ³ /m	Peak Supply m ³ /a	Long + Peak Supply m ³ /a
South	12	119	241776	2901312	57816	693792	3595104
South-West	1	10	0	0	21900	262800	262800
North	6	37	52560	630720	44676	536112	1166832
North-West	2	15	13140	157680	26280	315360	473040
Total	21	181	307 476	3 689 712	150 672	1 808 064	5 497 776

3.0 HIGH LEVEL DOLOMITE STABILITY REVIEW

During the Public Participation (PP) for the EIA and WULA Process the need for a high-level dolomite stability review was identified. The PP process relates to the planned exploitation of the groundwater resources SD1 and SD2 in proximity to the Danielskuil and Postmasburg towns, respectively.

Golder Associates Africa Pty Ltd (Golder) were appointed by Sedibeng Water (Sedibeng), through Proplan Consulting Engineers (Pty) Ltd (Proplan), to conduct a preliminary stability evaluation of the risks associated with inherent dolomite hazards (i.e. sinkhole and subsidence development) at SD1 and SD2, based on a high-level review of the available borehole data.

The following material sources were consulted for the review:

- Available borehole information from previous investigations carried out at SD1 and SD2 by Golder (2012-2014).
- 1:250 000 Geological Map Series, 2822 Postmasburg: Issued by Geological Survey of South Africa (Council for Geosciences, 1977)
- Proposed Method of Dolomite Land Hazard and risk Assessment in South Africa by D. B. Buttrick, A. Van Schalkwyk, R.J. Kleywegt and R.B. Watermeyer 2001, Journal of the South African institution of Civil Engineering, Volume 43, Number 2
- South African National Standards (SANS) 1936 (2012) Parts 1-4

The available information comprised one hundred and one percussion boreholes

Note that the boreholes were drilled for hydrogeological studies to determine water quality, groundwater levels for evaluating groundwater flows and groundwater production estimates and were not specifically catered for dolomite stability investigations. This review is therefore considered to be high-level only, with the hazard assessment and zonation provided to give an initial perspective of the potential hazard characterisation and potential impact of anthropogenic groundwater level draw-down. The evaluation additionally occurs in the absence of geophysical gravity surveys with appropriate levels of data points.

3.1 Geology

Regional and local geology of the two sites have been inferred from the 1:250 000 geological series map: 2822 Postmasburg as well as the drilling conducted during the Golder hydrogeological studies. Characteristic lithostratigraphy of both sites at a regional scale is similar and is presented in the Table 46.

Table 46: Regional-Scale Geology of the Sites

Age	Supergroup, Formation	Lithology
Tertiary	-	Qs: white to flesh coloured wind-blown sand
Quaternary	-	Ql: surface limestone
Mongolian	-	Di: Diabase
Vaalian	Ongeluk, Postmasburg	Vo: Amygdaloidal andesite lava with interbeds of tuff, agglomerate, chert and red jasper

Age	Supergroup, Formation	Lithology
	Asbesberge, Kuruman	Vak: Banded ironstone with bands of amphibolite and lenses of flat-pebble conglomerate in places, tuff
	Ghaap, Danielskuil	Vad: Brown jaspilite and crocidolite with alternating layers of shale and mudstone, riebeckite-amphibolite
	Ghaap, Lime Acres	Vgl: Dolomitic limestone with subordinate coarsely crystalline dolomite, chert and lenses of limestone

The 2228 Postmasburg map sheet series shows that geology within the investigated areas comprises predominantly tertiary and quaternary sediments. These sediments consist of aeolian deposits and surface limestone. The geology also includes banded ironstone which may sometimes be characterised by bands of amphibolite and lenses of flat-pebble conglomerate, in places tuff. In addition, dolomitic Ghaap Formation as well as diabase/dolerite intrusions also characterise the local geology of the sites.

3.2 Geohydrology

According to the referenced reports and Numerical Groundwater Flow Model for SD1 and SD2, these areas are characterised by the following aquifers: Unconfirmed Intergranular aquifer, Weathered and fractured BIF aquifer and Karst Dolomite Bedrock aquifer. Regional groundwater flow is towards the west.

The average groundwater levels are approximately 13 mbgl (meters below ground level) and 21 mbgl within the SD1 and SD2 areas respectively. Within SD1, the depth range to the groundwater table ranges from 1-123 mbgl. Groundwater flow towards the west was delineated in the SD2 areas and an assessment indicated lower transmissivity for the BIF hard rock aquifer.

3.3 Site Characterisation

The investigated areas are generally underlain by dolomitic rocks at depth above 100 mbgl and therefore classify as dolomitic terrain. The geotechnical conditions on site have subsequently been evaluated in accordance with the potential development for sinkholes and/ or subsidence and with reference to SANS 1936:1-4 and the proposed method of dolomite land hazard and risk assessment in South Africa by Buttrick *et. al.* (2001).

The borehole and groundwater data from geohydrological studies conducted in the SD1 and SD2 have been used to characterise the stability of the sites with respect to de-watering and ingress scenarios.

The following factors have been used for assessment:

■ Nature of blanketing material

The geotechnical character of the blanketing layer has been assessed, particularly its potential to mobilise and/ or act as aquitard (intrusions and Karoo rocks) with respect to potential receptacles for ingress. The blanketing material was also considered for a dewatering scenario; potential for compressible and low strength material (wad) to daylight upon groundwater level drawdown.

■ Bedrock morphology

Depth to competent dolomite rock is considered significant for evaluation of risk to sinkholes and subsidence development. Presence of pinnacles, potential development of grykes and general distribution and pattern of competent dolomite rock over the sites was evaluated.

■ Receptacle development

Existing cavities within investigated areas has been analysed from the available borehole data. This data has also been used to form an impression of the presence and extent of cavities. Evaluation of receptables form a significant basis for stability of the site.

■ Mobilising agency

The main trigger for ground instability within the investigated sites and the project is water drawdown (or dewatering). However, water ingress and ground vibrations are also considered important contributors for instability.

■ Groundwater Conditions

Natural fluctuating groundwater level forms a base level of subsurface erosion and 'protects' any underlying receptables and low strength compressible wad. Drawdown can potentially trigger instability due to exposure of receptacles and extension of the base level of erosion within the investigated sites.

■ Potential Development Space

Refers to maximum size receptable that may form due to ingress and/or dewatering within the investigated sites. Evaluation for potential development space related to cavities and has been is in accordance with available data which may be insufficient or limited at this stage.

A site is characterised in terms of eight standard inherent hazard classes, denoting likelihood of an event (sinkhole or subsidence) occurring (susceptibility) and its potential size (diameter). The larger the Inherent Hazard Class (IHC) number, the greater the likelihood of an even occurring and the larger its potential size should it occur.

Sinkhole sizes in this report are in accordance with diameter sizes presented in Table 47:

Table 47: Sinkhole Sizes (SANS 1936-2)

Maximum Diameter of surface manifestation (m)	Sinkhole Descriptor
<2	Small
2-5	Medium
5-15	Large
>15	Very large

Likelihood of the above sinkhole sizes has been categorised as low, medium and high, in accordance with the table below (SANS 1936:2):

Table 48: Sinkhole/Subsidence Categories

Sinkhole/Subsidence Likelihood per 20 years*	Inherent Susceptibility
Return period of an event occurring in an area of 1 ha is greater than 200 years.	Low

Sinkhole/Subsidence Likelihood per 20 years*	Inherent Susceptibility
Return period of an event occurring in an area of 1 ha is between 200 years and 20 years.	Medium
Return period of an event occurring in area of 1 ha is less than 20 years.	High

* Based on events that have occurred per hectare in a 20-year period in the "type" area with no special precautions taken in respect of the design and maintenance of water-borne services

Characterisation of the SD1 and SD2 sites and boreholes was subsequently done according to the terms presented in Table 49:

Table 49: Inherent Hazard Classes and Likelihood

Inherent Hazard Class	Inherent Susceptibility	
	Sinkhole Development	Subsidence Development
1	Low susceptibility to sinkhole development	Low susceptibility to sinkhole development
2	Medium susceptibility to small sinkholes	Medium susceptibility to subsidence
3	Medium susceptibility to up to medium-size sinkholes	
4	Medium susceptibility to up to large sinkholes	
5	High susceptibility to small sinkholes	High susceptibility to subsidence
6	High susceptibility to up to medium-size sinkholes	
7	High susceptibility to up to large sinkholes	
8	High susceptibility to sinkhole development	

The resulting preliminary dolomite stability zones (Figure 99 and Figure 100) have been designated as follows:

Inherent Risk Class (IHC) (Water Ingress) // Inherent Risk Class (anthropogenic groundwater level drawdown)

As an example:

IHC 1//4 – low risk to sinkholes and subsidence due to ingress but medium risk from groundwater drawdown.

IHC 4(6)//4(6) – medium risk to up to large-size sinkholes and subsidence due to ingress and groundwater drawdown but with localised areas of high risk to small-size sinkholes and subsidence.

3.4 Preliminary Dolomite Stability Assessment

The preliminary dolomite stability assessment has been assessed for both the SD1 and SD2 sites, and the resulting dolomite zonation maps Figure 99 and Figure 100 present the various dolomite stability zones from the interpretation of borehole data.

It must be re-iterated that due to scope of the drilling conducted to develop the hydrogeology studies, the information used for this assessment is not considered to be a detailed-level dolomite stability investigation. Dolomite specific investigations would be required to refine the assigned hazard classes.

The general conditions between the zones are discussed below:

■ Dolomite Stability Zone I

The ground conditions are typically a very thick (> 50 meters on average) succession of calcrete, clay and banded ironstone. Horizons of breccia, sand, gravel and dolerite intrusions are also present in the boreholes within this zone. The borehole profiles show no dolomite and/or very deep dolomite. Neither cavities nor wad was intersected in boreholes within this zone. However, localised zones of high risk to sinkholes and subsidence may exist.

■ Dolomite Stability Zone II

Typical borehole data within this zone show some overburden horizons found in Zone 1 discussed above, although these are underlain by chert horizons, weathered dolomite and dolomite bedrock between approximately 15 and 30 m depths. Thin wad material and cavities of no more than 2 m were occasionally intersected and inferred from drilling.

These areas, in particularly within 'SD2' are often localised with wad material and cavities of more than 2 m thickness.

■ Dolomite Stability Zone III

These areas are characterised by groundwater level that is within very shallow to shallow dolomite bedrock - usually above 15 m.

The above zones across SD1 and SD2, have been designated as follows:

Table 50: Inherent Dolomite Stability within SD1 and SD2

Dolomite Stability Zone	Investigated Areas	
	SD1 Area	SD2 Area
Dolomite Stability Zone I	IHC 1//4: Low susceptibility to small-size (< 2m) sinkholes and subsidence due to ingress but low-medium susceptibility due to groundwater drawdown	
Dolomite Stability Zone II	IHC 4//4: Medium susceptibility to up to medium-size (< 5m) sinkholes and subsidence due to ingress and groundwater drawdown	
	IHC 4(6)//4(6): Where localised areas of high susceptibility to up to medium-size (< 5m) sinkholes and subsidence occur	In some areas the susceptibility to sinkholes and subsidence can range from low to medium - IHC 2/4/4
Dolomite Stability Zone III	3/5//1 Medium to high susceptibility to medium-size sinkholes and subsidence due to ingress but low susceptibility due to groundwater drawdown	

The preliminary findings provide high-level characterisation of the site and should be used conservatively and confirmed at a later stage where additional, specific, investigations are carried out to satisfy standards for a more detailed-level study.

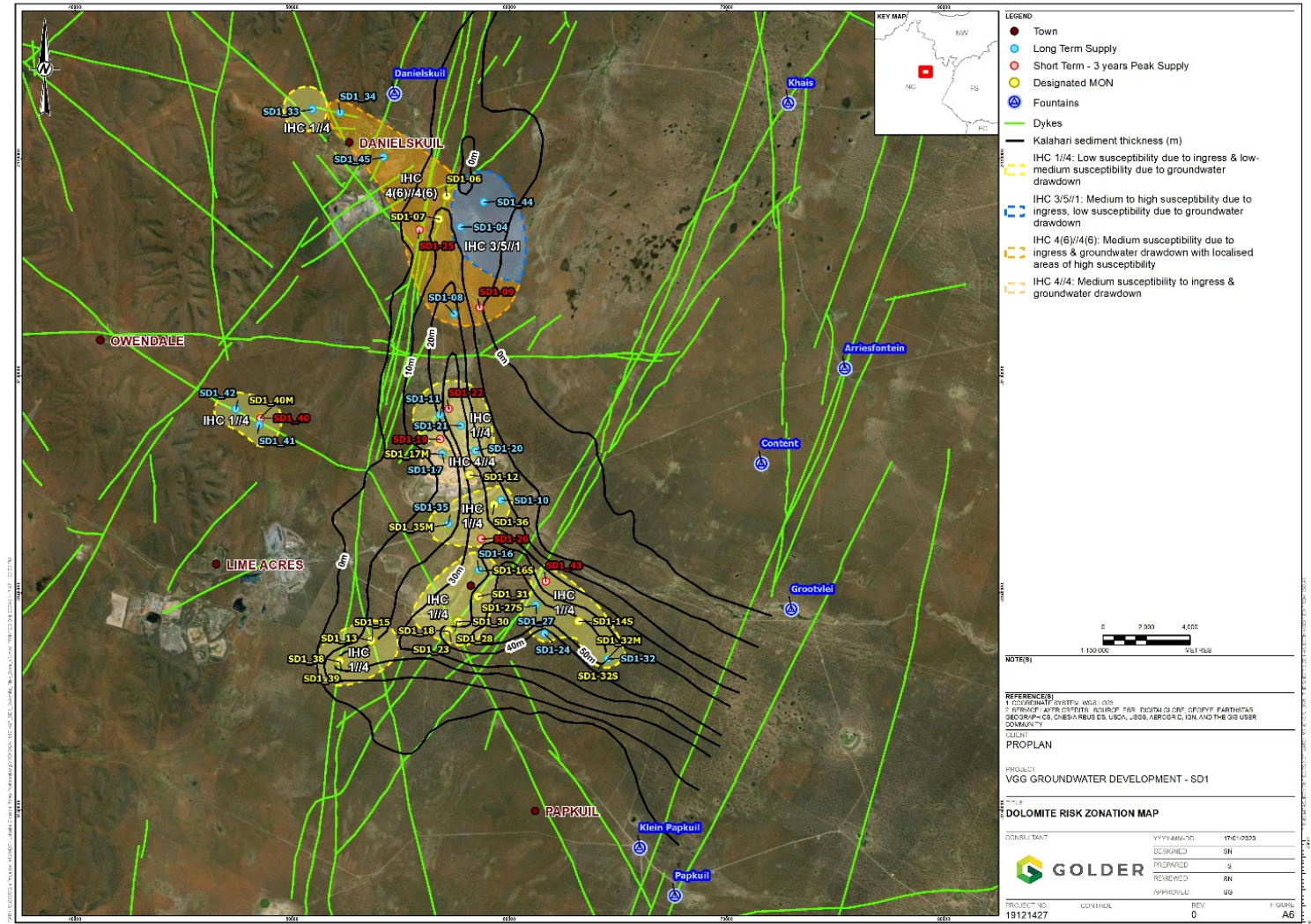


Figure 99: SD1 Dolomite Risk Zonation Map

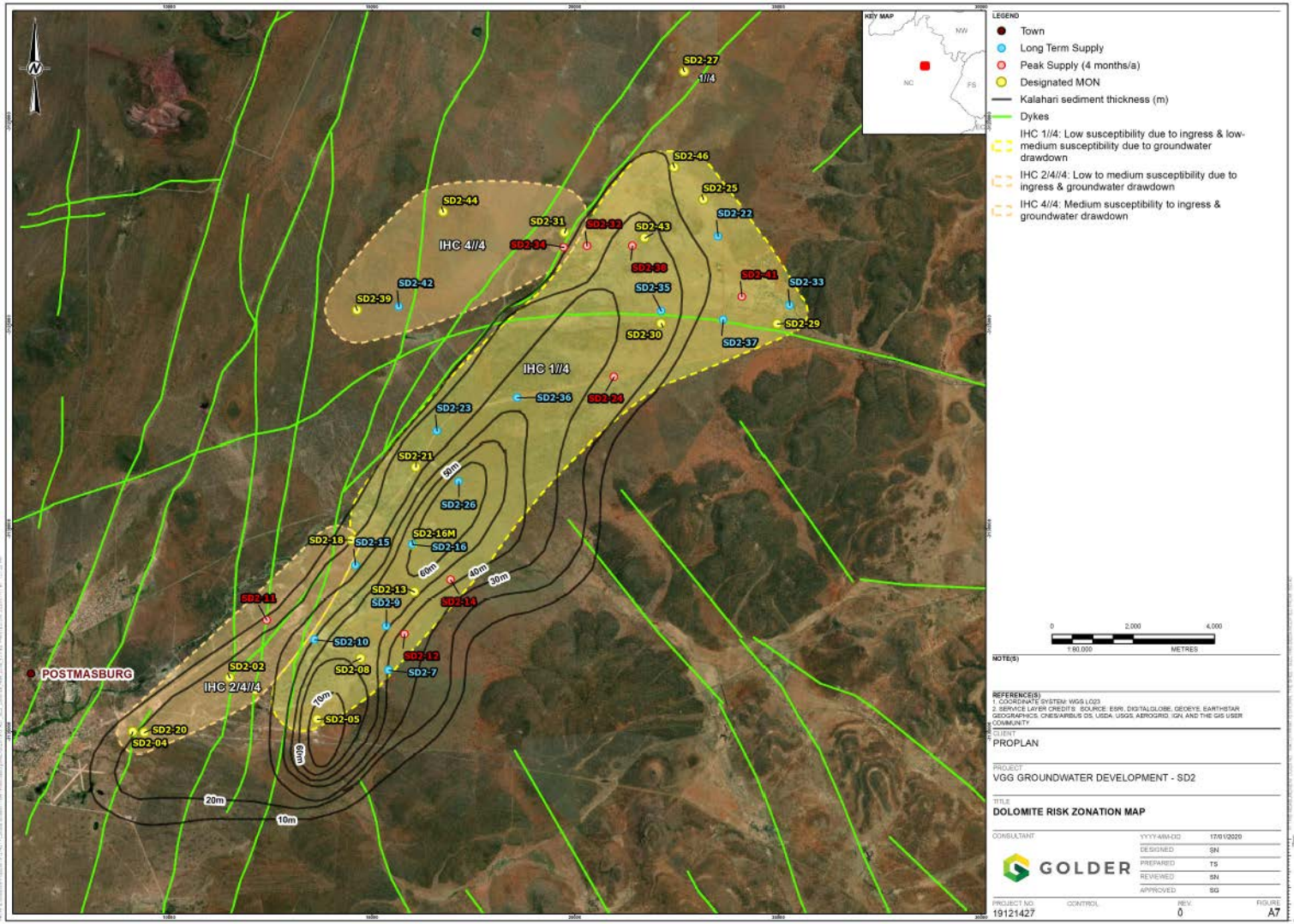


Figure 100: SD2 Dolomite Risk Zonation Map

4.0 OLEA AFRICANA (“OLIENHOUTBOOM”) AND DEPENDANCE ON GROUNDWATER AT DEPTH

An area immediately east of Lime Acres is recognized as having a unique very large forest of wild olive trees (Olienhout or *Olea europaea* subsp. *Africana*). Concerns have been raised that the extraction of groundwater could harm the wild olive trees and lead to their demise. An assessment is made by DR EH Stettler of available geophysical information to determine if the growth pattern of wild olive trees is influenced by groundwater abundance?

Olive trees are incredibly hardy and do best in rocky terrain with only a very shallow overburden. The question is therefore if their roots remain shallow or extend down to the natural water level like other trees that exploit the presence of dykes and fractures in the subsurface. Typically, trees and shrubs are in better condition or more abundant along dykes and fractures.

Looking at the Olienhout tree occurrence pattern on Google over an area called SD1 east of Lime Acres (Figure 104), they have an almost random distribution pattern except for small oval or roundish barren patterns in between the trees, where no trees grow. These barren patterns (Figure 104) could indicate small depressions in the topography where rainwater may stagnate in wetter periods and the Olienhout trees probably cannot handle stagnant water at surface.

Airborne geophysical data consisting of K, U, Th concentrations at surface, digital topography model and magnetic data enables one to identify the subterranean geological units present. Not visible at surface are relics of past drainage (water filled gravel beds) shown in Figure 101 where groundwater can move more freely in these channels because of the increased permeability and porosity of the subsurface. If the Olienhout trees have an affinity for such subsurface sediment-channel then their distribution pattern should mimic that. Alternatively it was also determined if the Olienhout trees show any preference for the geology or overburden characteristics, then that can be determined from the available geophysical data.

Analysing large amounts of data layers to determine areas at surface/subsurface with similar parameters such as K, U, Th concentrations, magnetite distributions, common elevation patterns is difficult/subjective and therefore automated with clustering or grouping algorithms.

■ Cluster analysis or grouping:

In mineral exploration or geological mapping, a combination of various geophysical techniques are often used to generate potential exploration targets or make deductions about the geology or the soil cover. Evaluation of the various data sets is usually done successively and results in a manual subjective interpretation of the database. When considering the comprehensive multimethod databases, which often are encountered in exploration geophysics, traditional analysis and interpretation are time-consuming and rely heavily on human skills. Alternatively, an integrated approach based on multivariate statistical analysis tools, such as cluster analyses, can enable data-driven, automated, and rapid data integration as well as value-added map generation.

Clustering (grouping) algorithms can detect several predefined groups in a multimethod database. The detected groups ideally are characterized by little within-group variations, but between-group variations are expected to be significant.

Clustering of airborne geophysical data was first presented during the 1980s and 1990s to support geologic mapping. These studies were constrained by poor computer capacity and data quality, but with

the advent of more powerful and faster computer facilities, the conditions to apply multivariate statistical analyses in geophysics and remote sensing have improved, thus enabling a varied field of applications.

Early applications of clustering airborne geophysical data mostly used hierarchical cluster techniques. Hierarchical clustering tends to be agglomerative creating strongly nested structures with often poor geologic association. For this reason, partitioning cluster algorithms increasingly came into use when striving for fast, automated, and objective map creation from large airborne geophysical data sets.

The result of the clustering process is a classified map. Each class (cluster) is linked to geophysical attributes underlying the clustering procedure. Subsequently geological attributes are ascribed to each cluster in an interpretational step to obtain a pseudo-lithology map. This concept was proven successful for data-driven and rapid regional-scale mapping (Paasche and Eberle, 2009; Eberle et al., 2010).

Crisp clustering techniques were introduced for the integration of multi-parameter airborne geophysical data sets and Paasche and Eberle (2009) applied the principle of fuzzy partitioning clustering, employing the fuzzy c-means (FCM) algorithm. Crisp cluster algorithms do not provide a quality measure for the classification of each multi-parameter sample. Trustworthiness of cluster assignment can be obtained from running fuzzy cluster analyses adding value to the visualization of pseudo-lithology maps (Paasche and Eberle, 2009, 2011). Paasche and Eberle (2011) then added the fuzzy Gustafson-Kessel (GK) cluster algorithm (Gustafson and Kessel, 1978), to the FCM algorithm. The results obtained by the GK algorithm have proven to be superior in terms of structural clarity to those obtained by the FCM algorithm.

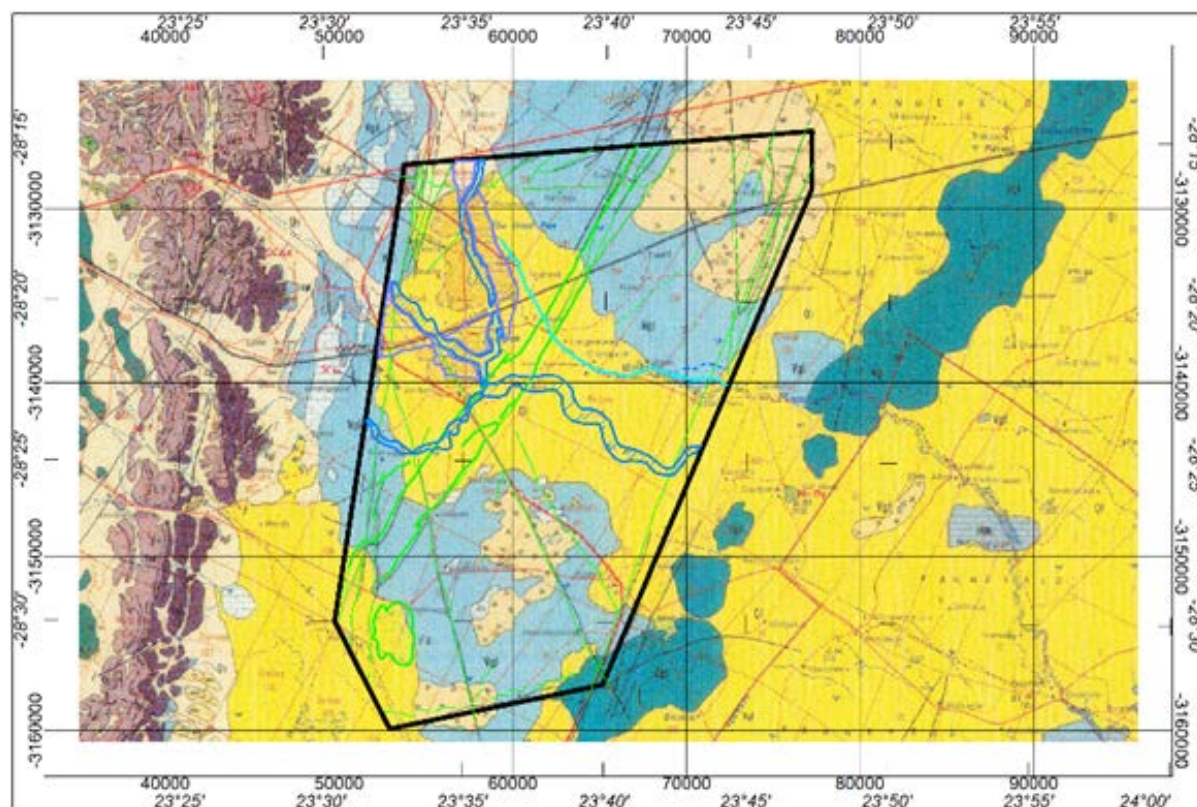


Figure 101: Geology Map with the Outlines of the Subterranean Relics of a Paleo-drainage System (indicated in blue)

Like other fuzzy partitioning cluster algorithms, the GK algorithm (Gustafson and Kessel, 1978) objectively integrates and reveals the structural heterogeneity of a database in a fuzzy sense. The GK algorithm groups n

samples located in a t-dimensional space into a specified number of c clusters. For the present case the clustering was unsupervised which means that the result was not steered towards a specific end-result. The agreement therefore between the geology map and the GK derived product gives confidence in the results.

The data sets were also subjected to the Fuzzy C-Means clustering algorithm but the best agreement to the mapped surface extent of the Kalahari sand, calcrete rich layers and dolomitic bedrock was the unsupervised, fuzzy logic, GK algorithm with between 7 and 9 clusters. The result is shown in Figure 102 and the colours allocated just indicate different groups.

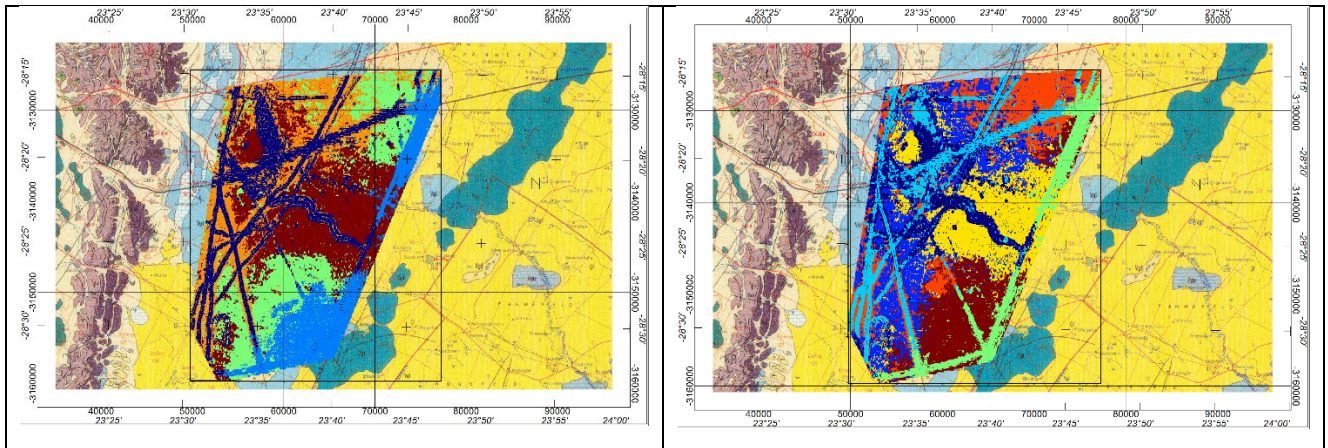


Figure 102: Left- Gustafson Kessel (GK) Classification with 7 Groups and Right with 9 groups

If the effect of the magnetic dykes and palaeo channels are removed, then the results are as shown in Figure 103.

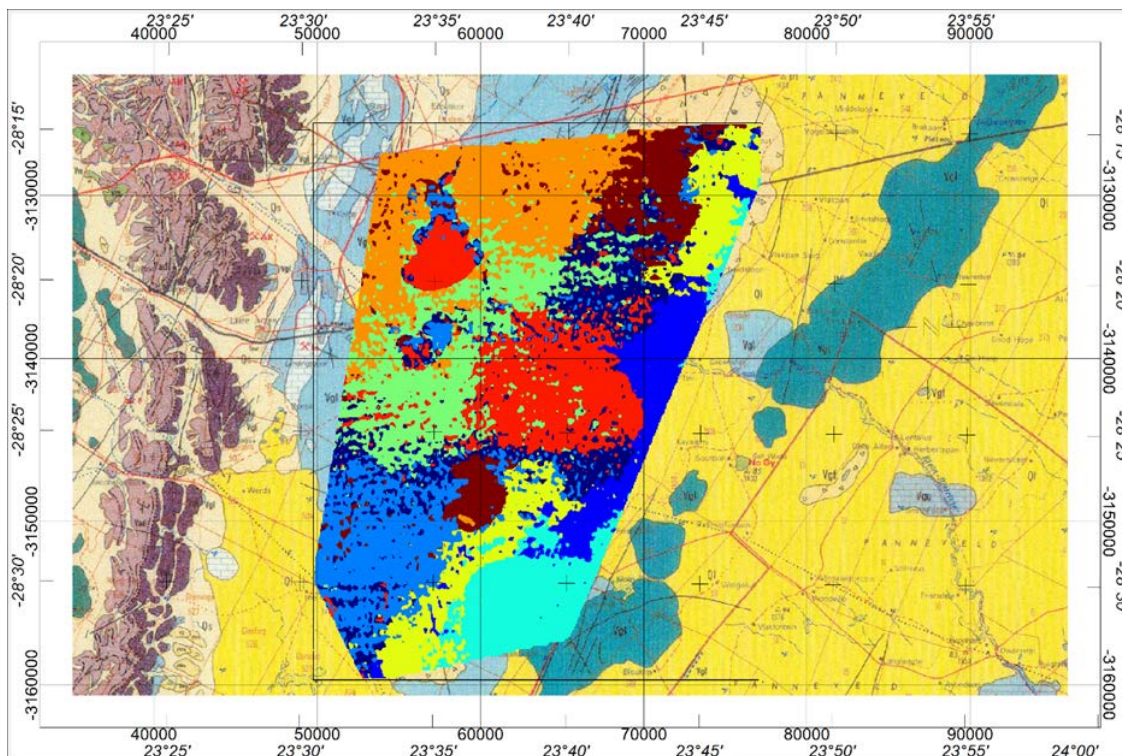


Figure 103: Gustafson Kessel (GK) Classification with 11 Groups but Magnetic Data Excluded

One of the spectacular items on the SD1 map is the subterranean gravel bed that flows from the NW to the SE and south (Figure 102). The material in the gravel bed is magnetic and was verified by drilling. However, when comparing the areal extent of the gravel bed there is no correlation between the Olienhout tree abundance or distribution patterns and the subterranean gravel bed or any other structure (Figure 104).

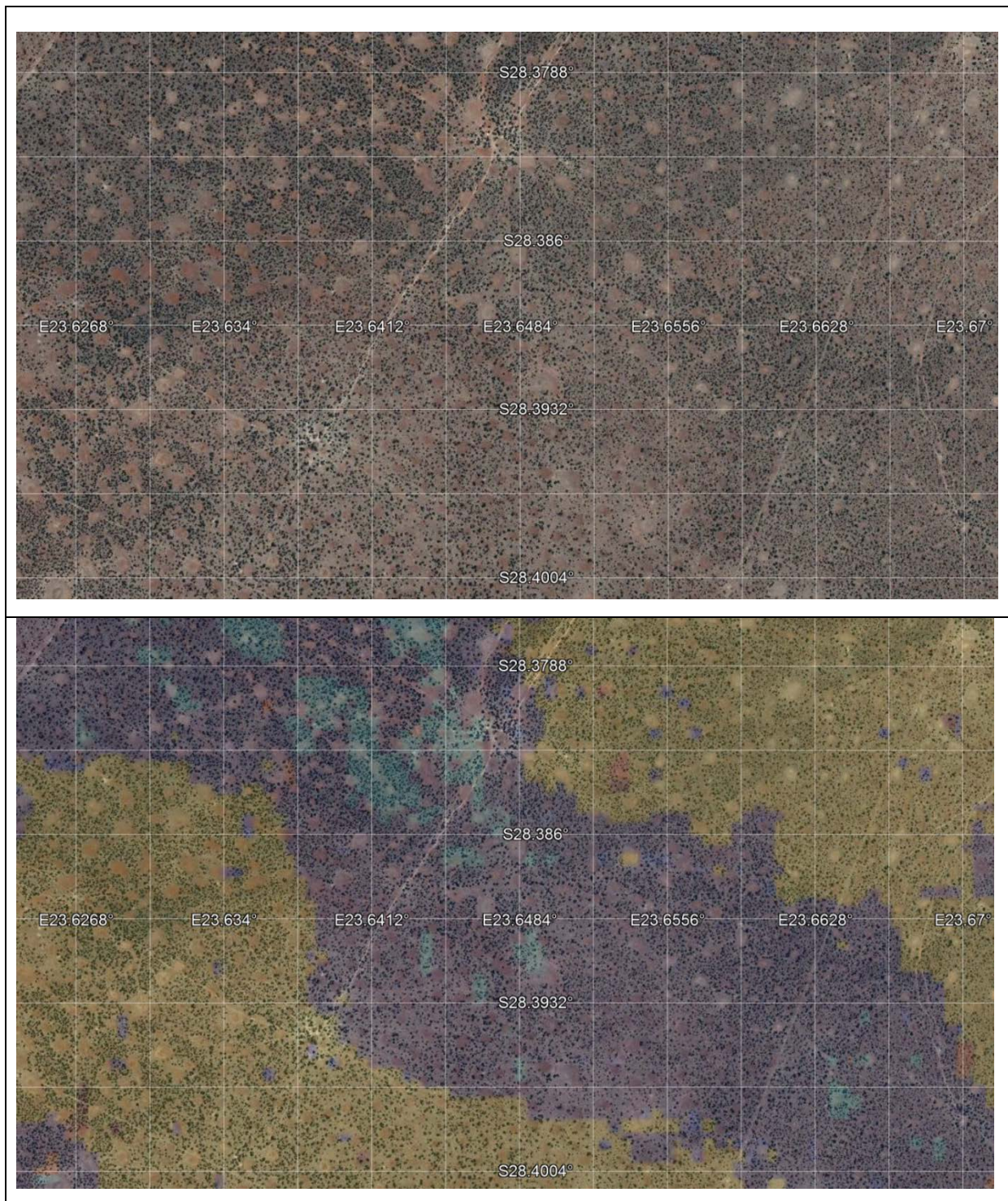


Figure 104: Olienhout Tree Distribution over the Palaeo-channel (marked in dark blue)

The clustering of the geophysical data shows a very good correlation with the mapped geology. However the Olienhout tree distribution pattern show no obvious correlation with the types of soil at surface or geology and

the only conclusion that can be drawn is that the root system of the trees must be very shallow and groundwater extraction should not influence the well-being of the Olienhout trees unduly.

There is no obvious difference between the tree abundance on or off the paleo-channel.

5.0 2019 HYDROCENSUS SURVEY

The SD1 and SD2 Areas groundwater exploration phases comprising of drilling and test pumping were conducted in the 2012-2013 period. A monitoring programme was implemented, and several water level data loggers were installed on a selected group of boreholes. No additional field work was conducted after 2014 in the SD1 and SD2 Areas, however, the water level-temperature dataloggers that were installed during 2013, logged at an interval of 2-hours until the data was downloaded the first time in 2019 (October). Unfortunately, a few of these dataloggers were stolen from the boreholes in the Glen Haven area, SD2 Area.

During October 2019, the hydrocensus survey's objective was to update the water level dataset, therefore, included water level measurements in most of the SD1 and SD2 Area's exploration boreholes – no private boreholes were visited during this survey.

5.1 Results of the 2019 Hydrocensus Survey

The hydrocensus survey's objective was to revisit the exploration borehole sites and conduct water level measurements in the SD1 and SD2 Area. In addition, a field investigation in the SD2 Area was conducted to verify fountains and boreholes on the farm Vinci (Mr. Theo Coetzee) where occasional artesian conditions have been reported since 1972. There seems to be a groundwater barrier (dyke) intersection on the farm.

To correlate the 2013-2019 water level dataset with rainfall depths, updated rainfall-depth measurements from three rainfall station in the SD1 and SD2 Areas were obtained from SAWS. Five (5) SAWS Stations in the SD1 and SD2 Areas were obtained and used as the baseline groundwater recharge input for the 2019 Update of SD1 and SD2 Areas Numerical Models.

5.1.1 Update of groundwater level trends from 2013 to 2019

Given the extended drought cycle noted in the SD1 and SD2 Areas during the said period, the aquifer saturation level trend provides an indicator of how the water source system would operate during a "drought-cycle" stress period. The water level time series data is listed in Appendix X. The median water level differences between the 2014 and 2019 measurements are -1.34 m and -2.74 m in the SD1 and SD2 Areas respectively. The aquifer saturation levels over the 2013/14-2019 period was, therefore, in a recession mode – as noted in the time series water level plots as well.

The 2013-2019 groundwater level trends illustrate in the following figures:

- Figure 105: (monitoring site SD1-05) – this time series water level-temperature and annual cumulative rainfall graph is from SD1 Area and shows that rainfall events between February and April 2014 and January and April 2017 generated aquifer storage recharge – the 2017 season's rainfall input created the largest water rebound of ~3.5 m. In dolomite aquifer storage terms, this can be regarded as a significant recharge. Rainfall inputs for the other wet seasons did not generate sufficient recharge to override the background natural discharges from the aquifer system [due to surface water support, abstractions and to a lesser degree, evapotranspiration (E_T)]. This monitoring site is located in the northern part of the SD1 Area and represents a typical karstic aquifer condition with regional recharge directed to this area.
- Figure 106: (monitoring site SD2-02) – this time series water level-temperature and annual cumulative rainfall graph is from SD2 Area. This monitoring site is located in the southern part of the SD2 Area (Groenwaterspruit drainage valley) and is affected by aquifer losses across the southern boundary. The time series graph shows that only the January to April 2017 has resulted in a reverse of the long-term

water level recession trend – thus indicating that the aquifer storage has occurred only 1 out of 4 seasons as result of the prevailing drought conditions since the 2009-2010 period in the region. The effect of the poor rainfall depths in the area is clearly illustrated in the 2013-2019 time series dataset – showing a water level recession of ~3.5 m. As discussed above, this recession is related to local abstractions, evapotranspiration (E_T) and natural leakages (i.e. discharge from the larger aquifer system) bypassing the southern boundary system.

- Figure 107: (monitoring site SD2-31) – this time series water level-temperature and annual cumulative rainfall graph is from the upper northern part of the SD2 Area and is close, or directly centred in the recharge area. The water table rebound (viz. ~2.6 m) due to significant aquifer recharge in the SD2 Area was during January to April 2017; although some small responses are noted throughout the 2013-2019 period. The background recession in the SD2 Area during the 2013-2019 period was in the order of 0.8 mm/d due to local groundwater use, evapotranspiration (E_T) and natural leakages from the aquifer system.

In closing, the long-term water level gradient, which is an indication of the aquifer storage potential, in the SD1 and SD2 Areas has dropped during the 2013-2019 period. The period, however, covers a large portion of an almost decade (2009-2010 to 2018-2019 hydrological cycles) of inconsequential rainfall in the region. The 2016-2017 hydrological cycle has recorded the highest rainfall, i.e. ~470 mm – of which 375 mm occurred from December 2016 to end-February 2017 (for the Postmasburg and Daniëlskuil SAWS Stations). The rainfall depths for the remaining months over the 2013-2019 period are low to insignificant, i.e. <50 mm/m which does not generate groundwater recharge, and fails balance to groundwater use, evapotranspiration (E_T) and natural discharges.

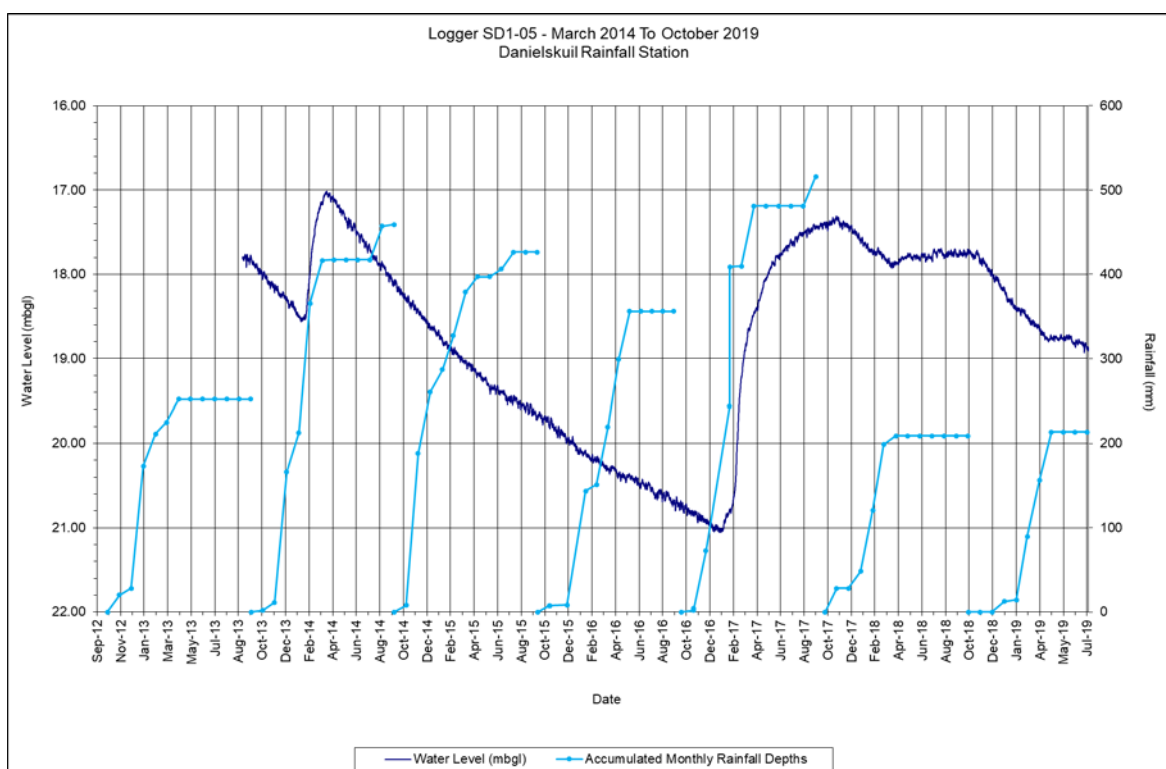


Figure 105: SD1 Area cumulative monthly rainfall depths and borehole water level time series graph 0 SD1-05

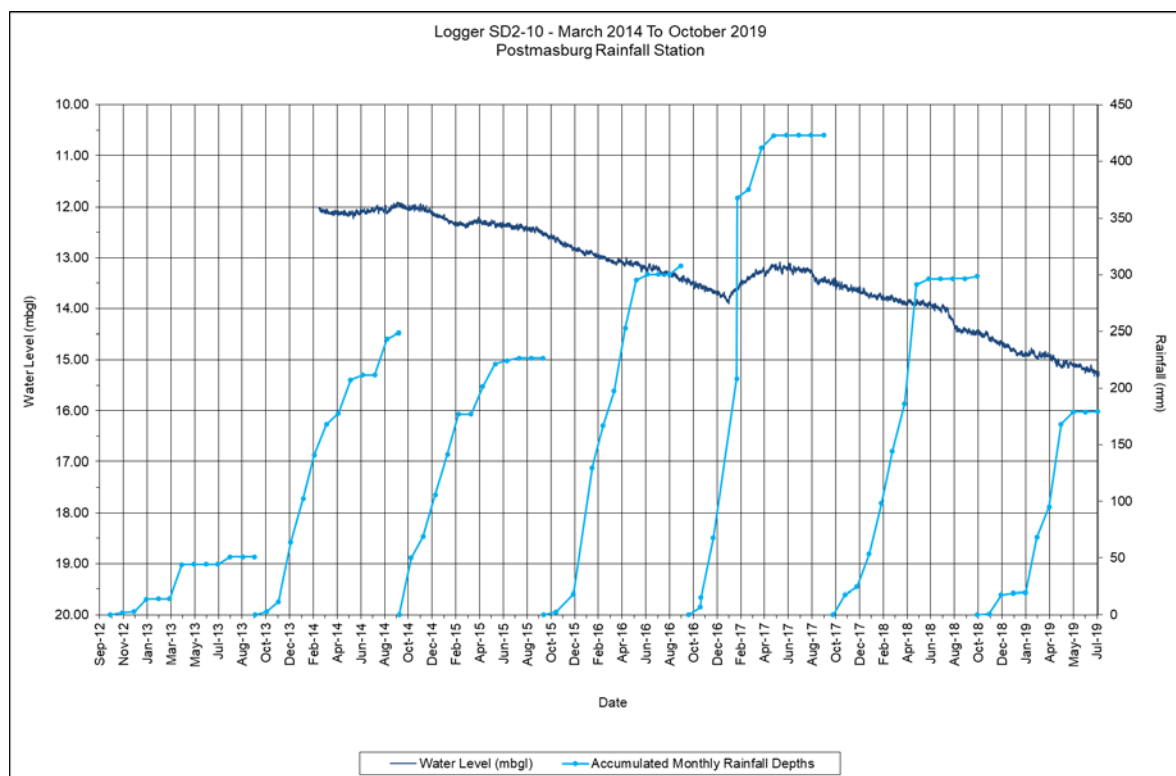


Figure 106: SD2 Area cumulative monthly rainfall depths and borehole water level time series graph - SD2-10

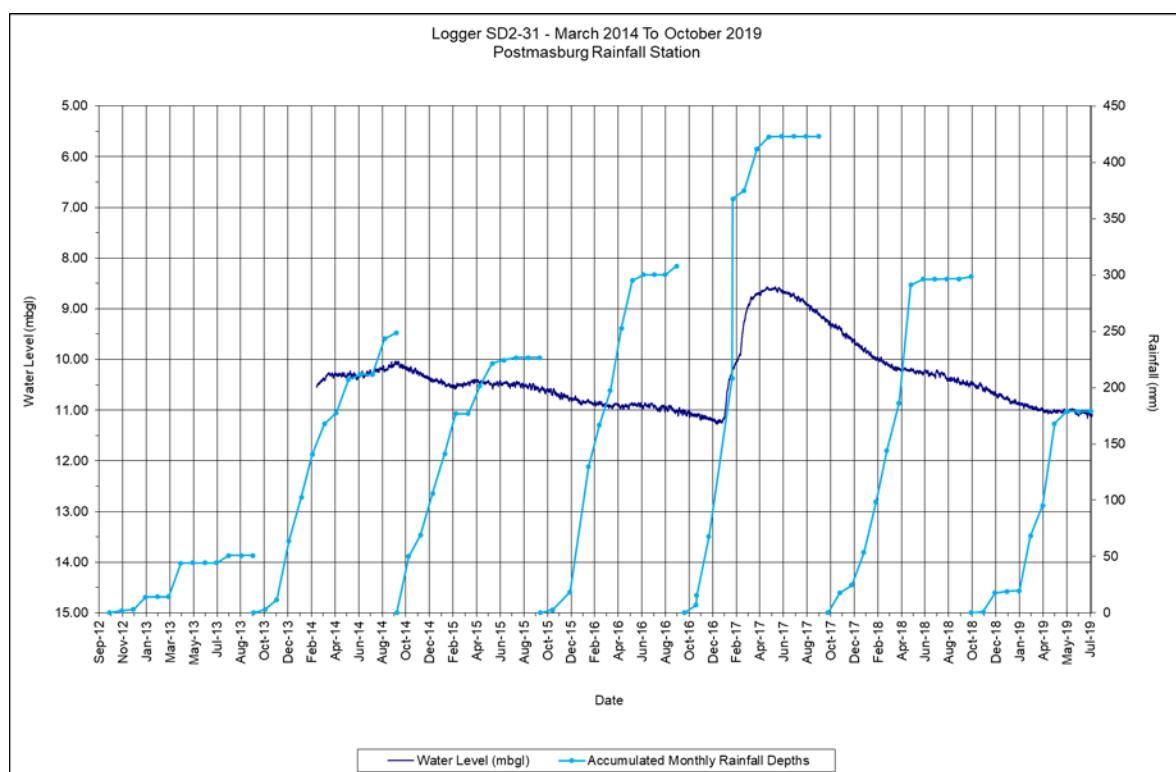


Figure 107: SD2 Area cumulative monthly rainfall depths and borehole water level time series graph - SD2-31

6.0 2019 UPDATE OF SD1 AND SD2 NUMERICAL MODELS

The model scenario completed in 2014 will be updated with the last 5 years of rainfall figures for the Danielskuil and Mount Carmel rainfall stations as well as the available water level (logger) monitoring data for this period. The 2014 measured water levels for the wellfield area were augmented with the 2019 hydrocensus survey data. The updated calibrated groundwater flow model will be used to ascertain the groundwater impacts from the wellfield abstraction.

6.1 Scope of Work

The scope of work can be summarised as follows:

- Data retrieval for model input files (Hydrocensus and Rainfall) data.
 - Update of production borehole abstraction rates for simulation
- Re-calibration and update of model
 - Steady state calibration (2019) and transient verification run (2014 to 2019)
- Predictive scenarios
 - Based on extrapolated rainfall up to 2043
 - Provide simulated water balance
 - Provide drawdown behaviour over time of production boreholes (and selected monitoring boreholes)
 - Map indicating extent of dewatering (2 m intervals)
 - Map indicating predicted water level depths vs. base case (2014)
 - Drawdowns at 3rd party boreholes in proximity (< 2 km) to the wellfield.
 - Drawdown graphs over time 2019 to 2043 compared to base case (2014)

6.2 Rainfall

The South African Weather Services (SAWS) active weather stations namely, Danielskuil, Mount Carmel and Postmasburg were collated and analysed for the model update. Data was also collated from Finch and Sishen mines. A comparison of the Cumulative Rainfall Departure (CRD) for the five rainfall stations since 1960 to 2020 is provided in Figure 108. The basic CRD method is often used to determine aquifer response to rainfall events. The basic CRD formula is:

$$CRD_i = CRD_{i-1} + Rf - ARf$$

Where ARf = average rainfall.

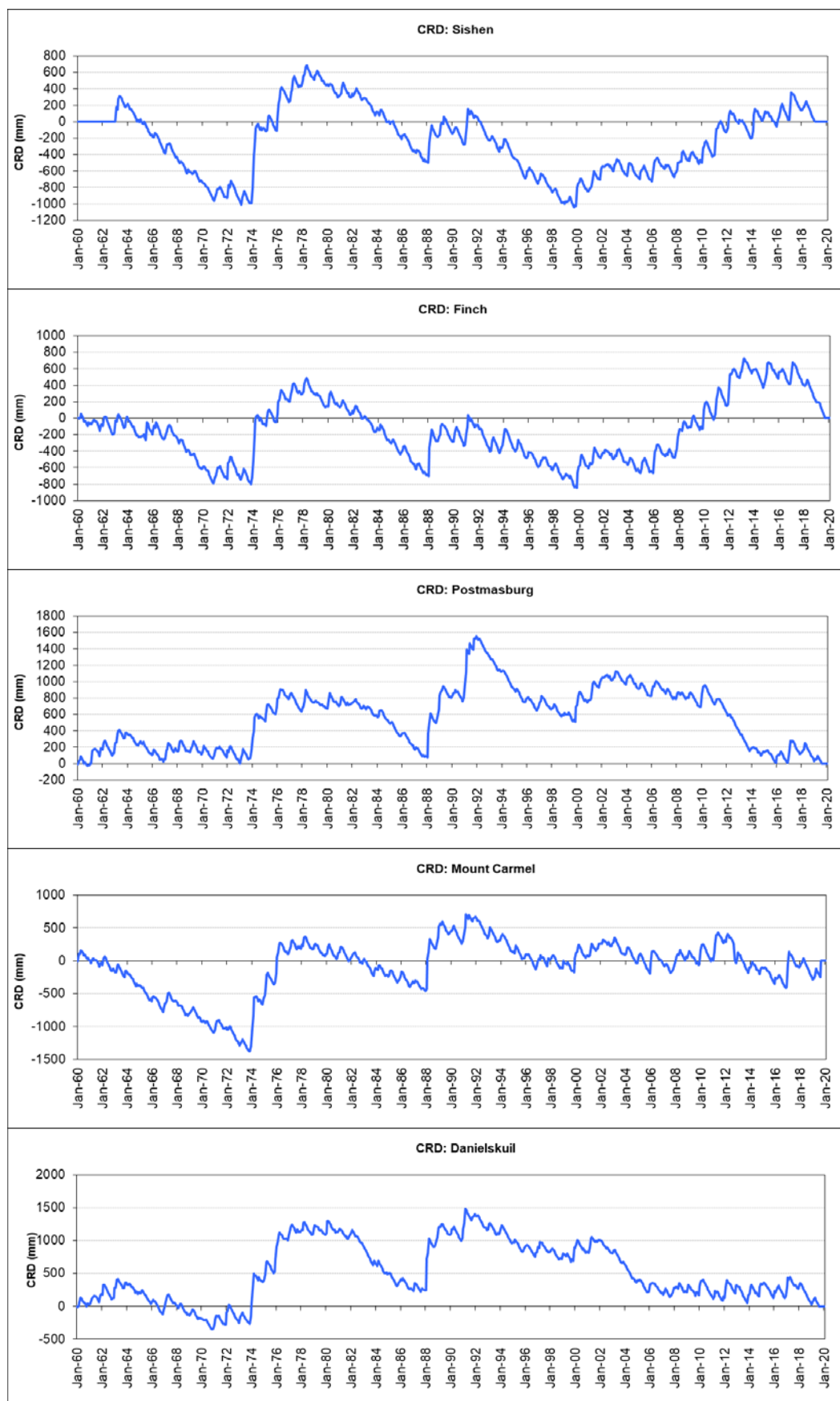


Figure 108: Rainfall CRD curves 1960 to 2020

6.3 SD1 Model Update

The total model domain covers an area of 1 826 km² and was spatially discretised into 111 512 nodes on 5 node layers, which make up 4 element layers with 121 468 elements (triangles and quadrangles) per layer, to account for the various hydrogeological units underlying the proposed well fields. The model boundaries were chosen along mapped dikes, often coinciding with the quaternary catchment (C92A) boundaries, to ensure a dependable water balance for the model with recharge being the main driver of groundwater flow. A number of head dependant boundary conditions were assigned mainly along the eastern and southern edge of the model domain representing potential groundwater outflow towards adjacent aquifer systems (Figure 109).

The upper layer (split into two model layers to increase the accuracy of the unsaturated flow calculations) represent the highly weathered- and karst aquifer to a depth of 4 m below the interpolated groundwater level. The third layer represents the highly karstified hydrogeological unit to a depth of 15 m below the interpolated groundwater level. The bottom elevation of the groundwater flow system was set at approximately 90 m below the current groundwater level, resulting in a model thickness ranging from 92 to 370 m.

For the model update no changes was made to the physical geometry of the model domain developed in 2014.

6.3.1 Sources and Sinks SD1

6.3.1.1 Rainfall Recharge SD1

Based on a brief overview of all rainfall stations the most relevant to the SD1 modelling area is Danielskuil and Mount Carmel. The annual precipitation statistics for the two-rainfall stations is shown in Table 51. The retrieved monthly rainfall data for the two stations together with the Cumulative Rainfall Departure (CRD) since 1995 is shown in Figure 110. Although Mount Carmel shows a slightly higher Mean Annual Rainfall (MAR) compared to Danielskuil, it's the response and rainfall pattern that's uniquely different between the two weather stations.

The distribution of rainfall and recharge mechanism is the main driver of water level responses and is clearly illustrated in Figure 110, which indicate the relationship between rainfall and groundwater fluctuations. Due to the levelling of the CRD curve of the Danielskuil weather station it's seems not to represent the general response of the water level from rainfall. Mount Carmel's rainfall data shows a better correlation with the observed water level fluctuations (Figure 111).

Table 51: SD1 Rainfall data summarised since 1952

Station	Average (mm/a)	Minimum (mm/a)	Maximum (mm/a)
Danielskuil	389	87	1192
Mount Carmel	429	100	1253

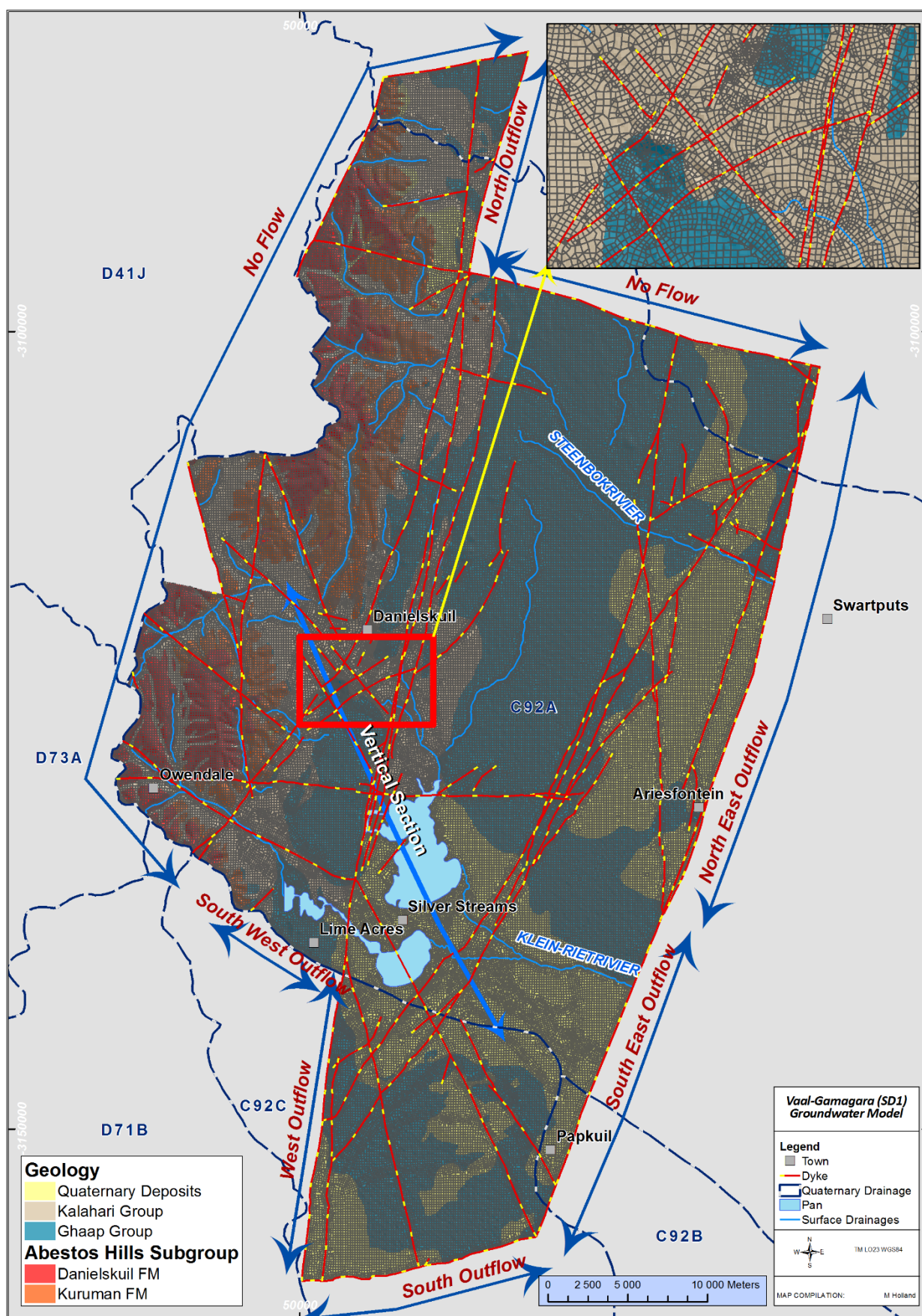


Figure 109: SD1 Regional surface geology and model boundary

The spatial distribution of the recharge rates used in the model together with the location of rainfall station is shown in Figure 112. Groundwater enters the model domains as direct recharge from rainfall. It was implied that certain areas may have greater recharge potential and may thus contribute a larger proportion of recharge towards the aquifer systems respectively. Based on the conceptual understanding of the SD1 groundwater system, the average annual recharge values range between 3.5 and 15 mm.

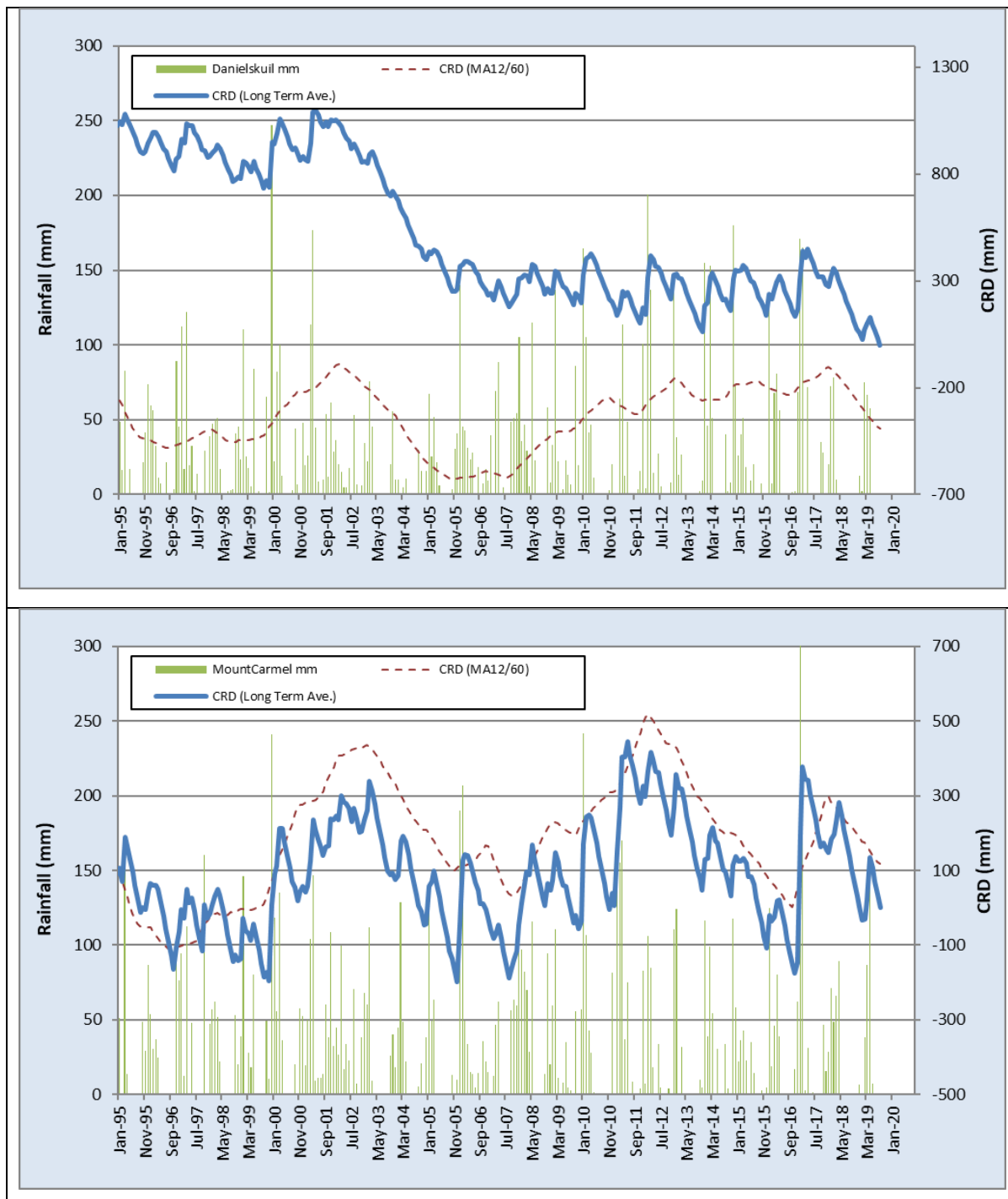


Figure 110: SD1 Monthly rainfall data vs. CRD (long term average)

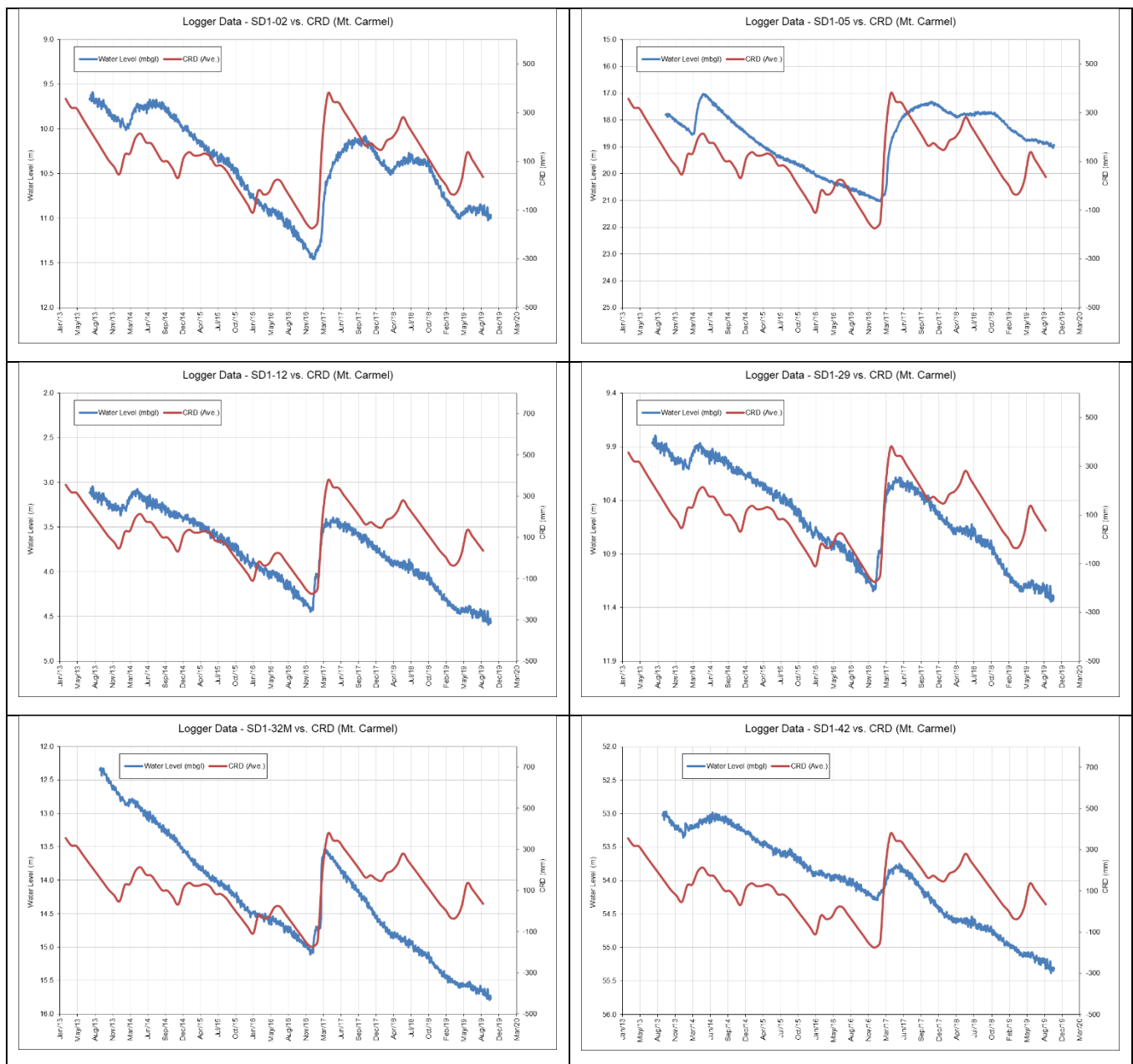


Figure 111: SD1 CRD (long term average) vs. monitoring water level (logger) data

6.3.1.2 Groundwater Abstractions SD1

The steady state and transient borehole abstraction from the modelled domain were simulated using the withdrawal well boundary condition. Outflow rates were assigned to single nodes (at the appropriate elevation) within the model mesh. For fully penetrating wells, equal heads are prescribed for all applicable well nodes and the inflows for each node automatically calculated by the software. The existing monthly abstraction rate for the model area was based on the 2014 hydrocensus. The distribution of the borehole is shown in Figure 112. The current abstraction for the model domain amount to 240,969 m³/month.

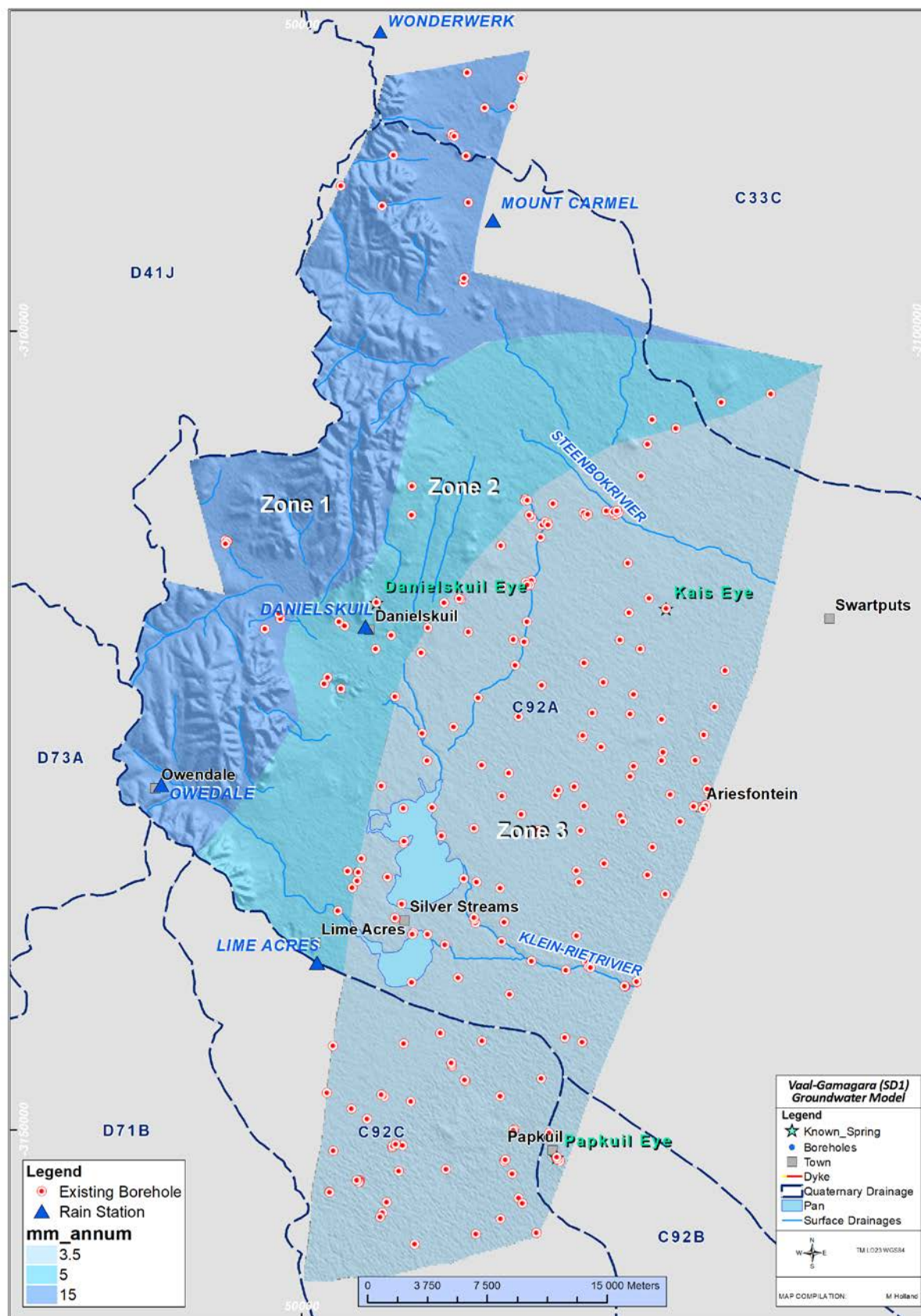


Figure 112: SD1 Recharge distribution areas and existing groundwater users

6.3.2 Calibration (2019) SD1

The water level calibration list compiled in 2014 was updated with the recent hydrocensus (2019) data as well as the retrieved logger information data. A good statistical correlation coefficient R^2 between modelled and observed values of essentially 90 % with no obvious bias of modelled heads was achieved for the steady-state calibration (Figure 113).

The root mean-square error (RMSE) and the normalised root mean square error (NRMSE) were used as quantitative indicators for the adequacy of the fit between the 32 ($=n$) observed (h_{obs}) and simulated (h_{sim}) water levels. The achieved root mean-square error of RMSE = **2.7** and normalised root mean square error of NRMSE = **5.9 %** for the steady-state calibration of the groundwater flow model are more than adequate for the purpose of the study, i.e. to inform the (hydraulic) basis for the SD1 model update.

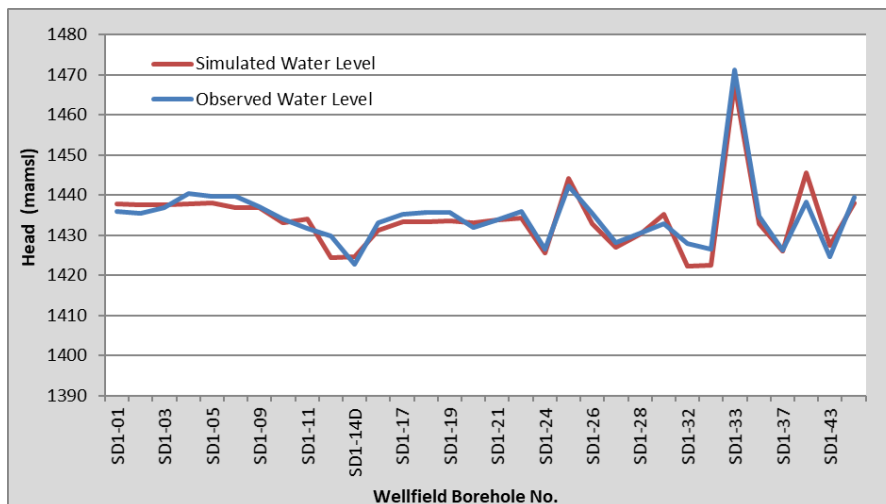
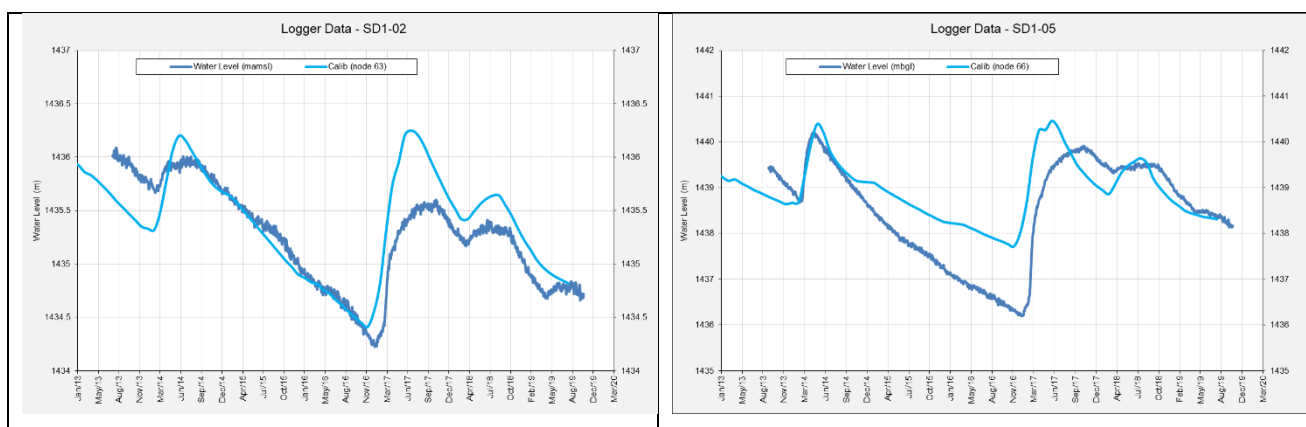


Figure 113: Steady state calibration of the SD1 groundwater model update

6.3.2.1 Transient forward run (2014 to 2019) SD1

For the transient verification calibration, the variable rainfall/recharge were updated with the retrieved rainfall datasets described in section 6.2. The transient calibration of monitoring water levels (loggers) refines and verifies the steady-state calibration by matching transient hydraulic-head trends which reflect the fluctuations due to recharge. An acceptable fit is observed and is shown in Figure 114. The spatial distribution of the calibrated conductivity values for layer I is shown in Figure 116.



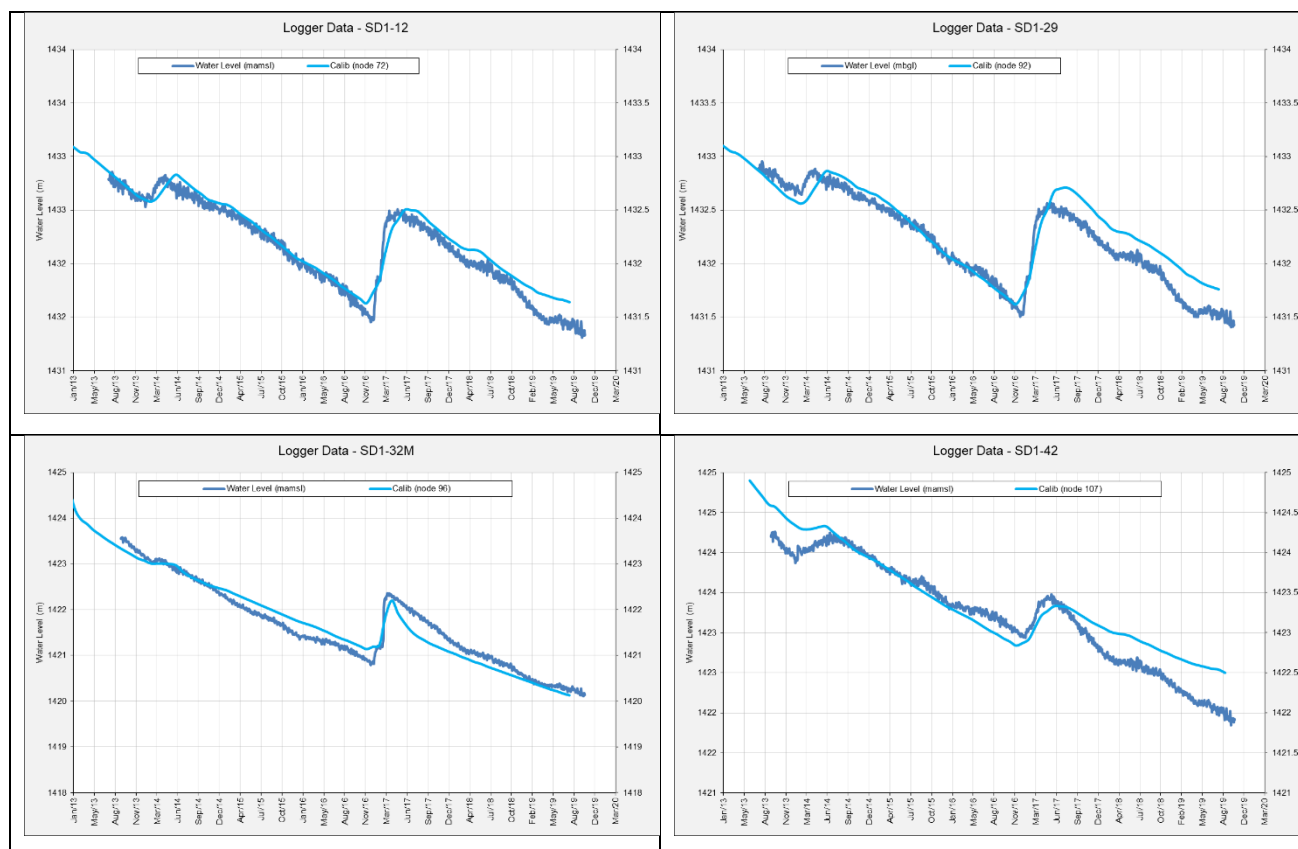


Figure 114: SD1 Transient model calibration using normalized (to initial static) drawdown (monitoring loggers)

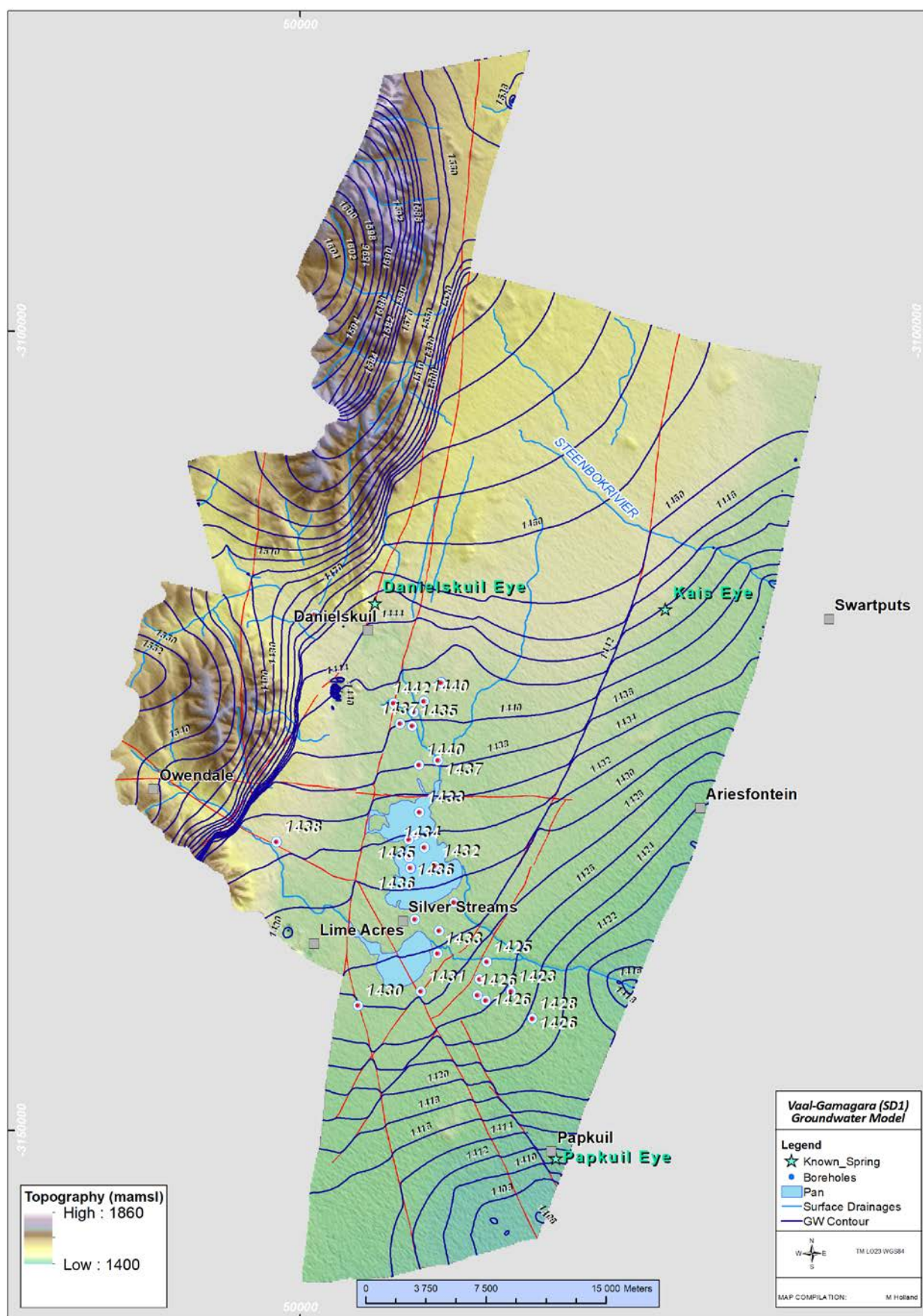


Figure 115: SD1 Simulated potentiometric heads (2019) (pre-wellfield)

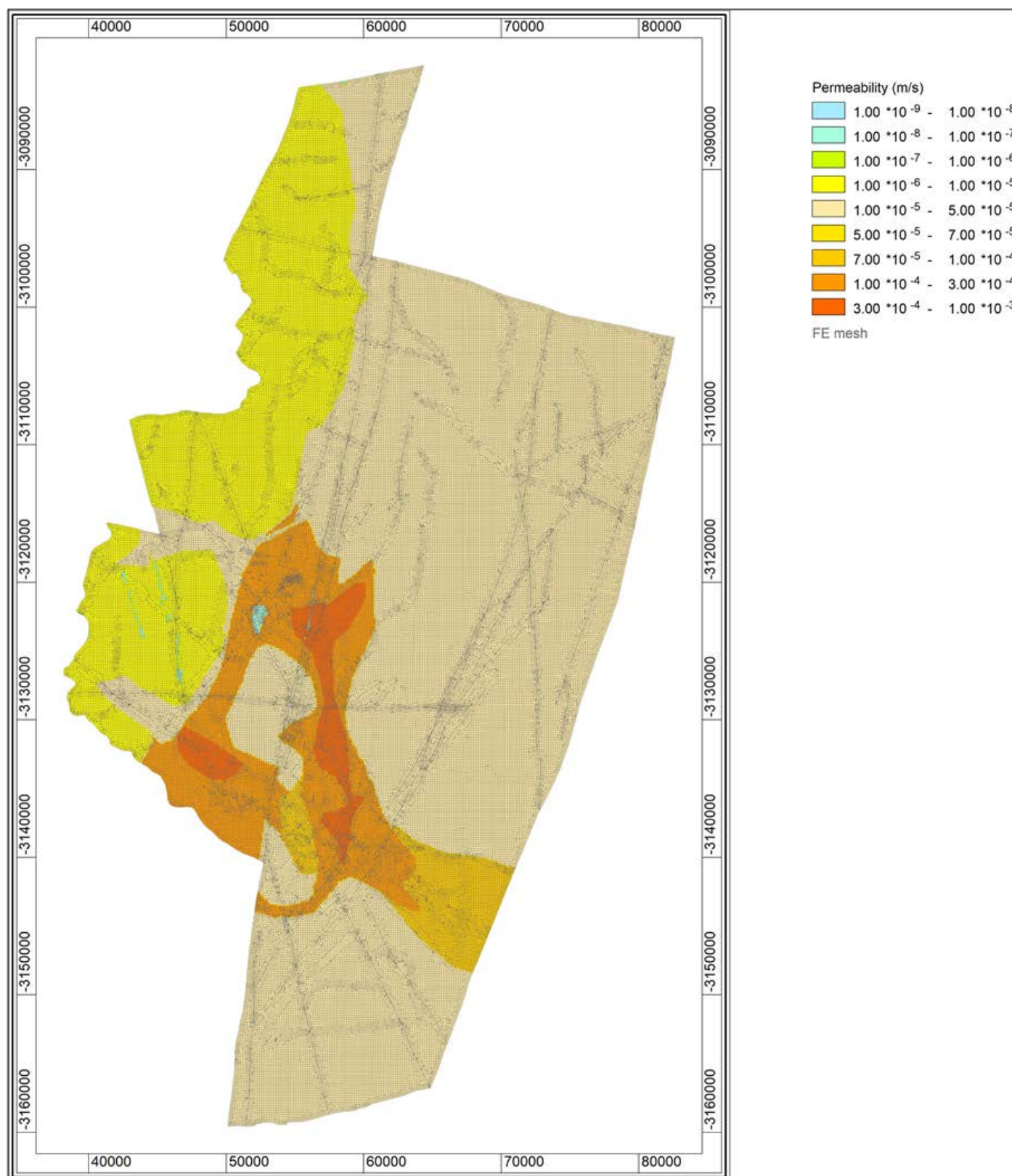


Figure 116: SD1 Distribution of calibrated permeabilities

6.3.3 Model Results (Predictive Simulations) SD1

6.3.3.1 Transient Recharge (Forward Simulation) SD1

The predicted rainfall was based on the observed period between 1993 and 2016. The simulated recharge for the forward prediction is shown in (Figure 117) resulting in 288 monthly time steps with variable monthly rainfall.

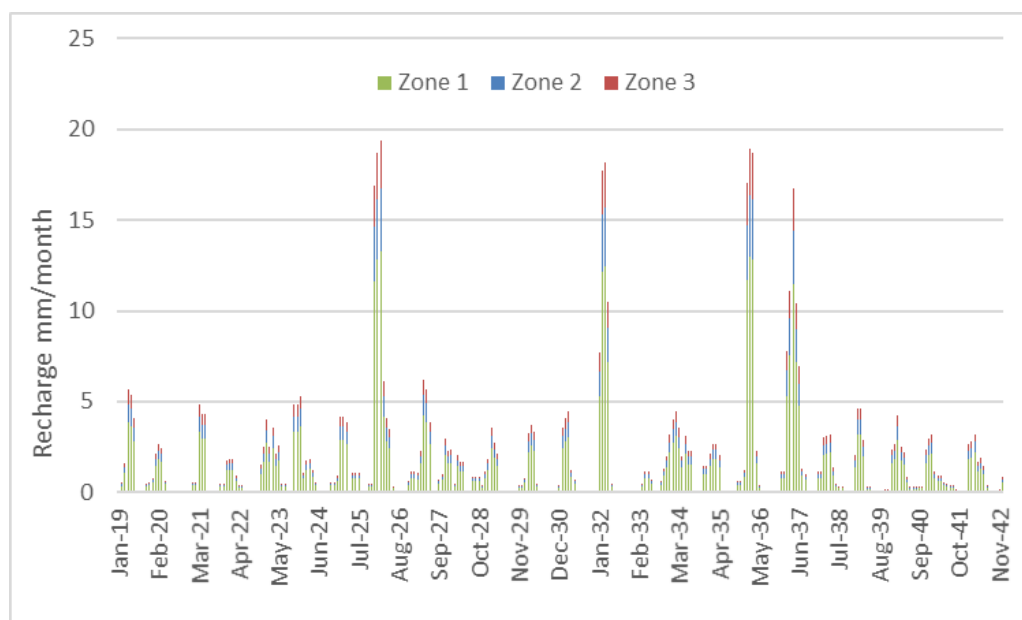


Figure 117: SD1 Monthly rainfall from 1999 to 2019 used for the transient model calibration

6.3.3.2 Abstraction (Forward Simulation) SD1

The forward simulations of the SD1 Well field considered the initially proposed 2014 scenario 2B abstraction volumes. After several un-reported iterative model runs and consideration of the dolomite hazard map (Figure 99), abstraction rates was adapted (reduced) for selected boreholes. The volumes of the SD1 modelled abstraction scenarios are shown in Table 52. In summary, the results present the 2014 abstraction scenario of 444,132 m³/month versus the mitigated proposed abstraction scenario of 347,772 m³/month.

The simulated impacts of the groundwater abstraction from the SD1 well field on the regional groundwater levels are shown in Figure 118 and Figure 119 as contour maps of drawdown by comparing the water levels simulated for the last stress period of the base case (no well field abstractions) (2044) simulation against the lowered water levels due to abstraction from the SD1 well field (2044). No drawdown values below 2 meters are visualised to account for the inaccuracy in the model calibration, which is within the expected seasonal variability of water table elevations. It is likely that any drawdown below 2 meters is within the range of natural water table fluctuations and therefore any potentially affected groundwater dependent ecosystem therefore adapted to it. Similarly, potential groundwater users are unlikely to recognise such drawdown as borehole yields are typically not significantly impacted by such seasonal fluctuations. For the mitigated scenario the cone of dewatering extent is expectedly less than the 2014 scenario and extends approximately 30 km north to south along the well fields and up to 20 km east to west (considering a 2 m cut-off value).

A comparison of the two abstraction scenarios simulated drawdown behaviour for each production borehole is shown in Appendix J. Average drawdown from production boreholes for the simulation period is around 8.1 m compared to 5.8 for the 2014 scenario and 2019 mitigated scenario respectively (Table 52).

Table 52. SD1 Abstraction rates for the 2014 forward scenario as well as the mitigated (2019) scenario.

Wellfield No.	BH no.	2014 Sc. 2b m ³ /month	2019 Mitigated m ³ /month	Final DD 2014 Sc.2b (m)	Final DD 2019 Mitigated (m)	Avail DD to main strike (m)	Main strike/Wad/Cavity
WF1	SD1-04	21 900	21 900	6.78	4.65	6	Strike at 19, Cavity at 18, wad at 20
	SD1-08	43 800	26 280	8.14	5.54	7	Strike at 22 and 27, Wad at 22m
	SD1-09	21 900	21 900	8.13	5.76	5	Strike at 10 to 19m, Cavity at 12to 14m
	SD1-44	52 560	26 280	6.89	4.5	6	Strike at 24m
WF2	SD1-10	32 850	32 850	9.59	6.9	12	Strike at 25m in BIF
	SD1-11	21 900	21 900	9.17	6.3	53	Strike at 67m, cavity at 67m
	SD1-16	10 512	10 512	8.68	6.25	43	Strike at 53m, cavity at 54 to 57m
	SD1-17	19 710	19 710	9.64	6.71	31	Strike at 40 and 52m, wad at 34m
	SD1-19	Do not pump		9	6.12	14	Strike at 17 and 21m
	SD1-20	52 560	26 280	9.88	6.53	25	Strike at 44m, Wad at 28m below BIF
	SD1-21	26 280	26 280	9.3	6.35	70	Strike at 73m, cavity at 99m
	SD1-22	Do not pump		8.86	6.04	35	Strike at 38m, Wad at 38to 49m EOH
	SD1-26	Do not pump		8.84	6.26	45	Strike at 56, Cavity at 56
	SD1-35	52 560	32 850	10.04	6.97	16	Strike at 26m
WF3	SD1-24	32 850	26 280	8.21	6.45	19	Strike at 57m, Cavity at 57m
	SD1-27	Do not pump		7.56	5.64	46	wad at 61m

Wellfield No.	BH no.	2014 Sc. 2b m ³ /month	2019 Mitigated m ³ /month	Final DD 2014 Sc.2b (m)	Final DD 2019 Mitigated (m)	Avail DD to main strike (m)	Main strike/Wad/Cavity
	SD1-32	32 850	32 850	9.12	6.61	57	Strike at 71m
	SD1-43	Do not pump		7.52	5.56	45	Strike at 60m
WF4	SD1-40	Do not pump		5.62	4.53	29	Strike at 60m
	SD1-41	10 950	10 950	5.57	4.49	29	Strike at 73m
	SD1-42	10 950	10 950	5.95	4.87	71	strike at 108m
Total m³/month		444 132	347 772				
Total m³/annum		5 329 584	4 173 264				

The proposed long-term monitoring boreholes is shown spatially in Figure 120. A summary of the predicted drawdown for the 2014 and 2019 for the proposed long-term monitoring boreholes mitigated scenario is shown in Table 53 while the drawdown behaviour over the simulation period is shown in Appendix K.

Table 53. SD1 Predicted drawdown of the proposed long-term monitoring boreholes for the simulation period.

BH no.	Wellfield No.	Final DD 2014 Sc.2b (m)	Final DD 2019 Mitigated (m)
SD1-02	WF 1	6.9	4.7
SD1-05		6.9	4.5
SD1-25		5.47	3.94
SD1-12	WF 2	9.2	6.3
SD1-16S		8.7	6.2
SD1-17M		9.4	6.4
SD1-23		6.94	5.11
SD1-28		7.84	5.67
SD1-29		8.5	5.79
SD1-30		7.72	5.67

BH no.	Wellfield No.	Final DD 2014 Sc.2b (m)	Final DD 2019 Mitigated (m)
SD1-35M		9.53	6.65
SD1-36		9.2	6.49
SD-18		7.09	5.17
SD1-27S	WF 3	7.61	5.67
SD1-32M		7.49	5.59
SD1-32S		8.78	6.4
SD1-40M	WF 4	5.65	4.56
Average DD (in m)		7.8	5.6

6.3.3.2.1 Potential Impact on Existing Groundwater Users SD1

The simulated drawdown extent is shown spatially in Figure 120 together with the production boreholes and existing groundwater users. The drawdown behaviour for the simulation period is shown in Appendix L.

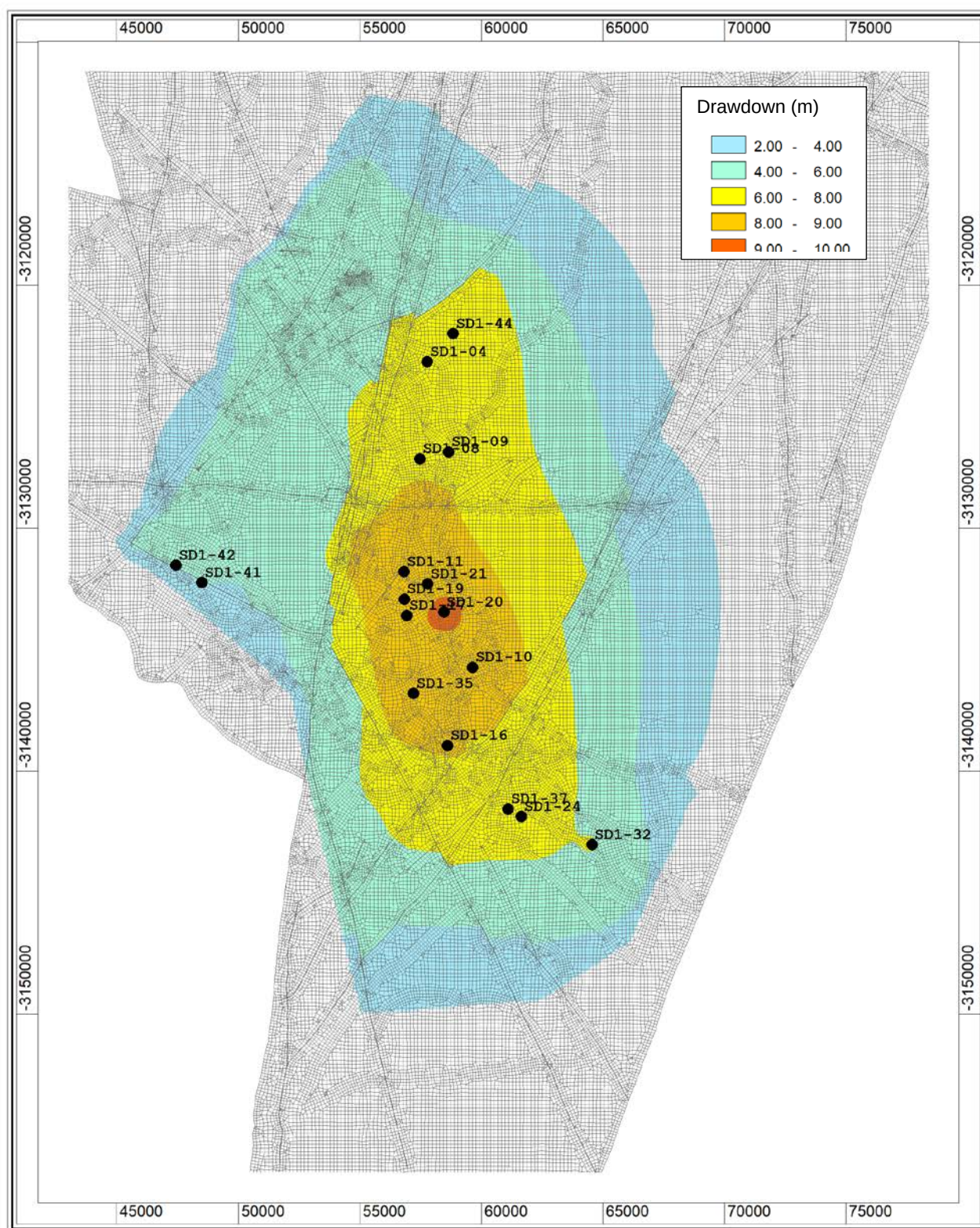


Figure 118: SD1 Drawdown extent [m] due to groundwater abstractions from the SD1 well field, 2014 Scenario 2b

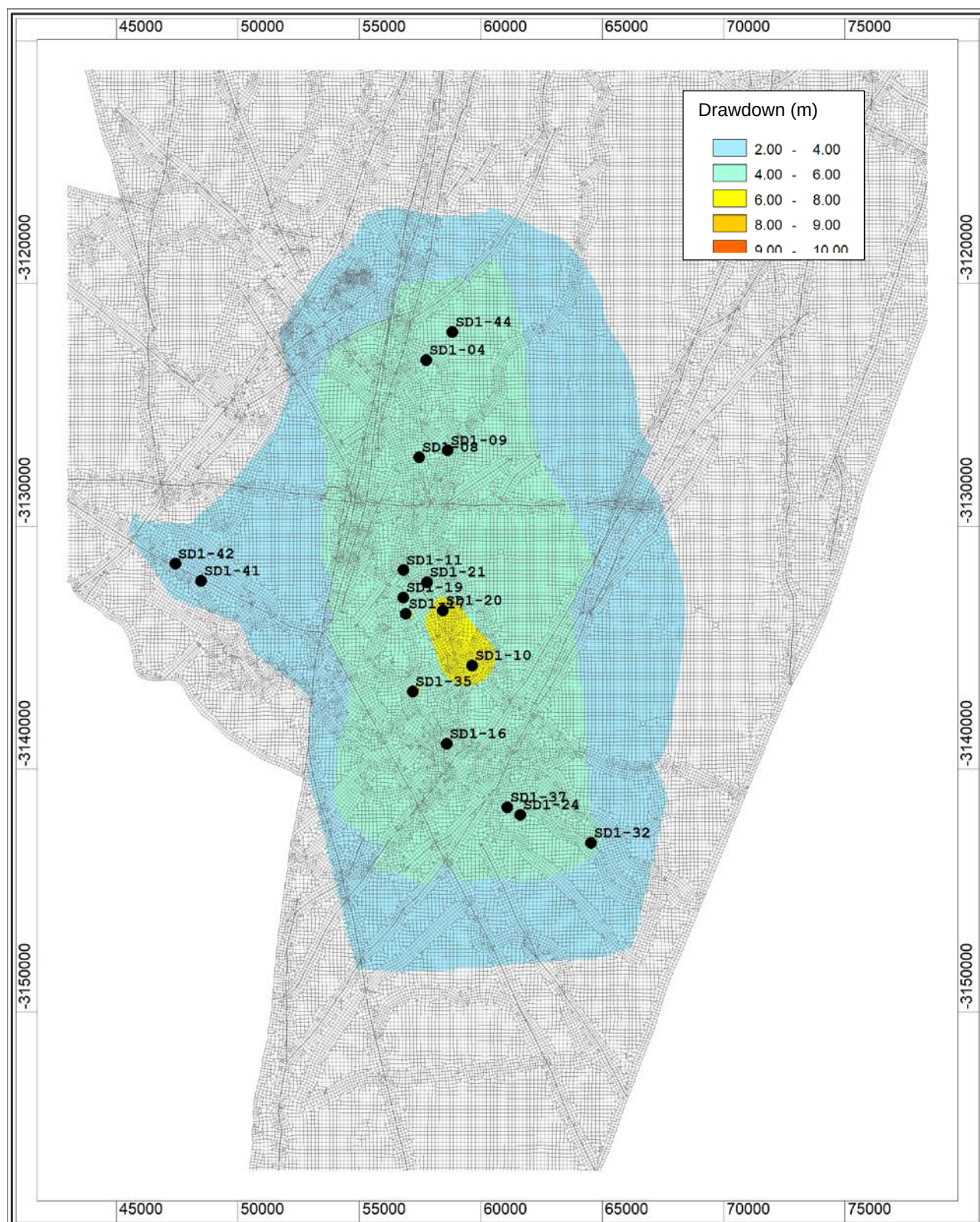


Figure 119: SD1 Drawdown extent [m] due to groundwater abstractions from the SD1 well field, 2019 mitigated scenario

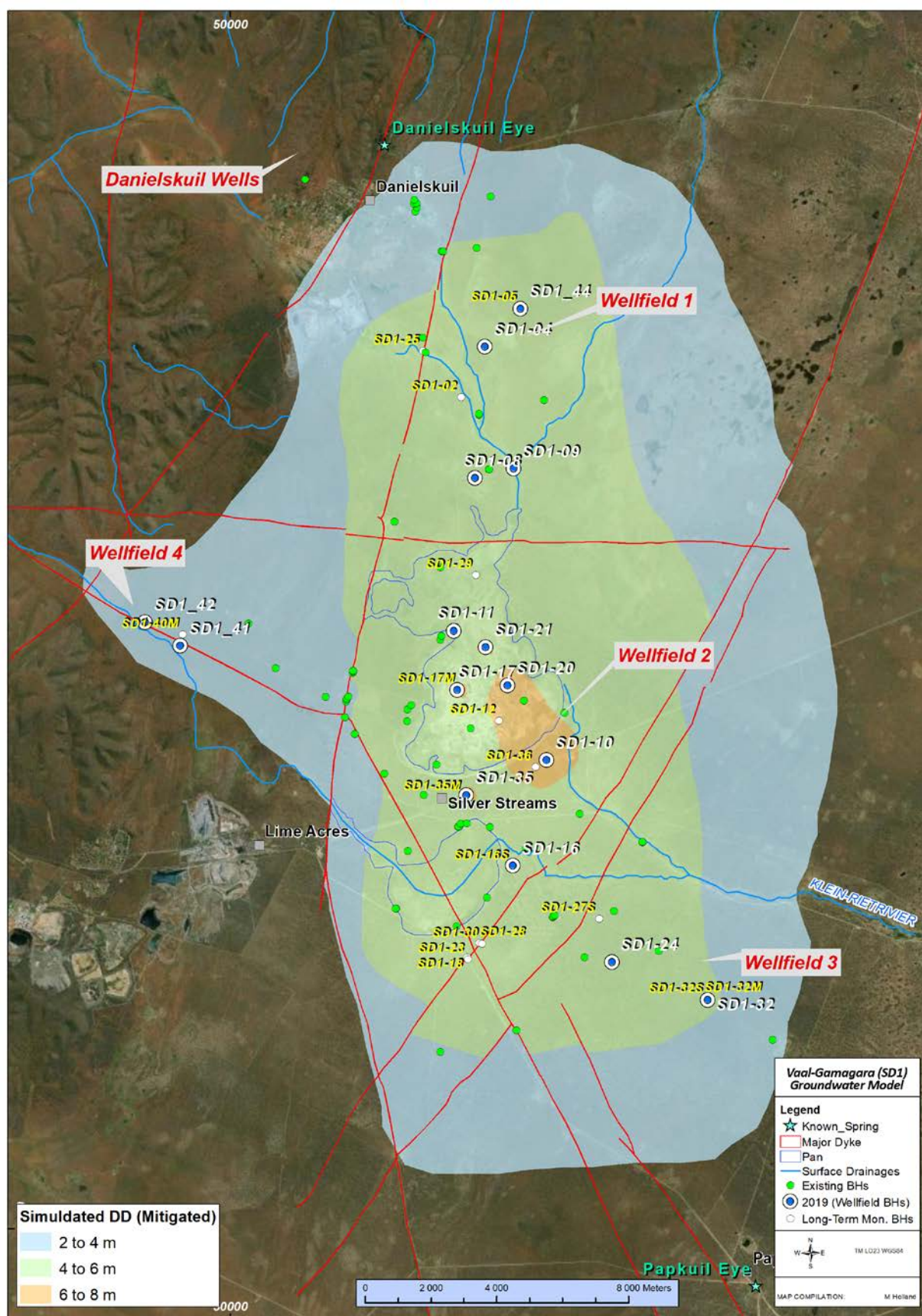


Figure 120: SD1 Production boreholes shown spatially in relation to the drawdown extent and potential existing groundwater users

6.3.3.3 Water Balance SD1

A summary of the water balance for the final transient step for the base case as well as 2014 and 2019 mitigates scenario is shown in Table 54. The abstractions from the SD1 well fields result in a change of storage together with a reduction in flows across the outflow boundaries (to downstream catchments) and groundwater contributions to seepages/springs and drainages. The mitigated abstraction scenario amounts to approximately 50 % of the average recharge of 1,188,352 m³/month.

Table 54. SD1 Simulated water balance (average recharge) (transient state)

Regional Water Balance	Base	2014	Mitigated 2019
Inflow	M3/month		
Recharge	1 188 352	1 188 352	1 188 352
Outflow	M3/month		
Boreholes Abstraction	-240 969	-685 101	-588 741
Contribution to Drainages and potential evapotranspiration	-263 858	-193 131	-202 859
Seepages (shallow) and Springs	-584 866	-366 237	-412 920
Outflow Boundary	-41 579	-36 754	-38 547
Idwala Pit Inflows	-21 356	-8 438	-11 355
Outflow	-1 152 628	-1 289 662	-1 254 422
Change in Storage	-35 723	+101 310	+66 070
Total Outflow	-1 188 352	-1 188 352	-1 188 352

6.3.4 Summary of Model Update SD1

For the model update no changes was made to the physical geometry of the model domain developed in 2014. However, the model was re-calibrated in both steady- and transient state, based on the 2019 hydrocensus and borehole water level logger information from 2014 to 2019 as well as updated rainfall records. The calibrated model was subsequently used to simulate the impacts of the proposed SD1 well fields on the groundwater environment. Model scenarios included a base case (i.e. no wellfield implementation), the 2014 abstraction scenario of 444,132 m³/month and a mitigated (optimised) proposed abstraction scenario of 347,772 m³/month.

Impacts was shown as regional water level drawdown figures and individual borehole drawdowns. For the mitigated scenario, the cone of dewatering extent is expectedly less than the 2014 scenario extend approximately 30 km north to south along the well fields and up to 20 km east to west (considering a 2 m cut-off value). Average drawdown from production boreholes for the simulation period is around 8.1 m compared to 5.8 m for the 2014 scenario and 2019 mitigated scenario, respectively.

Due to the intrinsic heterogeneity of the dolomitic groundwater system the potential impact of the groundwater abstractions on other groundwater users may not be equally distributed (spatially) around the proposed abstraction areas. Further, some surfaces drainages and pans may be perched on a low-permeability

substrate (i.e. the calcrete layer) and may not be in hydraulic continuity with the aquifer beneath and therefore not impacted by a drawdown of the water table.

6.4 SD2 Model Update

The SD2 model domain is situated within the upper Groenwaterspruit catchment, quaternary drainage region D73A within the Lower Vaal Water Management Area (WMA). The total model domain covers an area of 951 km² and was spatially discretised into 127 684 nodes on 9 node layers, which make up 8 element layers with 145 056 elements (triangles and quadrangles) per layer. The model boundaries were chosen along mapped dykes, often coinciding with the upper quaternary catchment (D73A) boundaries, to ensure a dependable water balance for the model with recharge being the main driver of groundwater flow.

Head dependant boundary conditions were assigned along:

- the northern boundary, representing shallow inflows along the non-perennial drainage system towards quaternary catchment D41J and
- the south-western edge of the model domain, representing potential groundwater outflow towards downstream aquifer systems (Figure 121).

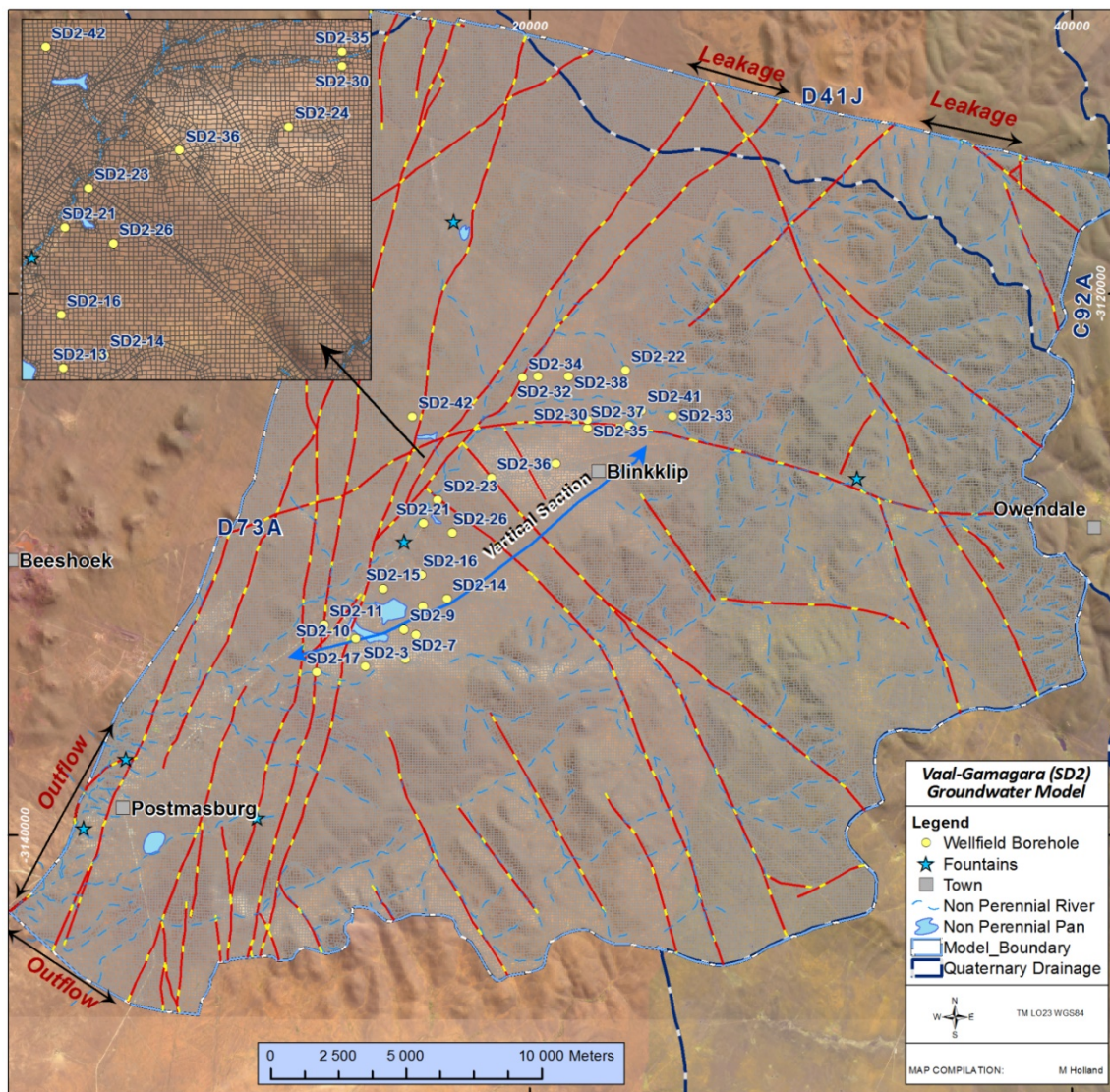


Figure 121: SD2 Regional surface geology and model boundary

The thickness of the Kalahari Group layer (split into four model layers) was based on the isopach's interpolated by Golder. The Banded Ironstone Formation and Ventersdorp lava's, where present in the model domain, were represented as two model layers with an inferred thickness ranging from 15 to 170m. The dolomitic units are discretised into 4 model layers, representing both the highly karstified dolomites as well as the deeper dolomitic bedrock. The bottom elevation of the active groundwater flow system was set at approximately 120 m below the current groundwater level, resulting in a model thickness ranging from 145 to 335 m.

For the model update no changes was made to the physical geometry of the model domain developed in 2014.

6.4.1 Sources and Sinks SD2

6.4.1.1 Rainfall/Recharge SD2

Based on a brief overview of all rainfall stations the most relevant to the SD2 modelling area is Postmasburg and Mount Carmel (further east towards the SD1) area. The annual precipitation statistics for the two-rainfall stations (since 1952) is shown in Table 55. The retrieved monthly rainfall data for the two stations together with the Cumulative Rainfall Departure (CRD) since 1995 is shown in Figure 122. The distribution of rainfall and recharge mechanism is the main driver of water level responses and is clearly illustrated in Figure 122, which indicate the relationship between rainfall and groundwater fluctuations. Both Postmasburg and Mount Carmel's CRD curves data shows similar behaviours over the last decade, while the Postmasburg CRD curve reflects a better response behaviour in comparison to the observed water levels (Figure 123).

Table 55. Rainfall data summarised since 1952

Station	Average (mm/a)	Minimum (mm/a)	Maximum (mm/a)
Postmasburg	335	101	1076
Mount Carmel	429	100	1253

The spatial distribution of the recharge rates used in the model update is shown in Figure 124. Groundwater enters the model domains as direct recharge from rainfall. It was implied that certain areas may have greater recharge potential and may thus contribute a larger proportion of recharge towards the aquifer systems respectively. The recharge zones were updated from the 2014 zones based on the updated rainfall, logger data as well as iterative model runs. The average annual recharge values range between 1 and 15 mm.

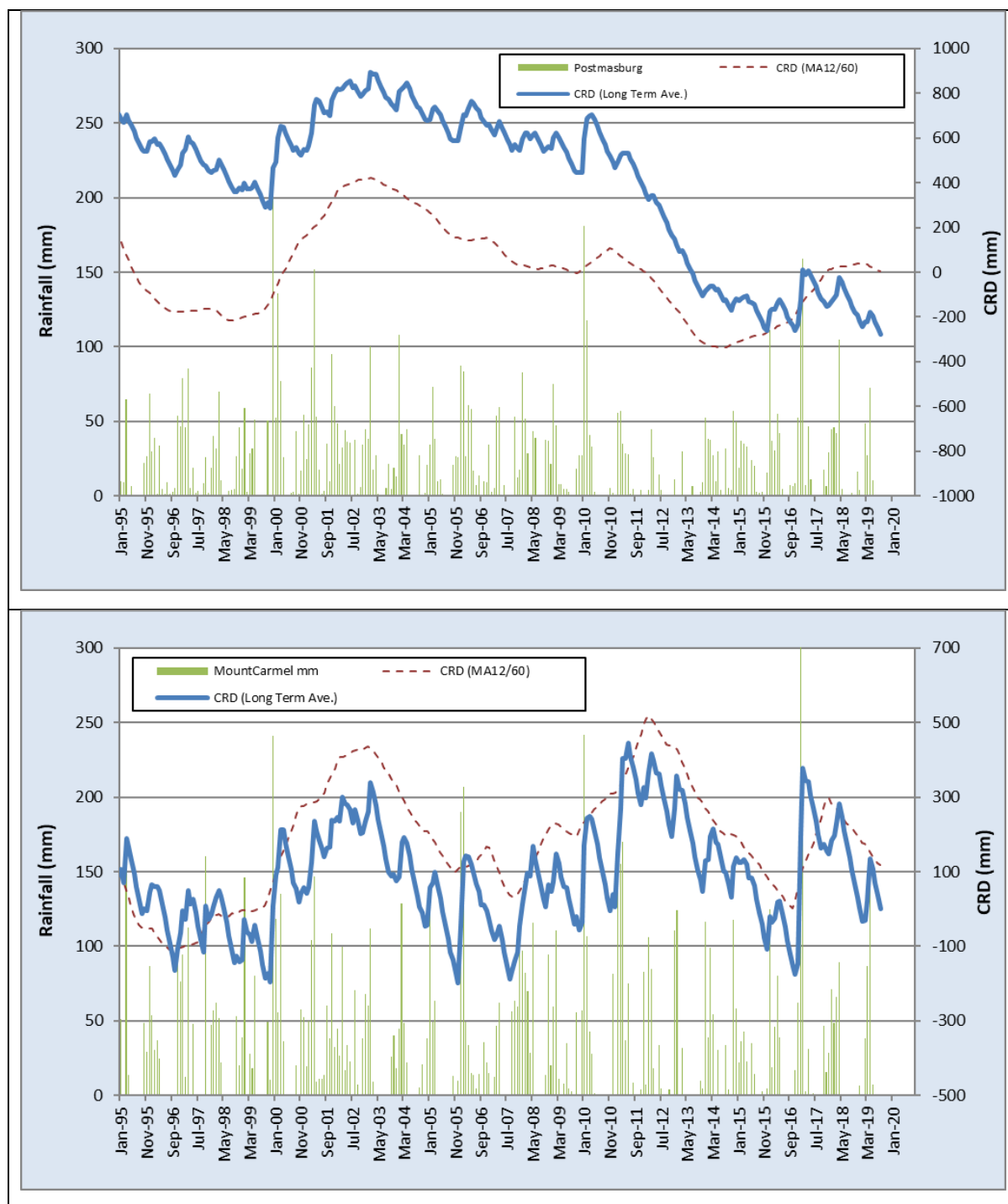


Figure 122: SD2 Monthly rainfall data vs. CRD (long term average)

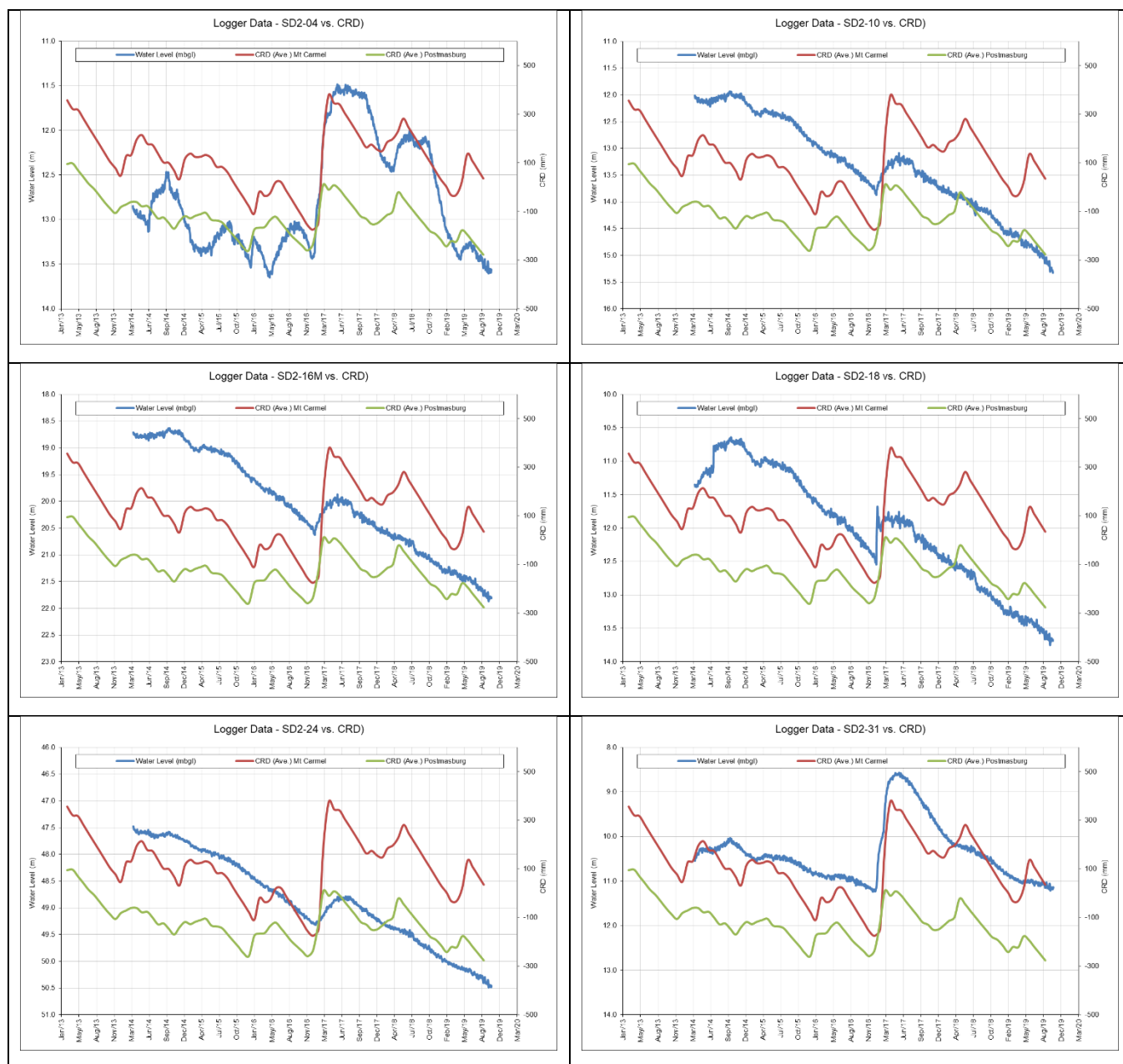


Figure 123: SD2 CRD (long term average) vs. monitoring water level (logger) data

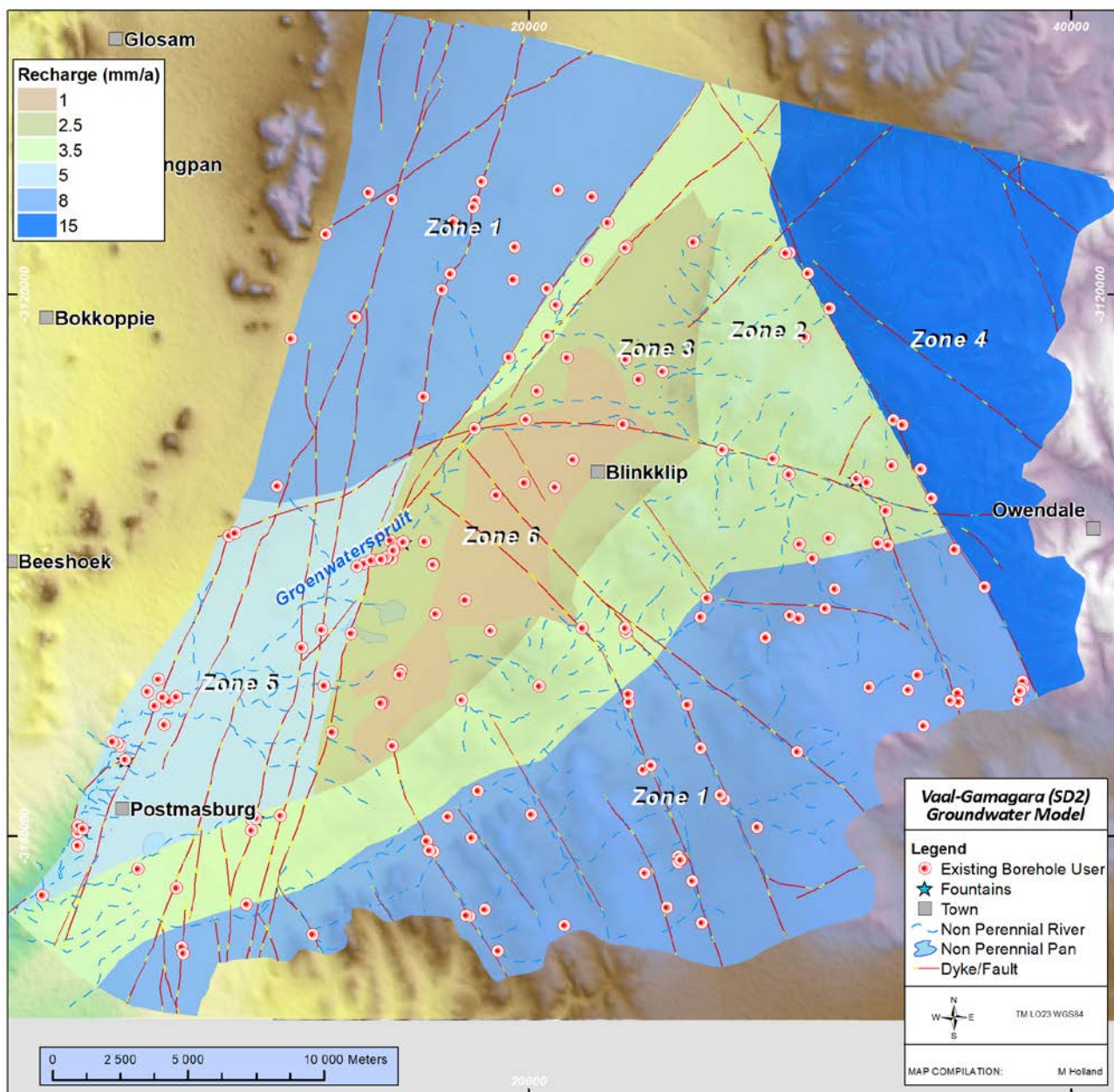


Figure 124: SD2 Recharge distribution areas and existing groundwater users

6.4.1.2 Groundwater Abstractions SD2

The steady state and transient borehole abstraction from the modelled domain were simulated using the withdrawal well boundary condition. Outflow rates were assigned to single nodes (at the appropriate elevation) within the model mesh. For fully penetrating wells, equal heads are prescribed for all applicable well nodes and the inflows for each node automatically calculated by the software. The existing monthly abstraction rate for the model area was based on the 2014 hydrocensus. The distribution of the borehole is shown in Figure 124. The current abstraction for the model domain amount to 124,441 m³/month.

6.4.2 Model Calibration (2019) SD2

The water level calibration list compiled in 2014 was updated with the recent hydrocensus (2019) data as well as the retrieved logger information data. The distribution of the obtained water level points and simulated 2019 pre-wellfield heads is shown in Figure 127, while a complete list of the water levels used is provided [in](#)

Appendix M. A good statistical correlation coefficient R^2 between modelled and observed values of essentially 97 % with no obvious bias of modelled heads was achieved for the steady-state calibration (Figure 125).

The achieved root mean square error of RMSE = **3.0** and normalised root mean square error of NRMSE = **10%** for the steady-state calibration of the groundwater flow model are more than adequate for the purpose of the study, i.e. to inform the (hydraulic) basis for the SD2 model update.

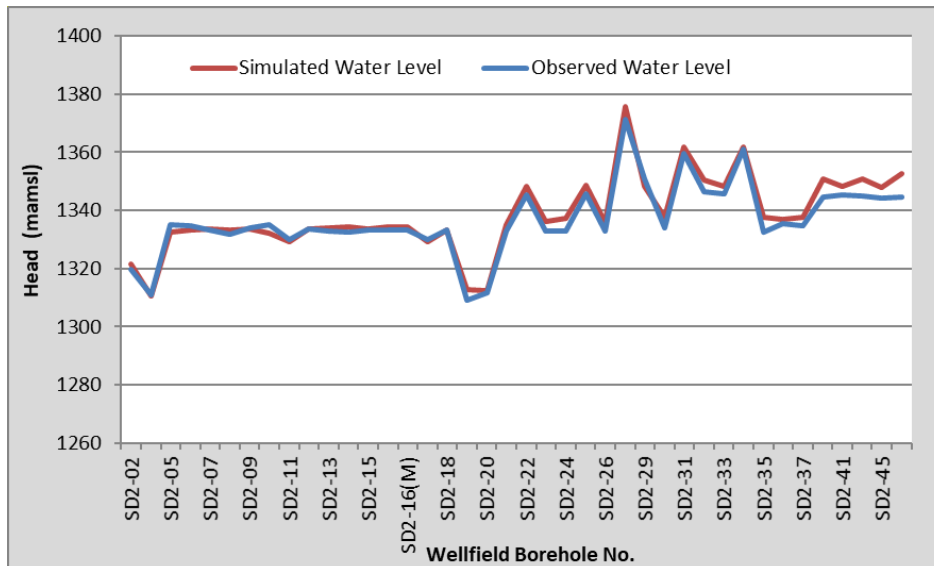
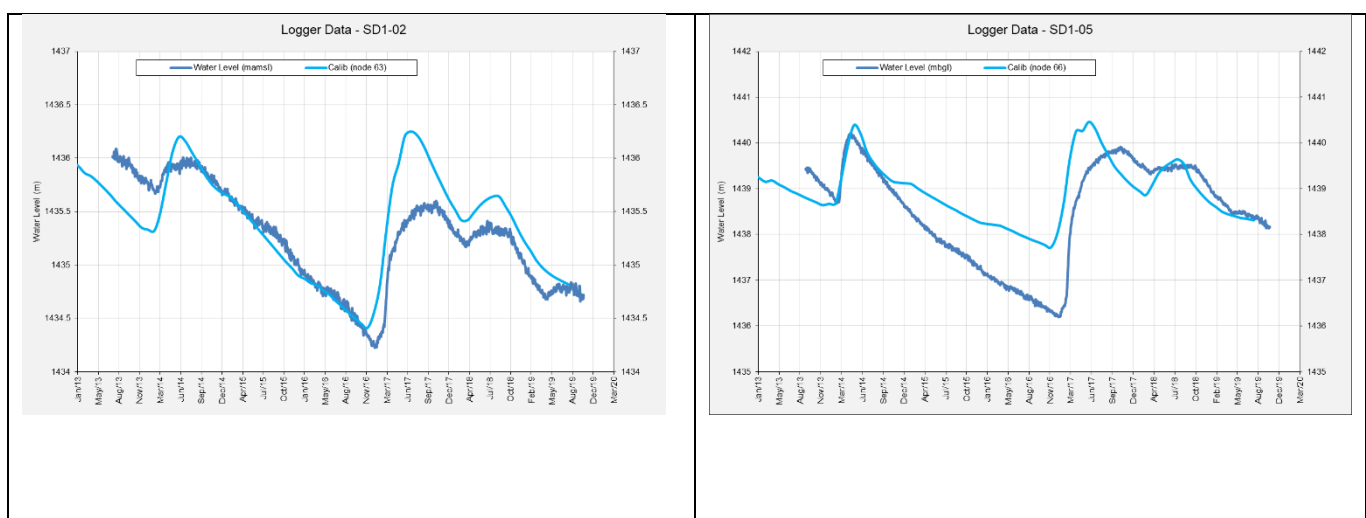


Figure 125: Steady state calibration of the SD2 groundwater model update

6.4.2.1 Transient Forward Run (2014 to 2019) SD2

For the transient verification calibration, the variable rainfall/recharge were updated with the retrieved rainfall datasets described in section 6.2. The transient calibration of monitoring water levels (loggers) refines and verifies the steady-state calibration by matching transient hydraulic-head trends which reflect the fluctuations due to recharge. An acceptable fit is observed and is shown in Figure 126. The updated calibration did not result in significant changes to the 2014 calibrated conductivity values.



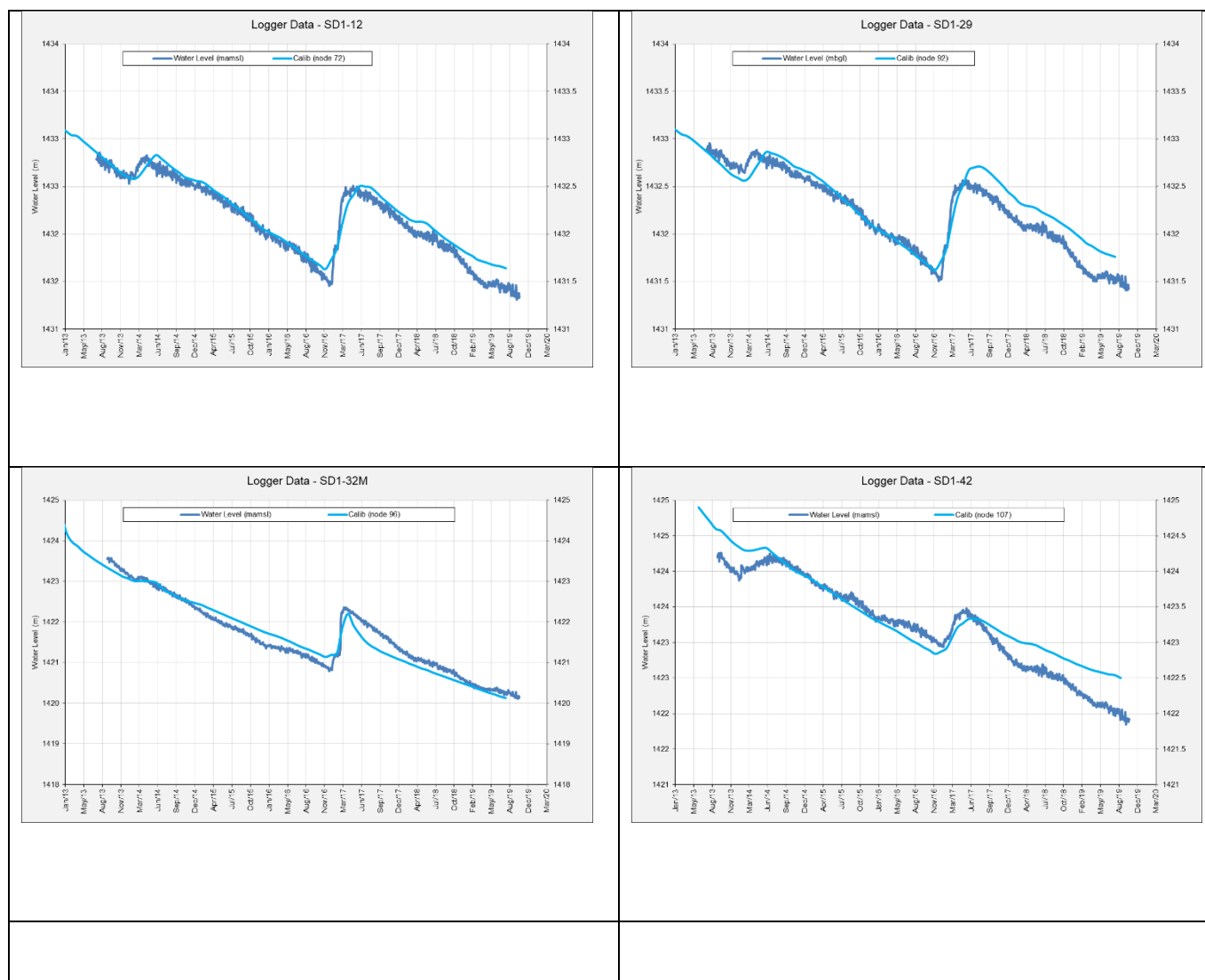


Figure 126: SD2 Transient model calibration using normalized (to initial static) drawdown (monitoring loggers)

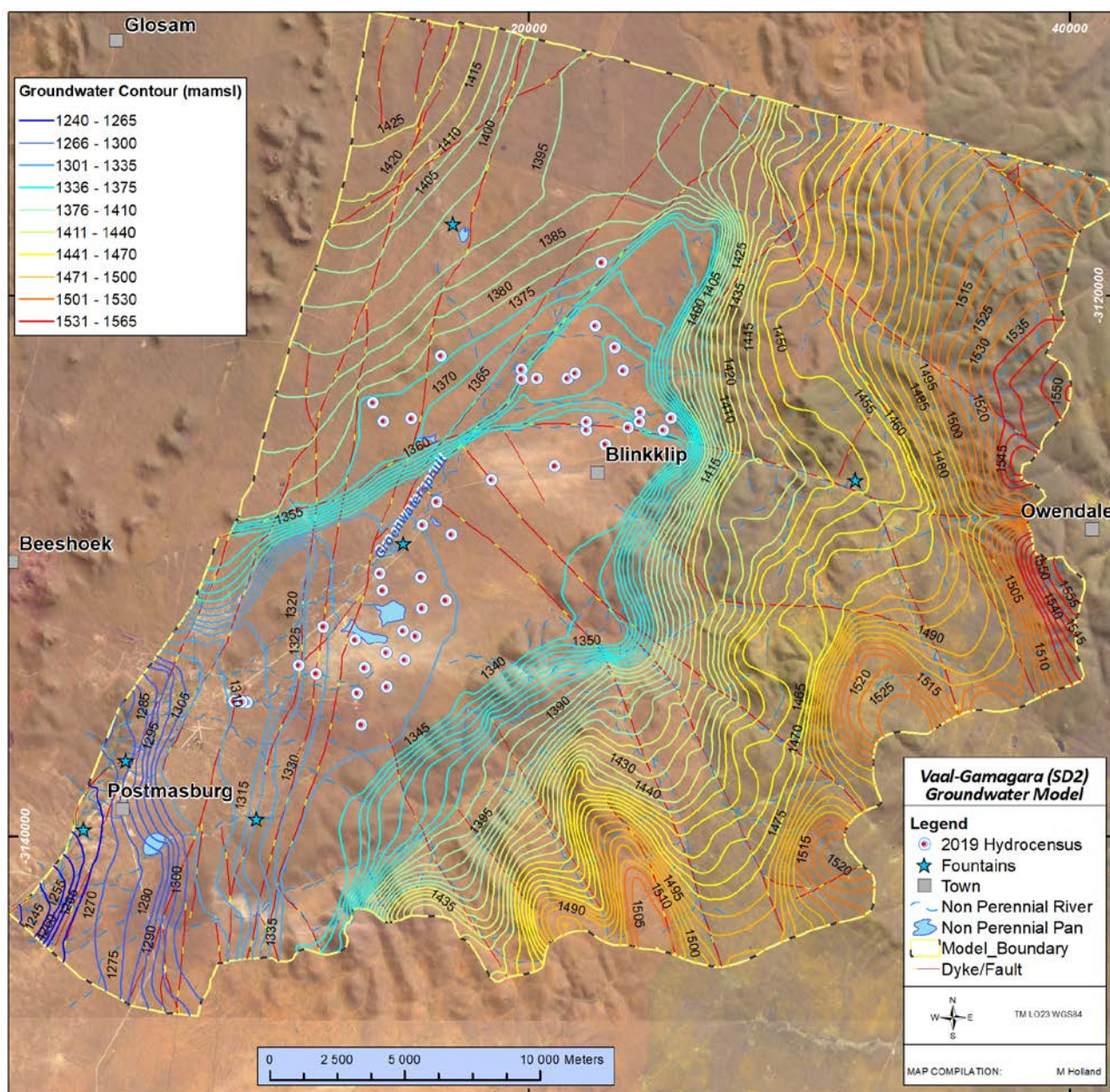


Figure 127: SD2 Simulated potentiometric heads (2019) (pre-wellfield)

6.4.3 Model Results (Predictive Simulations) SD2

6.4.3.1 Transient Recharge (Forward Simulation) SD2

The predicted rainfall was based on the observed period between 1993 and 2016. The simulated recharge for the forward prediction is shown in (Figure 128) resulting in 288 monthly time steps with variable monthly rainfall.

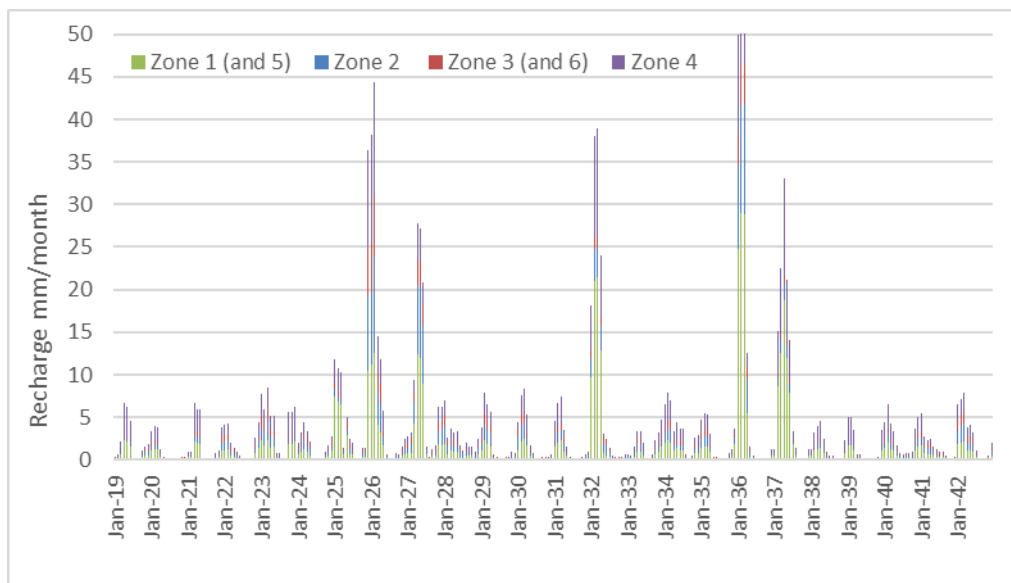


Figure 128: SD2 Monthly rainfall from 1999 to 2016 used for the transient model calibration

6.4.3.2 Abstraction (Forward Simulation) -SD2

The forward simulations of the SD2 Well field considered the initially proposed 2014 scenario 3 abstraction volumes. After a number of un-reported iterative model runs and consideration of the dolomite hazard map (Figure 100), abstraction rates was adapted for selected boreholes. The volumes of the SD2 modelled abstraction scenarios are shown in Table 56. In summary, the results present the 2014 abstraction scenario of 307,476 m³/month versus the mitigated proposed abstraction scenario of 249,660 m³/month. The final (proposed) mitigated abstraction rate was based on a number if iterative abstraction scenarios (not reported).

The simulated impacts of the groundwater abstraction from the SD2 well field on the regional groundwater levels are shown in Figure 129 and Figure 130 as maps of drawdown by comparing the water levels simulated for the last stress period of the base case (no well field abstractions) (2044) simulation against the lowered water levels due to abstraction from the SD2 well field (2044). No drawdown values below 2 meters are visualised to account for the inaccuracy in the model calibration, which is within the expected seasonal variability of water table elevations. It is likely that any drawdown below 2 meters is within the range of natural water table fluctuations and therefore any potentially affected groundwater dependent ecosystem therefore adapted to it. Similarly, potential groundwater users are unlikely to recognise such drawdown as borehole yields are typically not significantly impacted by such seasonal fluctuations. For the mitigated scenario the cone of dewatering extent is expectedly less than the 2014 scenario and extends approximately 19 km (elongated SW to NW) along the wellfield and up to 10 km east to west (considering a 2 m cut-off value). A comparison of the two abstraction scenarios simulated drawdown behaviour for each well field borehole is shown in Appendix N. Average drawdown from production boreholes for the simulation period is around 8.7 m compared to 6.6 for the 2014 scenario and 2019 mitigated scenario respectively (Table 57).

Table 56: SD2 Abstraction rates for the 2014 forward scenario as well as the mitigated (2019) scenario

Wellfield	BH no.	2014 Sc. 2b m ³ /month	2019 Mitigated m ³ /month	Final DD 2014 Sc.2b (m)	Final DD 2019 Mitigated (m)
Northern	SD2-22	13140	10950	11.54	9.14
	SD2-32	0	10950	3.29	4.89
	SD2-33	13140	10950	14.1	10.94
	SD2-37	26280	17520	11.41	9.86
North-West	SD2-34	0	17520	0	5.98
	SD2-42	13140	13140	2.43	2.22
Southern	SD2-7	26280	17520	10.78	7.06
	SD2-9	26280	0	9.72	6.16
	SD2-10	26280	17520	9.93	6.32
	SD2-12	0	17520	9.35	7.17
	SD2-15	26280	17520	9.95	6.57
	SD2-16	26280	17520	10.51	7.04
	SD2-23	26280	17520	10.35	7.15
	SD2-26	31536	17520	10.33	7.01
Southern (N)	SD2-24	0	10950	10.04	8.01
	SD2-35	26280	17520	10.85	7.74
	SD2-36	26280	17520	10.25	7.19
Total (m3/month)		307 476	249 660	Ave. DD (8.7 m)	Ave. DD (6.6 m)
Total (m3/annum)		3 689 712	2 995 920		

A summary of the predicted drawdown for the 2014 and 2019 for the proposed monitoring boreholes mitigated scenario is shown in Table 57 while the drawdown behaviour over the simulation period is shown in Appendix N.

Table 57: SD2 Predicted drawdown of the proposed long-term monitoring boreholes for the simulation period

BH no.	Final DD 2014 Sc.2b (m)	Final DD 2019 Mitigated (m)
SD2-3	7.59	4.77
SD2-9	9.72	6.16
SD2-11	5.61	3.38
SD2-13	9.40	6.22
SD2-14	9.26	6.19
SD2-17	5.28	3.09
SD2-21	9.44	6.53
SD2-30	10.78	7.69
SD2-38	3.02	3.97
SD2-41	11.54	9.02
Ave. DD	8.16	5.70

6.4.3.3 Potential Impact on Existing Groundwater Users – SD2

The simulated drawdown extent is shown spatially in Figure 131 together with the production boreholes and existing groundwater users. The drawdown behaviour over the simulation period of the existing users within the zone of impact is shown in Appendix O.

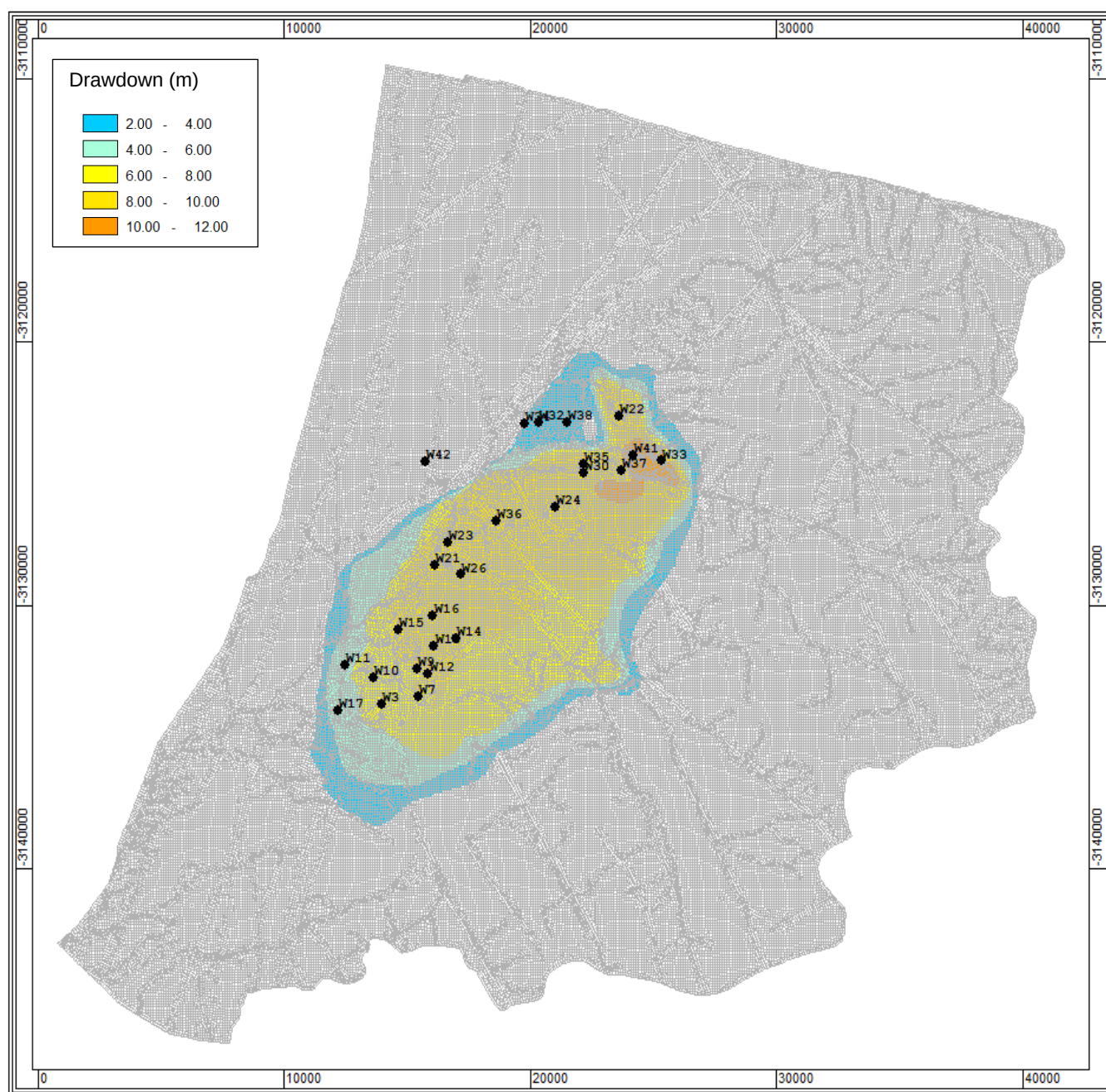


Figure 129: Drawdown extent [m] due to groundwater abstractions from the SD2 well field, 2014 Scenario 3 (long-term boreholes only)

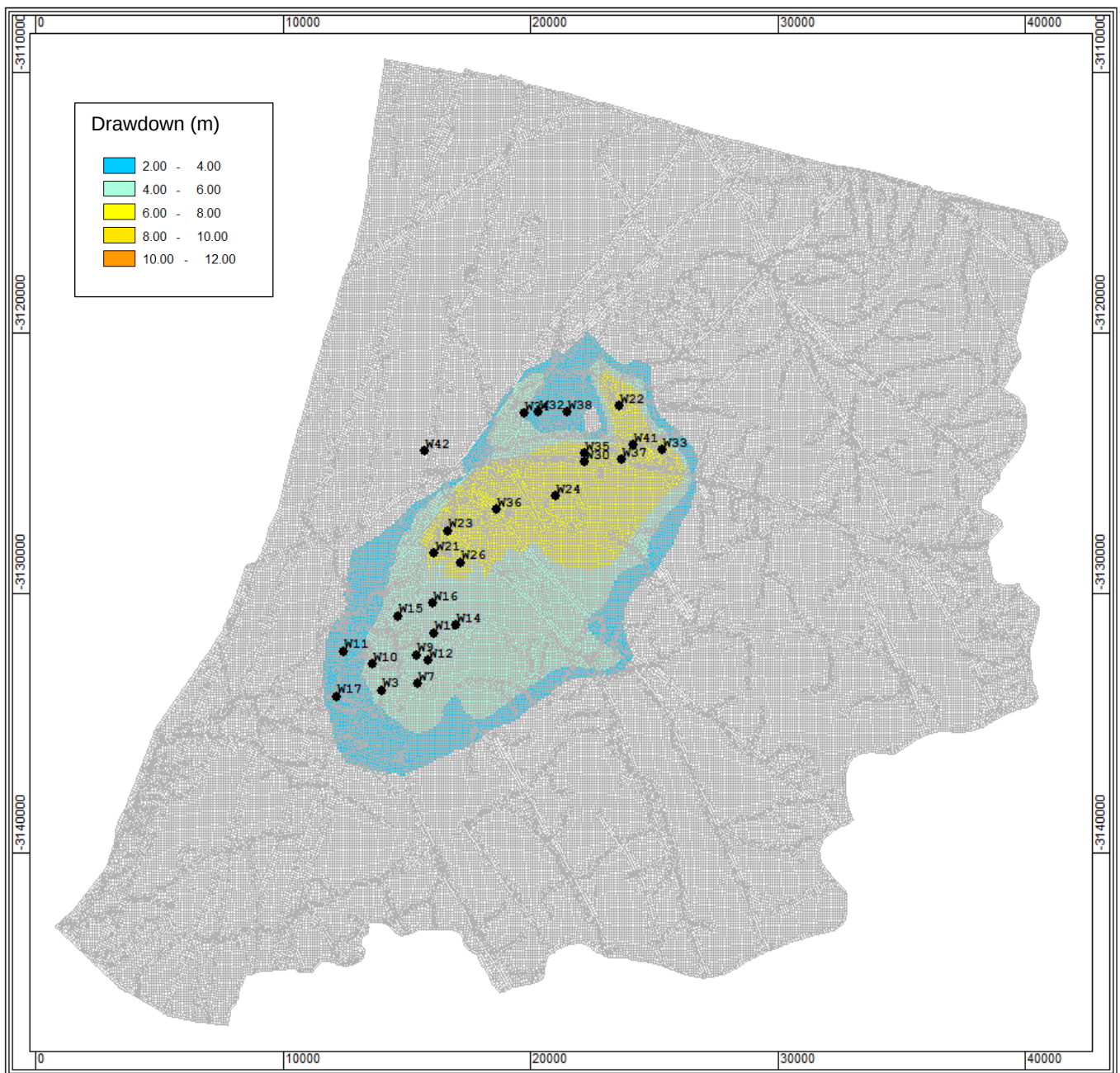


Figure 130: Drawdown extent [m] due to groundwater abstractions from the SD2 well field, 2019 mitigated scenario

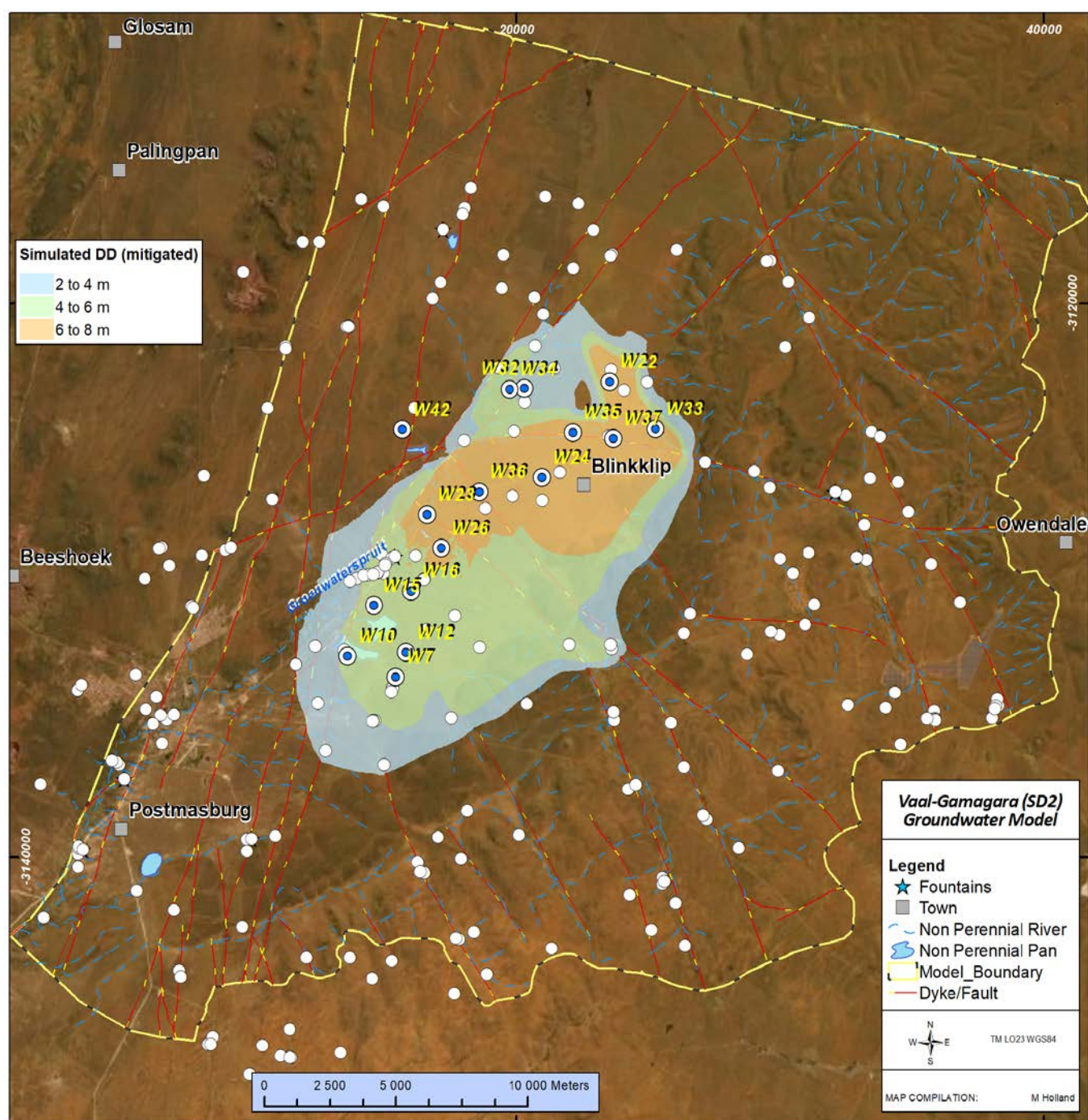


Figure 131: SD2 Production boreholes shown spatially in relation to the drawdown extent and potential existing groundwater users

6.4.3.4 Water Balance -SD2

A summary of the water balance for the transient step for the base case as well as 2014 and 2019 mitigates scenario is shown in Table 58. The abstractions from the SD2 wellfields result in a change of storage together with a reduction in flows across the outflow boundaries (to downstream catchments) and groundwater contributions to seepages/springs and drainages. The mitigated abstraction scenario amounts to approximately 42 % of the recharge of 884,413 m³/month. The determined catchment area of the wellfield is approximately 160 km², which relates to an abstraction rate per square kilometre of around 0.73 L/s and 0.59 L/s, for the 2014 (unmitigated) and 2019 (mitigated) scenarios, respectively.

Table 58: SD2 Simulated water balance (transient state)

Regional Water Balance	Base Case	2014 Scenario	2019 Mitigated
Inflow	m³/month	m³/month	m³/month
Recharge	884 413	884 413	884 413
Outflow	m³/month	m³/month	m³/month
Shallow seepages to pans and spring discharge	-129 188	-137 859	-160 451
Boreholes Abstraction	-124 442	-431 918	-374 102
Contribution to Drainages and potential evapotranspiration	-213 573	-237 965	-277 869
Outflow Boundaries	-90 119	-98 456	-105 225
Sub-Total Outflow	-557 322	-906 197	-917 648
Change in Storage	327 091	-21 784	-33 235
Total Outflow	-884 413	-884 413	-884 413

6.4.4 Summary of Model Update – SD2

For the model update no changes was made to the physical geometry of the model domain developed in 2014. However, the model was re-calibrated in both steady- and transient state, based on the 2019 hydrocensus and borehole water level logger information from 2014 to 2019 as well as updated rainfall records. The calibrated model was subsequently used to simulate the impacts of the proposed SD1 well fields on the groundwater environment. Model scenarios included a base case (i.e. no wellfield implementation), the 2014 abstraction scenario of 307,476 m³/month and a mitigated (optimised) proposed abstraction scenario of 249,660 m³/month.

Impacts was shown as regional water level drawdown figures and individual borehole drawdowns. For the mitigated scenario the cone of dewatering extent is expectedly less than the 2014 scenario and extends approximately 19 km (elongated SW to NW) along the wellfield and up to 10 km east to west (considering a 2 m cut-off value). Average drawdown from production boreholes for the simulation period is around 8.7 m compared to 6.6 m for the 2014 scenario and 2019 mitigated scenario, respectively.

Due to the intrinsic heterogeneity of the dolomitic groundwater system the potential impact of the groundwater abstractions on other groundwater users may not be equally distributed (spatially) around the proposed abstraction areas. Further, some surfaces drainages and pans may be perched on a low-permeability substrate (i.e. the calcrete layer) and may not be in hydraulic continuity with the aquifer beneath and therefore not impacted by a drawdown of the water table.

6.5 Recommendations

The following recommendations are given:

- The model should be utilized to develop optimal operational and management rules for the well field, considering their impact on the regional water balance and water levels.
 - Site-specific groundwater and rainfall monitoring data are vital for a reliable transient calibration of the model and to understand and simulate the aquifer responses to abstraction and recharge at higher confidence.
 - Monitoring the long-term groundwater level changes in a borehole that is not too close to be directly affected by individual production boreholes provides a very useful indication of the 'health' of the water balance in the aquifer.
 - In this regard a well field management plan should be developed which considers mitigation measures (or temporary cessation of abstraction), if the water level near a receptor (such as a wetland/pan) falls below a fixed threshold.
 - Annual review of the model predictions and model update if required.

7.0 SPECIFIC ISSUES RAISED DURING CRR SESSIONS

7.1 Upgrade of the Numerical Modelling: Actual Water Requirements – LoS¹

Prediction of aquifer saturation levels, herein referenced as groundwater level elevations, has been identified as the most important hydrological attribute to be monitored and reported pre-, operational LoS, and probably post- times. The status of groundwater levels is a clear indication of the sustainability of the aquifer system over time – depleting water levels indicate that aquifer becomes a risk for sustainable water supply, and rising water levels indicates aquifer recharge is taking place. Recharge is solely driven by rainfall in the aquifer's recharge areas.

Given the apparent variation on the rainfall patterns in the last 9-years, at least three (3) numerical modelling scenarios have been developed based on rainfall-time-intensity variations. The results have been illustrated in section 6.0 above. The conclusions are well stated and emphasises the important of (i) long-term hydrological monitoring and (ii) management of the well fields/sections of the well fields as per instructions from Scheme Management.

The most sustainable option, however, specify the following annual yields for the SD 1 and SD 2 Production Areas:

- SD1: 4.2 Mm³/a – Long-term median recharge based on hydrochemical mass balance is ~14 Mm³/a (existing use water use is ~4.2 Mm³/a); and
- SD2: 3.0 Mm³/a – Long-term median recharge based on hydrochemical mass balance is ~9 Mm³/a (existing use is ~2.1 Mm³/a).

7.1.1 Predicted groundwater level behaviour over LoS (predicted)

The potential impacts on the aquifer saturation levels is provided for the SD1 Area in section 6.3 and for the SD2 Area in section 6.4. However, as a summary is provided below:

- SD1 Area:

¹ LoS – Life of Scheme.

- Average drawdown from production boreholes for the simulation period is around 7.5 m compared to 5.6 m for the 2014 scenario and 2019 mitigated scenario respectively (ref. Table 53);
 - The long-term drawdown extent on existing groundwater users predicted to be less than 5.8 m with only a small area in Wellfield 2 where the simulated drawdown could be between 6 and 8 m (Figure 130);
 - A summary of the water balance for the final transient step for the base case as well as 2014 and 2019 mitigates scenario indicates that the abstractions from the SD1 well fields result in a change of storage together with a reduction in flows across the outflow boundaries (to downstream catchments) and groundwater contributions to seepages/springs and drainages. The mitigated abstraction scenario amounts to approximately 50 % of the average recharge of 1,188,352 m³/month (ref. Table 54; and
 - The results from the 2019 SD1 Model Update shows groundwater level impacts shown as regional water level drawdown figures and individual borehole drawdowns. For the mitigated scenario the cone of dewatering extent is expectedly less than the 2014 scenario extend approximately 30 km north to south along the well fields and up to 20 km east to west (considering a 2 m cut-off value).
- SD2 Area:
- Average drawdown from production boreholes for the simulation period is around 8.2 m compared to 5.7 for the 2014 scenario and 2019 mitigated scenario respectively (ref. Table 57);
 - The long-term drawdown extent on existing groundwater users predicted to be less than 5.7 m with only a small area in the where the simulated drawdown could be between 6 and 8 m (Figure 129);
 - A summary of the water balance for the transient step for the base case as well as 2014 and 2019 mitigates scenario indicates that abstractions from the SD2 wellfields result in a change of storage together with a reduction in flows across the outflow boundaries (to downstream catchments) and groundwater contributions to seepages/springs and drainages. The mitigated abstraction scenario amounts to approximately 42 % of the recharge of 884,413 m³/month (Table 58).
 - The results of the 2019 SD2 Model Update shows groundwater level impacts shown as regional water level drawdown figures and individual borehole drawdowns. For the mitigated scenario the cone of dewatering extent is expectedly less than the 2014 scenario and extends approximately 19 km (elongated SW to NW) along the wellfield and up to 10 km east to west (considering a 2 m cut-off value).

7.2 Impact(s) of significant wet-dry climate cycles

Since the exploratory drilling program started in 2012, the area was subjected to extreme climate conditions characterised by low rainfall and abnormal high temperatures. These conditions have a negative impact on groundwater resources, i.e. limited to no groundwater recharge and higher water use for stock farming and elevated evapotranspiration near wetlands and areas with <7 m water table depths. The rainfall dataset, however, indicates at least two high-intensity rainfall periods that have resulted in groundwater recharge events, as illustrated in Figure 132. Smaller water level “adjustments”, i.e. changes in the long-term water level recession, occurred in April 2018 and May 2019; thus, indicating that annual groundwater replenishment is still taking place, however due to natural aquifer drainage/discharge and abstraction, the water level trend remains in a recession mode.

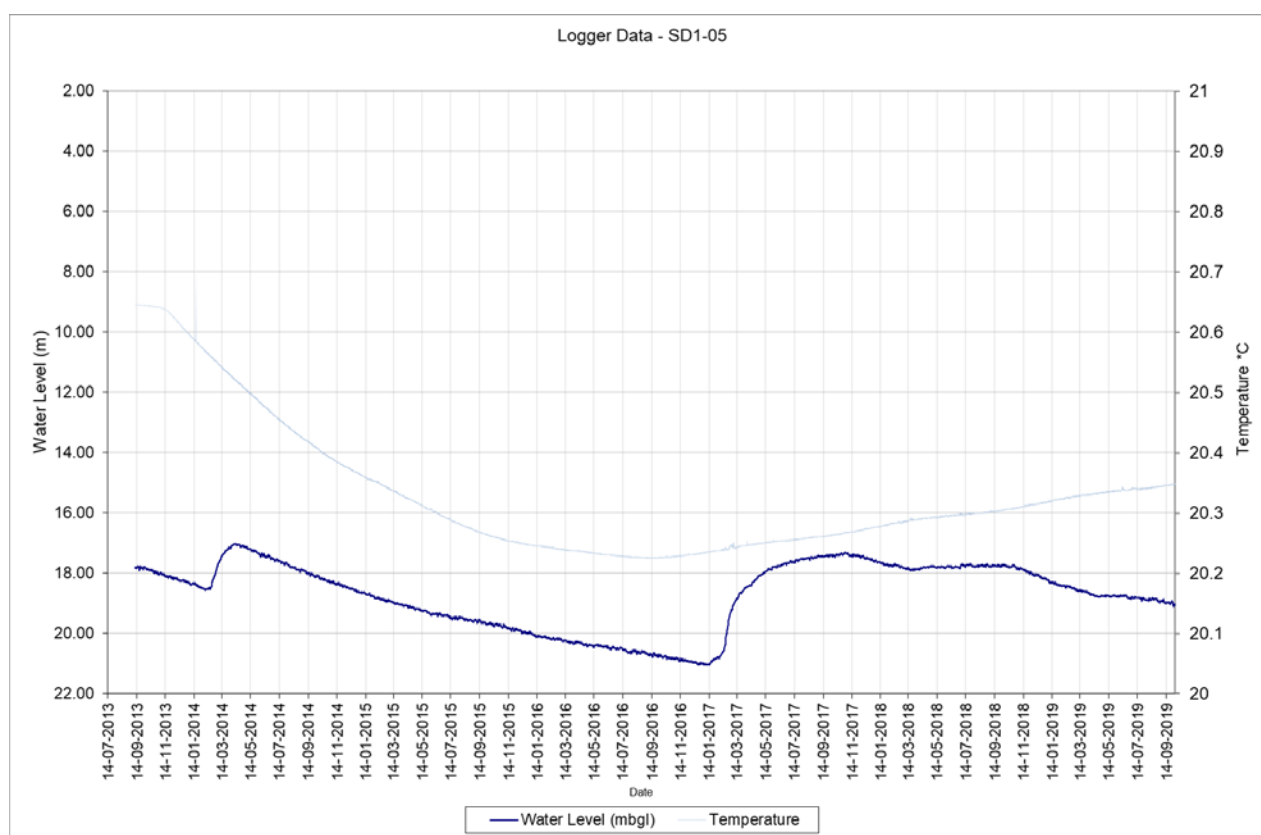


Figure 132: Illustration of groundwater level response in the SD1 Area since monitoring started in 2013 (Borehole SD1-05 – Main Aquifer System).

Groundwater level monitoring has commenced soon after the SD1 and SD2 exploration drilling and test pumping work were completed. Details of the water level trends over the 2013 to 2019 period (i.e. a period of 6-years) are discussed in section 5.1.1, page 147 above. The water level time series plot illustrated in Figure 132 represents a typical medium-term behaviour of the relationship between aquifer saturation levels and rainfall recharge). However, what is important to note from the 2013-2019 water level monitoring period for SD1 and SD2 Areas, the following aspects:

SD1 Area (Daniëlskuil-Lime Acres):

The SD1 area covers a southward dipping, low gradient sloping (~1%) terrain from the Daniëlskuil pan area towards the Grootpan Area. Currently the pan has no outlet system, i.e. a specific discharge area. It has, through millennia, developed into an “inland” wind-eroded depression and fills from time to time with local surface run-off water. Due to deep weathering of the local dolomite rock, a significant karst aquifer system has developed in the pan and upstream areas [towards Daniëlskuil] and represents the main, deep groundwater aquifer system (ref. MAS). Important water level observations are:

- There is a long-term, steady depletion of the water level due to natural aquifer drainage/discharges to wetlands and water use abstractions, that causes water level recessions in the order of 1.25 m over a period of 6.2 yrs. (viz. the SD1 & –2 monitoring period).
- In Figure 132, two aquifer storage recharge events occurred during the monitor period less than 3 years apart.
- The 2014 (February: 155 mm) and 2016-2017 (December: 70, January: 170 and February: 165 mm) rainfall pattern has resulted in an aquifer storage replenishment of 0.68 m and

3.72 m respectively – these can be regarded as high-episodic rainfall events, generally with a recurrence rate of 1 in 5 years in the South African semi-arid climate regions;

- The water table in the upper, shallow aquifer (present at ~16 mbgl) has remained stable at ~12.5 mbgl over the 6¼ yr. monitoring period, however, the two recharge events mentioned above (14 Feb'13 and 20 Feb'17, as noted in Figure 133 below) have resulted in a ~2 m water level rebound.

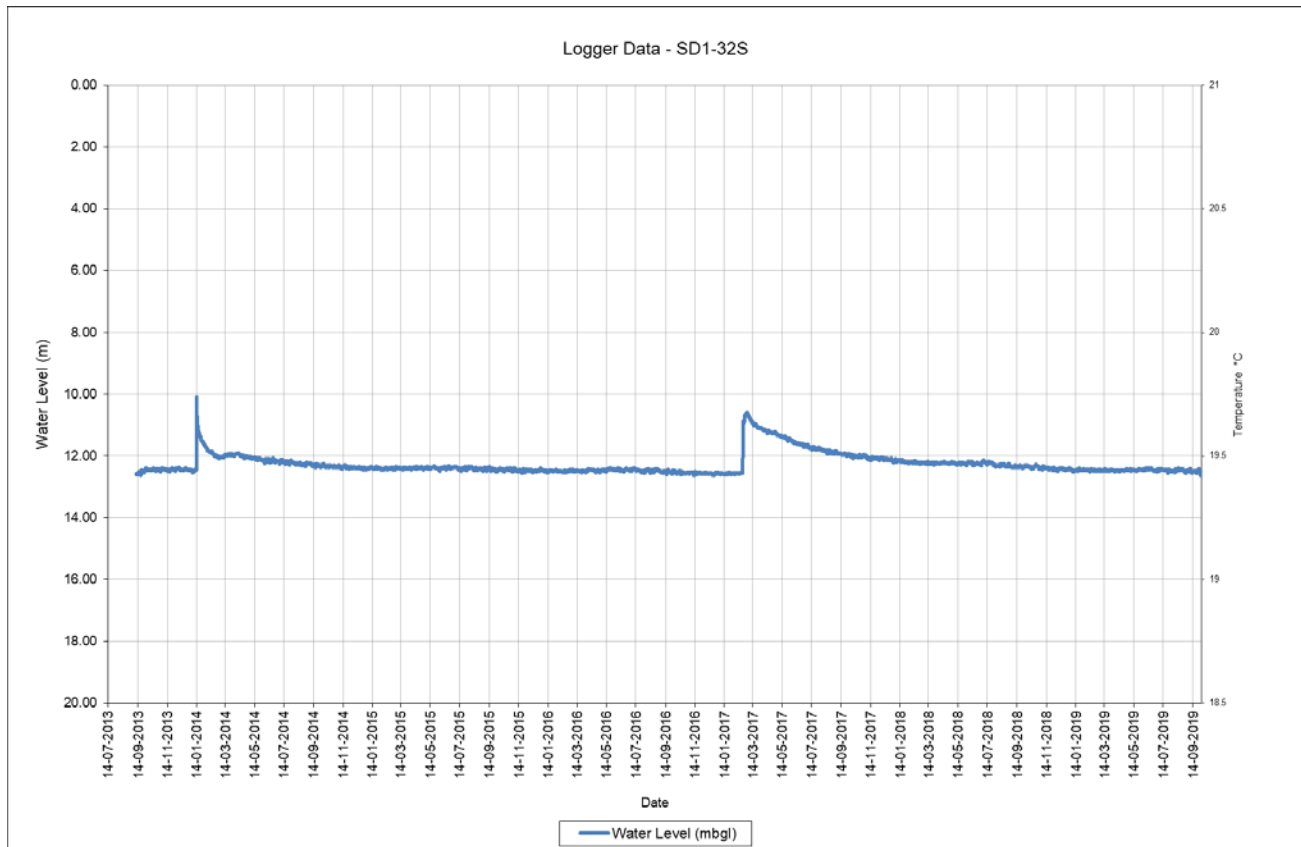


Figure 133: Illustration of groundwater level response in the SD1 Area since monitoring started in 2013 (Borehole SD1-32S – Calcrete Aquifer System).

- Evidence that the “mid” depth aquifer system (i.e. >16 and <72 mbgl) drains to the main, deeper aquifer system was noted, viz. SD1-32M (73 m deep, fully cased and water strike from 71-73 m) reporting a water level depletion of 3.35 m over the 6¼ yrs. monitoring period – as illustrated in Figure 134 below.

SD2 Area (Postmasburg):

The SD2 area lies northeast of Postmasburg, and just east of the Groenwaterspruit valley which runs to the quaternary catchment boundary (D73A-D41J) approx. 28 km's from the town centre. The well field sites fall in four (4) of the five (5) groundwater management units demarcated by groundwater flow boundary systems (viz. dykes and low permeable formations). The elevation of the well field area, from the northeast to the south west parts, falls at a steady gradient of ~0.5% and finally dips into the Groenwaterspruit valley south of the town area. Several redundant diamond mines (kimberlite pipe features) occurs in the lower part of the Groenwaterspruit valley; known the have been filled with (ground)water over time.

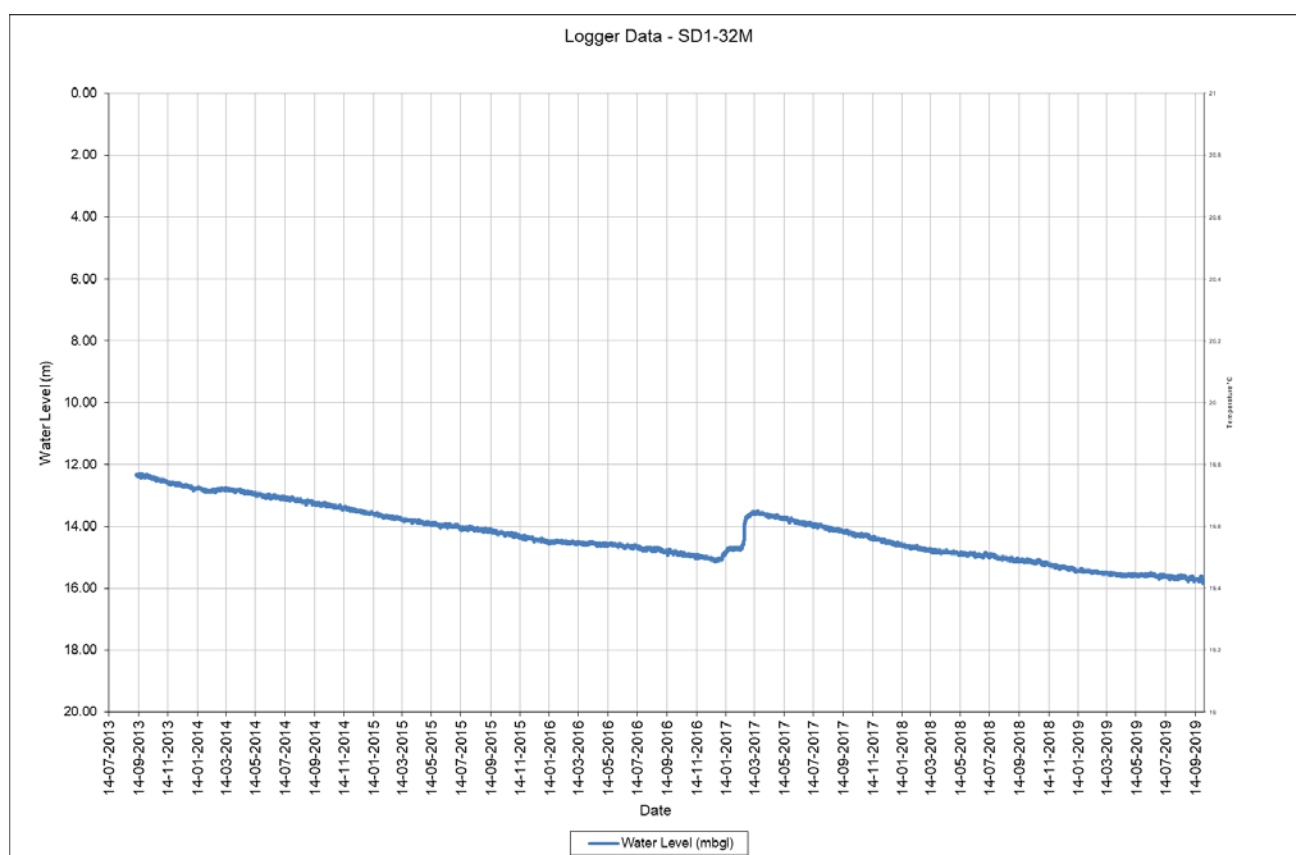


Figure 134: Illustration of groundwater level response in the SD1 Area since monitoring started in 2013 (Borehole SD1-32M – upper Main Aquifer System).

The following important groundwater level trends were noted following the 6¼ yr. monitoring period:

- The rainfall depth pattern in the SD2 Area was not as impressive as in the Daniëlskuil region, however, the highest monthly rainfall during the 2013-2014 season was in December (50 mm) and in the 2016-2017 season 140 and 150 mm for January and February respectively.
- Water level elevations in the SD2 Area just north of Postmasburg (i.e. monitoring site SD2-04) were stable with a slight drop of 0.65 m since 2013. Several seasonal water level rebounds² were noted of which the January 2017 rebound was the prominent one, resulting in a recharge 1.80 m in the local aquifer. The groundwater level trend is illustrated in Figure 135 below.
- Similar water level responses were noted at SD2-31 in the upper parts of the well field area where a water level rebound of 2.6 m occurred following the January 2017 rainfall event(s). The January 2017 (pre-recharge) water level was only reached in September 2019 – 2¾ years later.
- The overall long-term water level trend in the SD2 Area followed recessions in the order of -3.0 m over the 6¼ yrs. monitored in 6 monitoring boreholes – the highest depletions were noted in the upstream part of SD2 Area, e.g. water level in SD2-10 dropped by 3.52 m over the 2013-2019 monitoring period.
- Water level rebounds were noted at all the monitoring sites in the SD2 well field area varying between 0.5 to 2.60 m. Most impressive rebounds (~2.0 m) were noted in the upper and lower parts of the SD2 Area.

² Water level rise due to effective seasonal rainwater recharge.

As noted above and in addition to the prominent 2014 and 2017 recharge events, annual water level recession trends were notably changed (i.e. rebounded) even during seasons with lower rainfall events. Without these “smaller” water level trend adjustments, the 2019 water level elevations would be several metres lower than those observed in October 2019 (as illustrated in Figure 135).

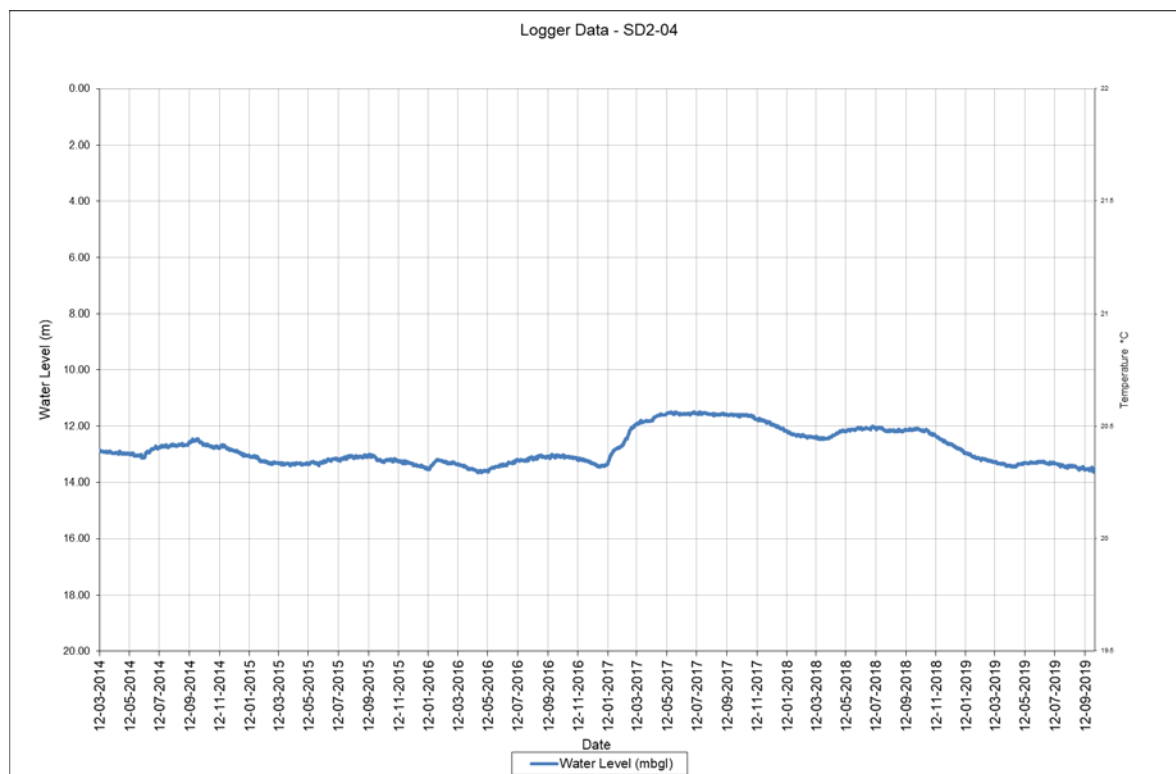


Figure 135: Illustration of groundwater level response in the SD2 Area since monitoring started in 2013.

7.3 Impact on Groundwater Quality over LoS

Previous studies, i.e. the Postmasburg (D73A) and Kathu-Sishen (D41J) quaternary catchments indicated point source pollution which were postulated to be the results of poor management of local waste sites on municipal waste lands, as well as cases where stock kraals/drinking troughs were situated within ~100 odd metres from production boreholes.

Although dolomite aquifer systems are highly vulnerable for receiving polluted substances due to local surface water runoff from waste site, the higher recharge rates tends do have a significant dilution effect. Water quality deterioration due to anthropogenic nature, i.e. insufficient wastewater treatment, is a known fact in SA, e.g. nitrate concentrations are on a steady rise throughout SA.

Both the SD1 and SD2 well fields are located in areas which are (i) protected from mines/industries/townlands by well field boundary systems (e.g. now flow boundaries), and (ii) free of any mining/industrial activities, especially in their upstream recharge sections. Migration of hydrochemical substances due to the planned abstraction, is regarded as insignificant and not a long-term risk. It is, however, important the so-called “Protection Zones” for the SD1 and SD2 well fields will have to designed and implemented.

Water qualities in the SD1 & –2 Areas are all recently recharged [rain]water and is classified as Ideal to Good water quality. Point source pollution in several of the existing boreholes, viz. elevated nitrate, has been noted which is merely related to local pollution from leaking/unmanaged sewer systems and/or nearby stock kraals.

The following two tables summarize the groundwater quality status to be used as a baseline for the LoS. Due to the unique aquifer system and “remote” locations of the SD1 and SD2 wellfields, these values would probably remain within these limits (e.g. $\pm 10\%$) unless extraordinary waste dumping and or neglected waste management occurs on the well field areas.

The background groundwater quality representative for SD1 study area is a calcium magnesium bicarbonate water type (viz. $\text{Ca-Mg-(HCO}_3)_2$, representing recently recharged groundwater, see Table 59. The groundwater quality characteristics [as per Piper Diagram] are illustrated in Figure 136 below. The high-lighted area indicates the water type resembling fresh, unpolluted groundwater [as explained above].

Table 59: Groundwater quality parameters for the SD1 Well Field Area (full reference see Table 10)

Item SD1	Physical Parameters			Macro Determinants (Major Ions)								Minor Determinant		
	pH	EC mS/m	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	SO4 mg/l	NO3 mg/l	MALK Mg/l	F mg/l	Fe mg/l	Mn mg/l
Median Baseline water Quality	7.54	67.1	420	<u>86.3</u>	<u>33.8</u>	11.7	2.49	29.3	28.2	3.32	<u>292</u>	0.1	0.05	0.05
Max. Allowable Limit (SANS 241:2011)	<5 >9	<170	<1200	<300	<100	<200	<100	<300	<500	<11	-	<1.5	<0.3	<0.5

The background groundwater quality representative for SD2 study area are calcium magnesium bicarbonate type of water ($\text{Ca, Mg(HCO}_3)_2$, representing recently recharged groundwater, with see Table 60 below and is virtually similar to the SD1 water quality signature.

Table 60: Groundwater quality parameters for the SD2 Well Field Area (full reference see Table 30)

Item SD2	Physical Parameters			Macro Determinants (Major Ions and Trace Metals)								Minor Determinant		
	pH	EC mS/m	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	SO4 mg/l	NO3 mg/l	MALK Mg/l	F mg/l	Fe mg/l	Mn mg/l
Median Baseline water Quality	7.71	57.20	378	<u>64.60</u>	<u>35.40</u>	19.0	2.90	28.70	19.90	2.97	<u>272</u>	0.18	0.05	0.05
Max. Allowable Limit (SANS 241:2011)	<5 >9	<170	<1200	<300	<100	<200	<100	<300	<500	<11	-	<1.5	<0.3	<0.5

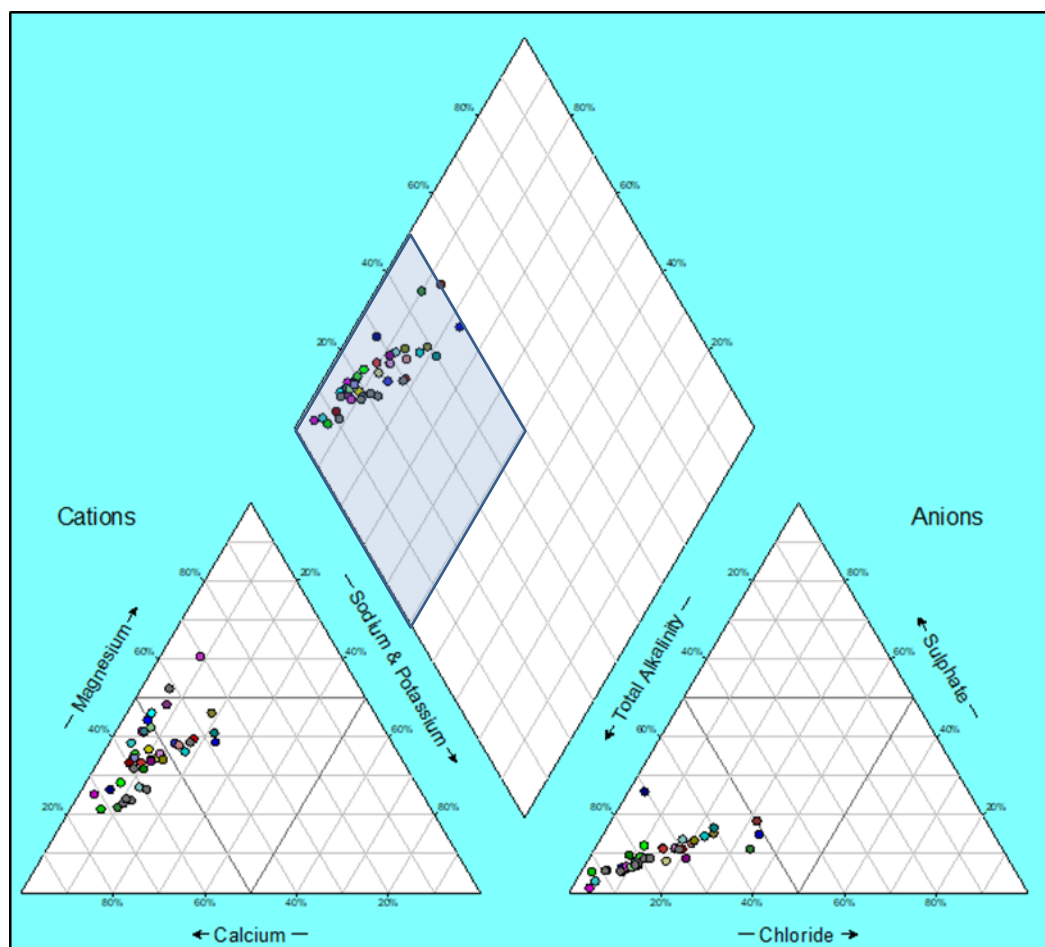


Figure 136: Piper Diagram: SD1 exploration borehole water quality characteristics

The background groundwater quality representative for SD2 study area is a calcium magnesium bicarbonate water type (viz. $\text{Ca-Mg-(HCO}_3)_2$), and as with the SD1 water quality characteristics, representing fresh, recently recharged groundwater.

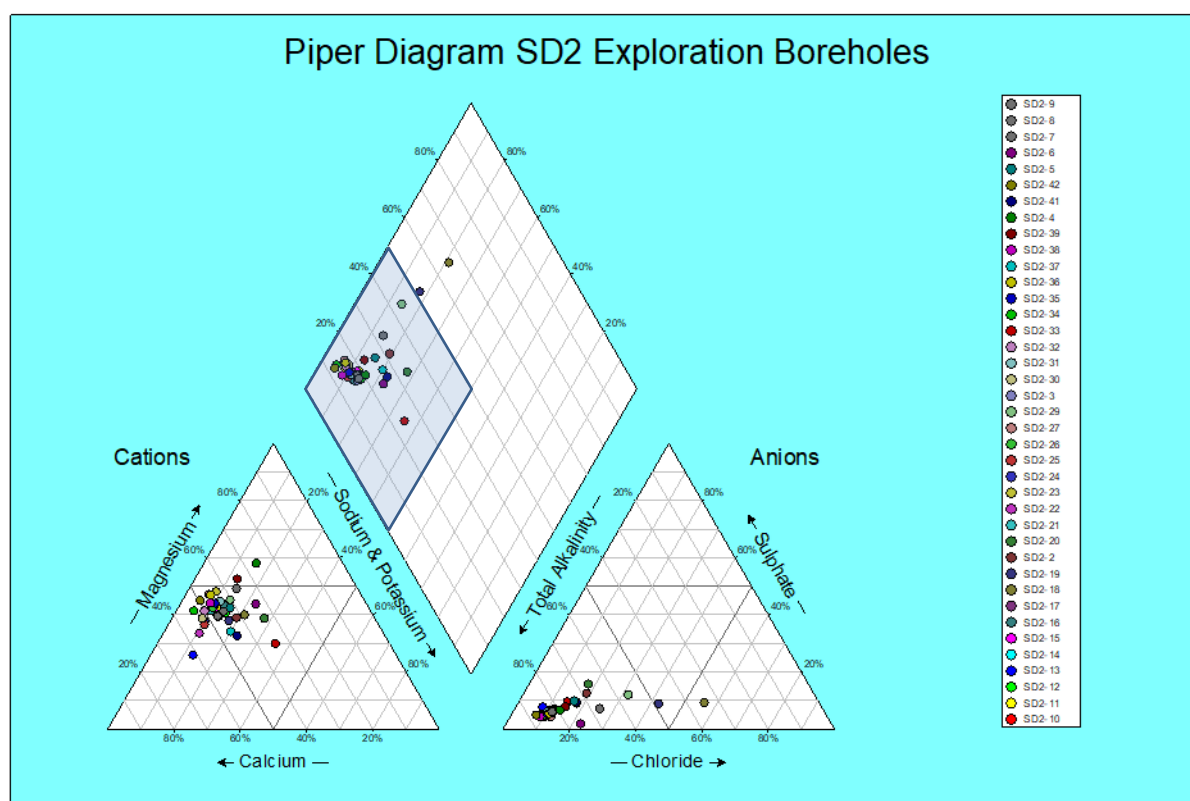


Figure 137: Piper Diagram: SD2 exploration borehole water quality characteristics

Other important hydrochemical constituents related to the toxicity of water used for domestic and stock watering in the SD1 and SD2 wellfield areas are (i) nitrate (NO_3 : 3.3 and 3.0 mgN/l respectively) and fluoride (F: 0.1 and 0.2 mgF/l respectively) – thus; both well field areas classifies as an “Ideal water Quality” criteria (WRC, et al, 1989). It is, however, important to note that the nitrate values are slightly higher than the general “background” for large dolomite aquifer systems which lies at ~2.5 mgN/l. The sources of nitrate in dolomite groundwater resources have a wide origin and may vary from industrial to domestic/agricultural sources.

In closing, there is, however, an indication that chloride (Cl) concentrations in the groundwater are rising probably as a result of the drier climate conditions in the region. In both well field areas (viz. SD 1 & 2), anion exchange from a prominent $\text{HCO}_3 + \text{CO}_2$ (indicated as TAL in both Piper Diagrams) towards a Cl-SO_4 anion signature is clearly visible.

7.4 Significance of Shallow and Deep Aquifer Systems in SD1 and SD2

During the drilling exploration programme, the following geological profile has been visualized for the well field areas:

■ Shallow “Calcrete” Aquifer System (CAS):

The SD1 and SD2 main well field areas are located within areas with covered by a significant cover of Tertiary-Quaternary Kalahari Group sediments (T-Qk). Frequently, the T-Qk sediments are covered with a much wider spread younger limestone deposit called “calcrete”, that can be as thick as ~60m. The calcrete formation represents a shallow calcrete aquifer system (CAS) where partially saturated with local recharged rainwater. With depth, the calcrete horizon becomes highly impermeable and acts as a purged aquifer system and hydraulically not linked with the underlying, deeper aquifer system(s) [viz. based on water level elevations].

The following specific details of the CAS were observed during the exploration drilling and assessments:

■ SD1 Area

- A profile of the different formations encountered during the exploration drilling program is illustrated in Figure 138 below. The cross-section shows the presence of the shallow Calcrete layer (2 to 6 m upstream at the Daniëlskuil area to between 20 to 60m downstream at the Papkuil area) that represent the CAS.

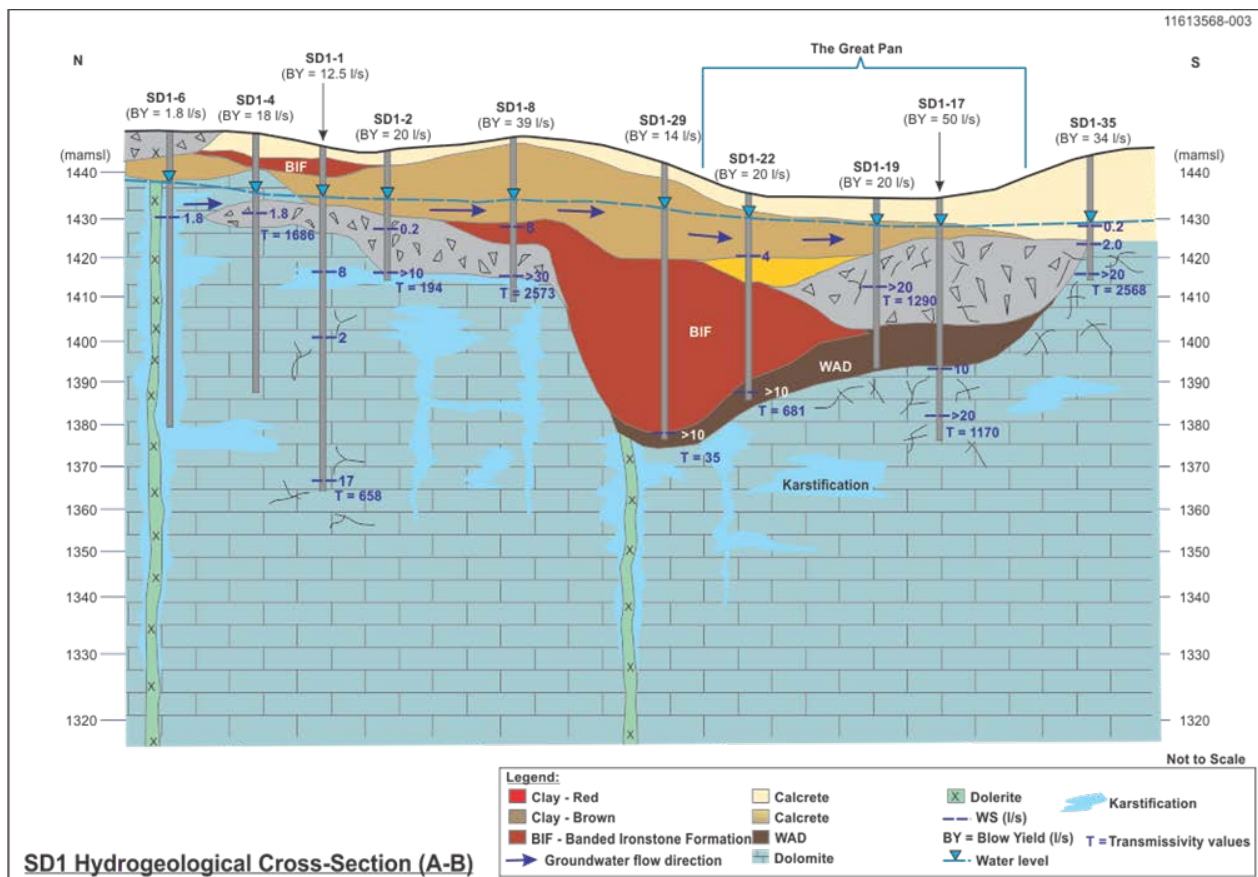


Figure 138: A North-South hydrogeological cross section through the Groot Pan showing the components of the main aquifer system in the SD1 Area

- At the Papkuil area, the CAS represent the host formation of the 'Olienhoutboom' forest.
- A few "shallow" boreholes at critical positions in the SD1 Area were drilled for monitoring shallow water level responses. Drill sites SD1-14S, SD1-16S, SD1-27S and SD1-32S were drilled to investigate hydrogeological conditions of the CAS.
- At these sites, the calcrete thicknesses were between 16 and 18 m at these CAS-test sites, with water levels between 9.7 and 14.1 mbgl – saturation levels were between 2.0 and 6.0 m. Test pumping in the areas where the CAS is present indicates no water level correlations to the water level responses in the MAS – thus, the CAS appears to be isolated due to low basal permeabilities.

A typical long-term water level (semi-confined condition) time series log of the purged water table in the CAS is illustrated in Figure 139. This water level log illustrates (i) two significant recharge events in the SD1 Area and (ii) the almost "steady state" water level condition in the CAS. For example, the water level recession in the last fourteen-months [from August 2018] was ~13 mm. This decrease is probably due to natural aquifer discharge (viz. piezometric-head drainage and evapotranspiration).

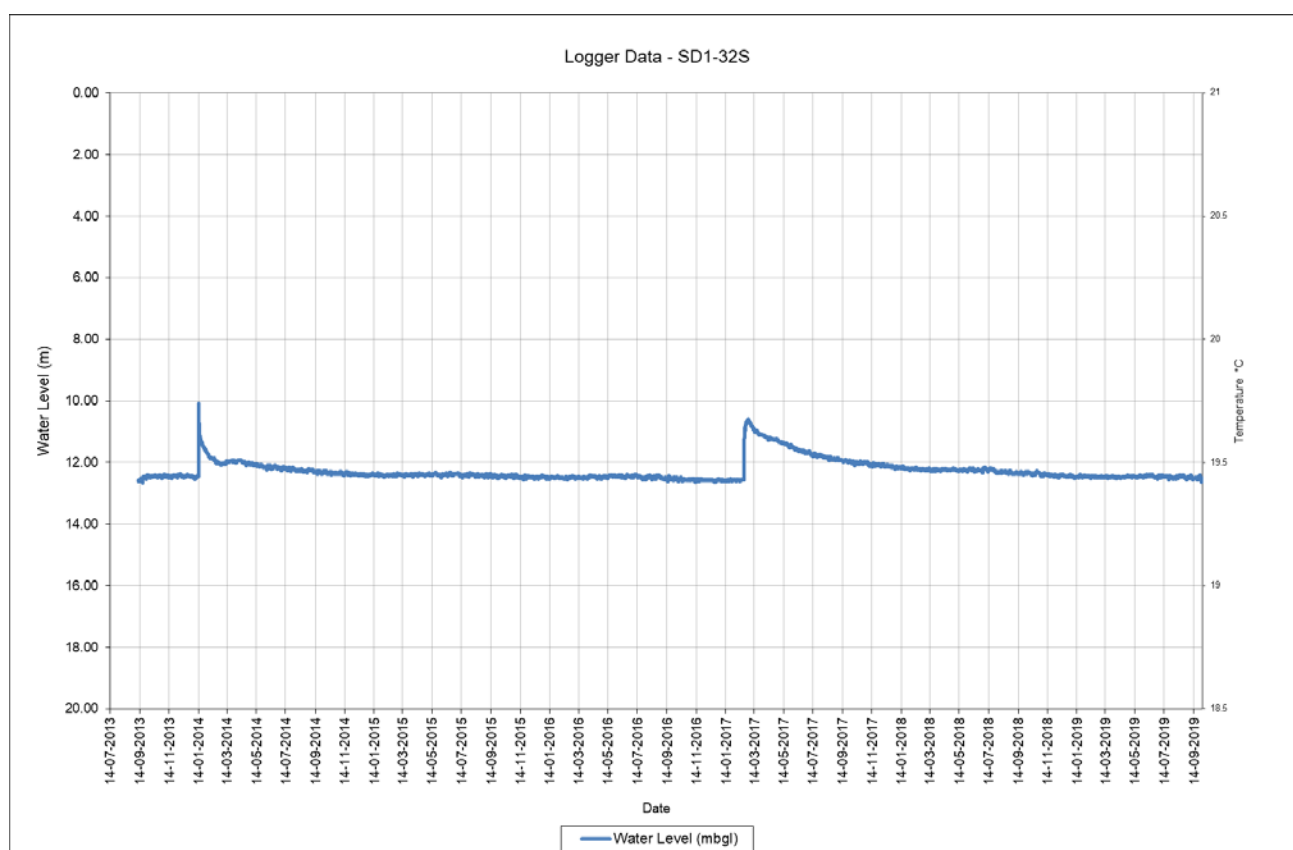


Figure 139: Long-term water level time series log at monitoring site SD1-32S (CAS at the Papkuil Area) illustrating effects of significant recharge events.

■ SD2 Area:

- A paleo drainage system was identified in this exploration area with T-Qk (Kalahari Group) floor with an average thickness of ~40 m, however, a maximum thickness of 106 mbgl was noted at exploration borehole SD2-1. Almost 55% of the SD2 exploration area is covered with T-Qk sediments.
- Cross-sections in the SD2 Area shows the presence of an overlying shallow calcrete aquifer system (CAS) of approximately 20 to 30m thickness with an expected low permeability, but significant aquifer storage potential.
- CAS saturation levels seems to be in the order of ~5 to 7 m (as per exploration borehole SD2-16M information).
- The Groenwater wetland area is underlain by calcrete with a static groundwater level of 19.4 mbgl with water strikes at 20m. (refer information on borehole SD2-21). In other areas
- This wetland is dependent on rainfall and surface run-off. Lowering of water levels of the underlying main banded ironstone formation/dolomite aquifer system up to 10m poses a very low risk for the overlying Wetland.
- The calcrete aquifer system has a relatively low hydraulic conductivity and acts as an aquitard (i.e. restricted vertical groundwater flow). The water level in the CAS was not affected during the test pumping program at test site SD2-16.

- Deeper Main Aquifer System (MAS): Consists of (i) semi-consolidated Kalahari Group (T-Qk) sediments/gravels, (ii) fractured and weathered semi-consolidated banded ironstone rubble - BIF)

residue, and (iii) deep developed karst (viz, weathered/broken dolomite with cavities). The latter formations are part of the Griqualand West Sequence (Griquatown [Asbestos Hills BIF] and Campbell [Ghaap Plateau Dolomite] Groups). The BIF represents the “root-zones” of paleo karst features filled with broken/recemented ironstone rubble. This combination means high storage (T-Qk gravels) combined with high aquifer transmissivities (viz. BIF & karst dolomite). These aquifer systems are regarded as one hydraulically linked unit.

Furthermore, compartmentalization of the dolomite aquifer by younger intrusive dolerite/diabase dykes allow “protection” of surrounding groundwater resources from a specific depth (~4 mbgl). During abstraction “additional” storage is generated to capture extraordinary rainfall recharge during wetter climate cycles. Dropping of the water table in these GRU’s will, therefore, “create” additional storage space that can be recharge/captured during wetter cycles.

■ SD1 Area:

- The MAS includes all the formations below the shallow CAS and illustrates the composition of the deeper T-Qk Aquifer System, the residual BIF and the dolomite/karst dolomite aquifer system. A typical MAS model is illustrated in Figure 138 above.
- A large paleo drainage system running from the Kuruman Hills and Daniëlskuil area in a south-easterly/southerly direction passing the Groot Pan area (ref. Figure 36 in Volume 1 of the SD1 Report) has been mapped (gravity surveys) representing the deeper main hard rock aquifer system in the area.
- Semi consolidated BIF rubble which fed into the paleo-river channel, chert rich dolomite and wad zones are present, with major karstification in the underlying dolomites.
- The presence of residual dolomite formation material, viz. WAD indicates significant karstification of the dolomite rocks. These karstification zones which developed below the paleo channel and along dolerite dyke contacts are highly permeable with blow yields intersected as high as 50l/s (SD1-17).
- Compartmentalization of the dolomite aquifer by younger intrusive dolerite dykes allows identification of ten (10) groundwater resource units in this area – these units can be managed in terms of their unique/combined hydraulic characteristics as 10 or less groundwater management units (GMU’s). Specific management protocols will be drafted for the GMU’s.
- The area around the Groot Pan area represents the largest coverage of the MAS, however, preferential flows along (i) the local paleo drainage system, and (ii) the large transacting dolerite dyke features link the MAS with a much larger groundwater recharge and storage area.

■ SD2 Area:

- Gravel deposits comprising out of BIF fragments, jasper and chert are represented below the CAS, underlain by dolomite with major karstification. Semi consolidated BIF is present to the northeast at surface also underlain by dolomite, though less karstification zones.
- A local T-Qk filled area which could be linked to a regional paleo drainage pattern for the Groenwaterspruit has been mapped from the gravity survey representing a similar deeper main aquifer system as in the SD1 Area. A geological profile of a section of the MAS in the SD2 area is illustrated in Figure 140 below.

- The intergranular T-Qk aquifers are presented by the upper (Eden Formation) as well as basal sand and gravel beds (Wessel Formation) of the Kalahari sediments. These aquifers are characterised by borehole yields generally less than 2 l/s, but with the ability to store large volumes of water. They are separated by the red clays of the Budin Formation acting as a confining layer. The basal sand and gravel formation and underlying bedrock can be regarded as one aquifer. In the absence of red clays, the upper sand and gravel aquifer of the Eden Formation are in hydraulic conductivity with the bedrock aquifers.
- The BIF and karst aquifers associated with the Ghaap Plateau dolomite formations are quite productive and support borehole yields > 40 l/s, in use at Kuruman, Sishen, Kathu, and Beeshoek. Delineation of dykes that may compartmentalize dolomite aquifers is critical to ensure sustainable use and reliable quantification of resource potential. Increased borehole yields, BIF and karst dolomite aquifers are often associated with contact ones of dykes and fault zones.
- These karstification zones which developed in the dolomite and along dolerite dyke contacts are highly permeable with blow yields intersected as high as 40l/s (SD2-26).
- The water level displacements from 5 up to 14m were surveyed between different dolomitic compartments as result of groundwater flow boundaries formed by the dolerite dykes.
- The geological formations, structural information, piezometric surface and water quality indicators were used to delineate groundwater management units. This enabled assessment of groundwater recharge at local scale, to assess how much water is locally available for use, at what quality and at which location. A total of six Groundwater Management Units (GMU's) were delineated for the entire SD2 area in order to quantify available water resources, estimate recharge volumes and calculate water balances on a sub-catchment management scale.
- The drilling and test pumping results confirm the presence of a semi-confined aquifer system in the dolomite and BIF formations.

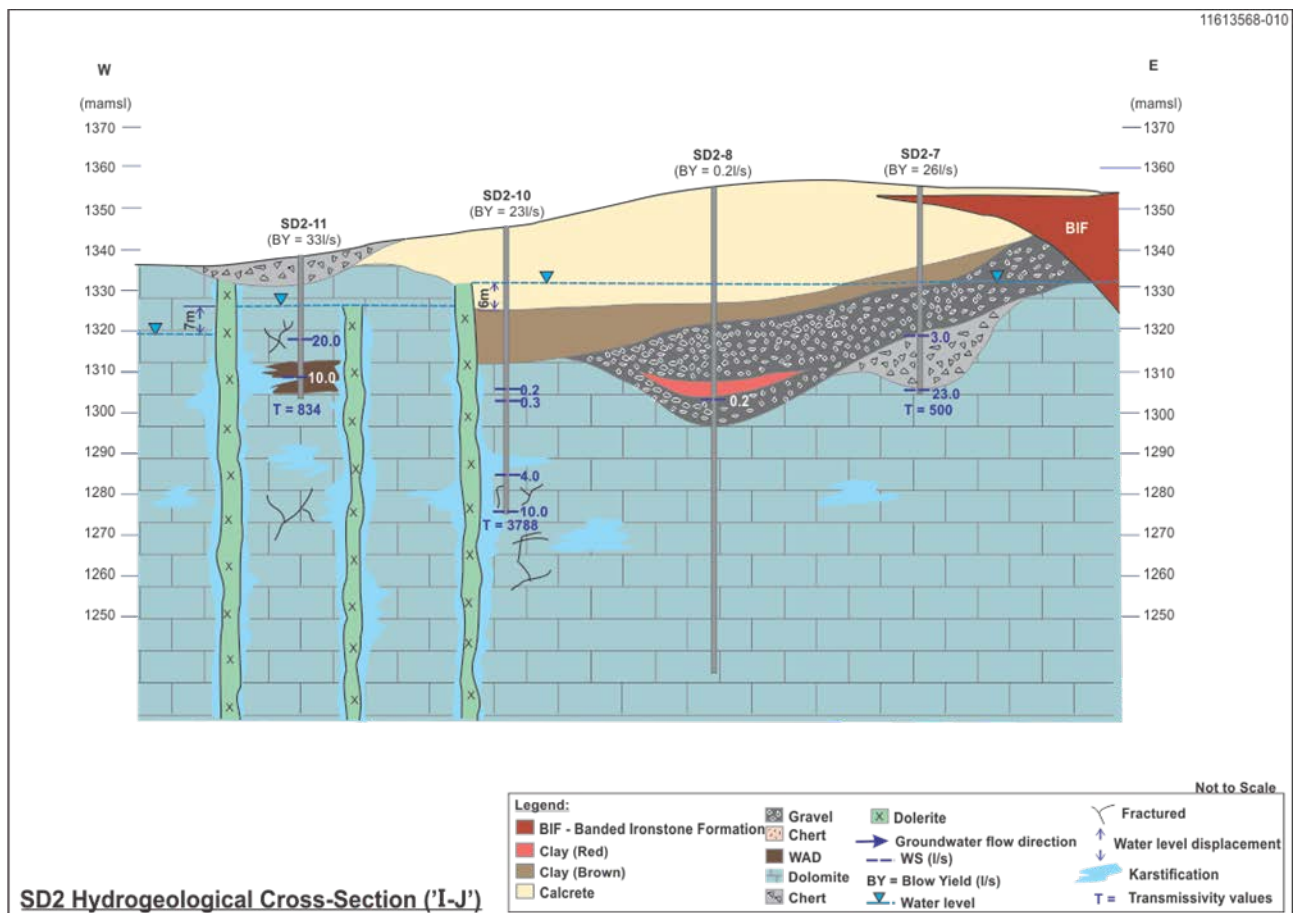


Figure 140: A West-East hydrogeological cross section east of the current Groenwaterspruit valley illustrating the components of the main aquifer system in the SD2 Area.

In closing, from the available drilling and test pumping data of SD1 and SD2, one shallow and three deeper aquifer systems were identified in the geological profile down to ~150 mbgl. They are as follows:

- Shallow calcrete system (CAS) with low permeability where saturated and merely overlying the MAS in low lying areas, i.e. stream valleys, plains and depressions (pans).
- Deep, main aquifer system (MAS) consisting of the following different [hydraulically connected] formations:
 - Basal Kalahari (T-Qk) sediments – intergranular, semi-confined aquifer system comprising of gravel and clay as the base of the T-Qk. This aquifer zone has a low permeability, retards and restrict lateral water movement, however, it acts as a significant storage unit for the deeper fractured & weathered hard rock aquifer system;
 - Banded Ironstone Formation (BIF) – fractured and weathered semi-consolidated BIF rubble, a semi-confined aquifer system with limited sub-surface exposure but moderate permeability; and
 - Dolomite Karst Aquifer System – unconfined to semi confined aquifer system (where overlain by thick basal Kalahari sediments, compartmentalised by dolerite dykes and highly permeable and significant aquifer storativity).

The T-Qk and BIF represents a combined hydraulic system and represents the upper section of the MAS with a moderate permeability, but high aquifer storativity. The Dolomite represents the basement aquifer system in the area with a much larger coverage, characteristically with high permeability and moderate aquifer storativity.

7.4.1 Monitoring of Shallow and Main Aquifer Systems

The groundwater levels measured in shallow and deep monitoring boreholes indicate that water levels of the deep (semi confined to confined aquifer) and shallow (unconfined) aquifer systems are not linked. These aquifer conditions were confirmed by aquifer testing results in the proposed SD1 and SD2 Areas wellfield terrains.

Water level elevation differences between the CAS and MAS were noted to be as high as 1.3 m (i.e. CAS water table elevation above the piezometric level in the underlying MAS).

In some cases, the daily electronic water level log indicates more direct responses to rainfall events than in those boreholes where only the deeper MAS were logged, i.e. the case of SD1-32S as illustrated in Figure 141 compared to the behaviour in the MAS, SD1-32M (Figure 142) for the period September 2013 to January 2014. It is clear from these illustrations that there is a hydraulic difference between the two water level time series datasets. Both sets show similar effects related to probably barometric changes in the area typical confirming semi/confined water level responses. These responses are present at several sites in the SD1 Area and could be the result of diurnal barometric pressure changes/weather changes. The water level behaviour in the CAS (Figure 141) is typical of a piezometric surface (unconfined, purged local aquifer system), whilst the water level behaviour in the MAS (Figure 142) is typical of a deep, hydraulically active (i.e. transient) aquifer system gaining and losing water over time. The Papkuil Area is situated in the discharge area of the SD1 Study Area.

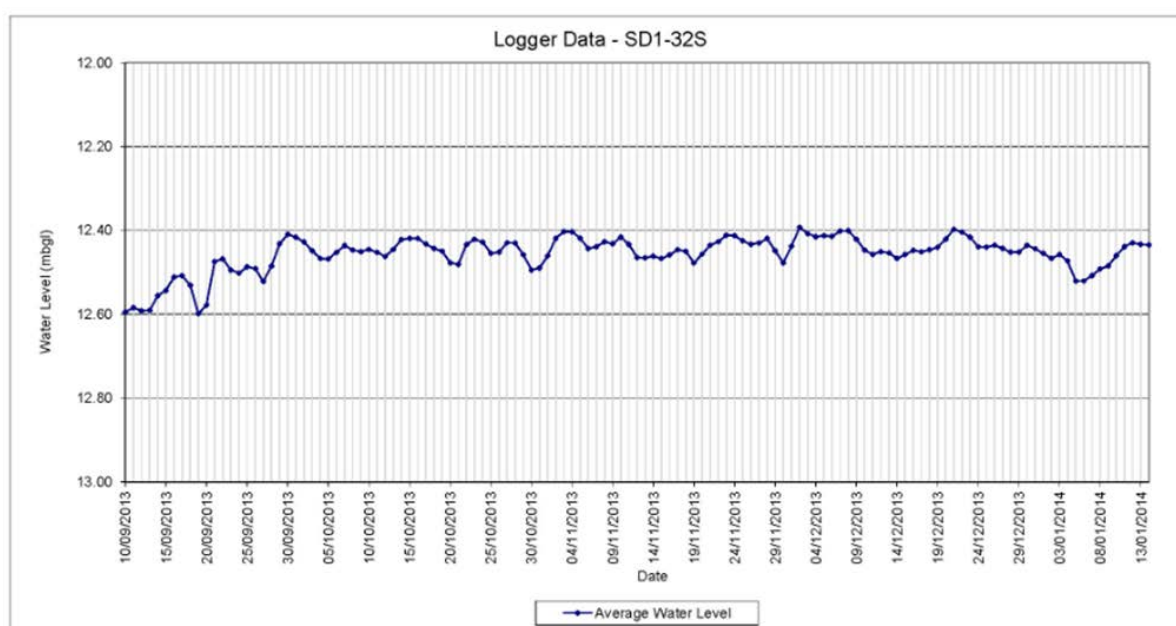


Figure 141: Water level trend in the CAS observed at monitoring site SD1-32S in the SD1 Area, Papkuil.

Unfortunately, no long-term time series dataset for the CAS is available in the SD2 Study Area. The T-Qk-BIF aquifer combination (viz. upper section of the MAS) has been explored in several exploration sites and at least 4 specifically drilled boreholes intercept this system – average water level depths are in the order of 20 mbgl, with blow-test yields varying between 0.1 l/s and 16 l/s. The water level time series behaviour for the SD2 Area (viz. SD2-16S) covering the 6¼ yr. monitoring period, is illustrated in Figure 143

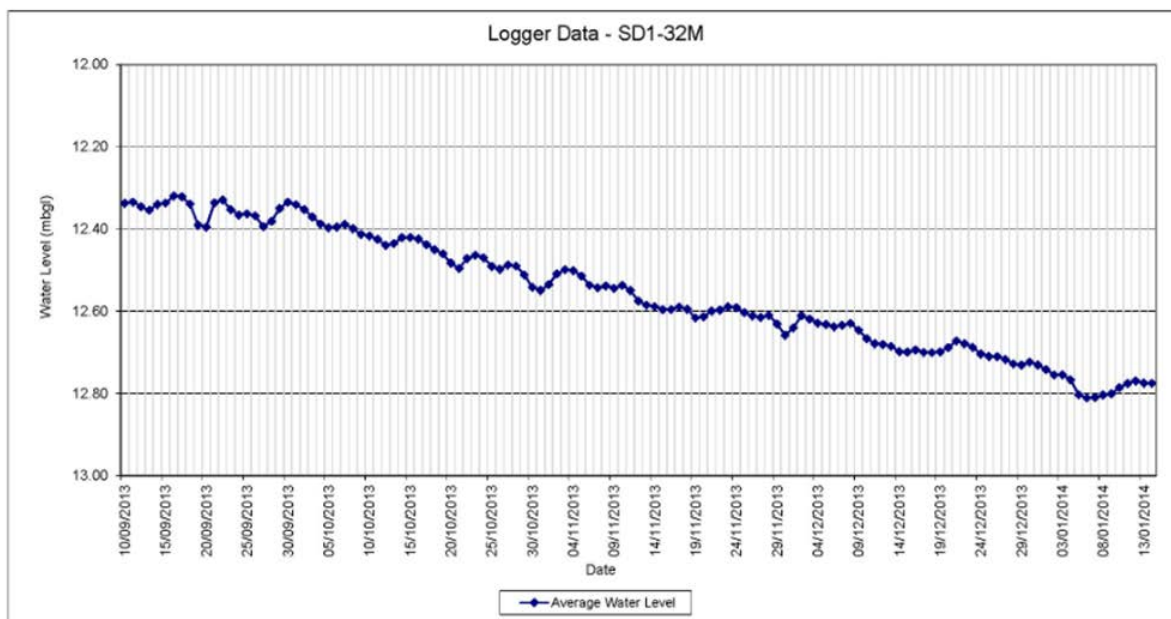


Figure 142: Water level trend in the upper section of the MAS (T-Qk-BIF gravel aquifer) observed at monitoring site SD1-32M in the SD1 Area, Papkuil.

The upper section of the MAS responds to rainwater recharge events, such as the January 2017 event. A prominent long-term water level recession trend is noted which is probably the result of natural aquifer drainages towards deeper parts of the larger MAS and ultimately driving distant discharges, i.e. groundwater abstractions and/or natural evapotranspiration near drainage channels. A similar response is noted for the deep MAS in the SD2 Area as illustrated in Figure 144.

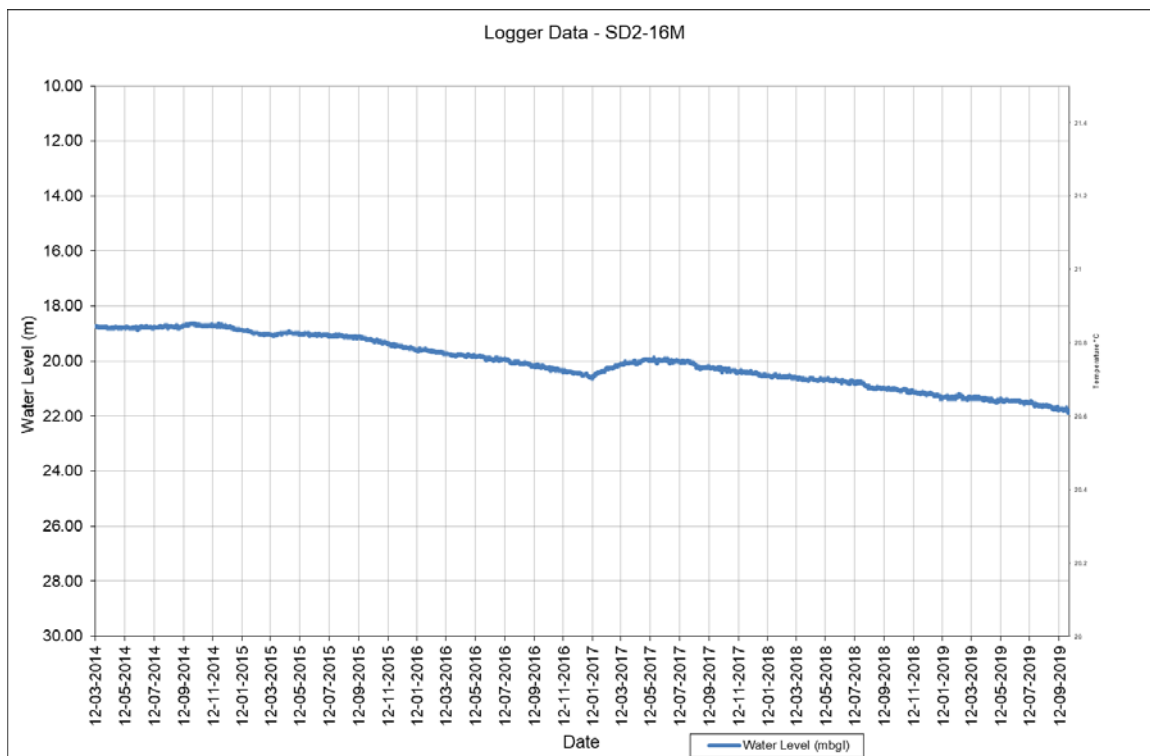


Figure 143: Water level trend in the upper section of the MAS (T-Qk-BIF gravel aquifer) observed at monitoring site SD2-16M in the SD2 Area

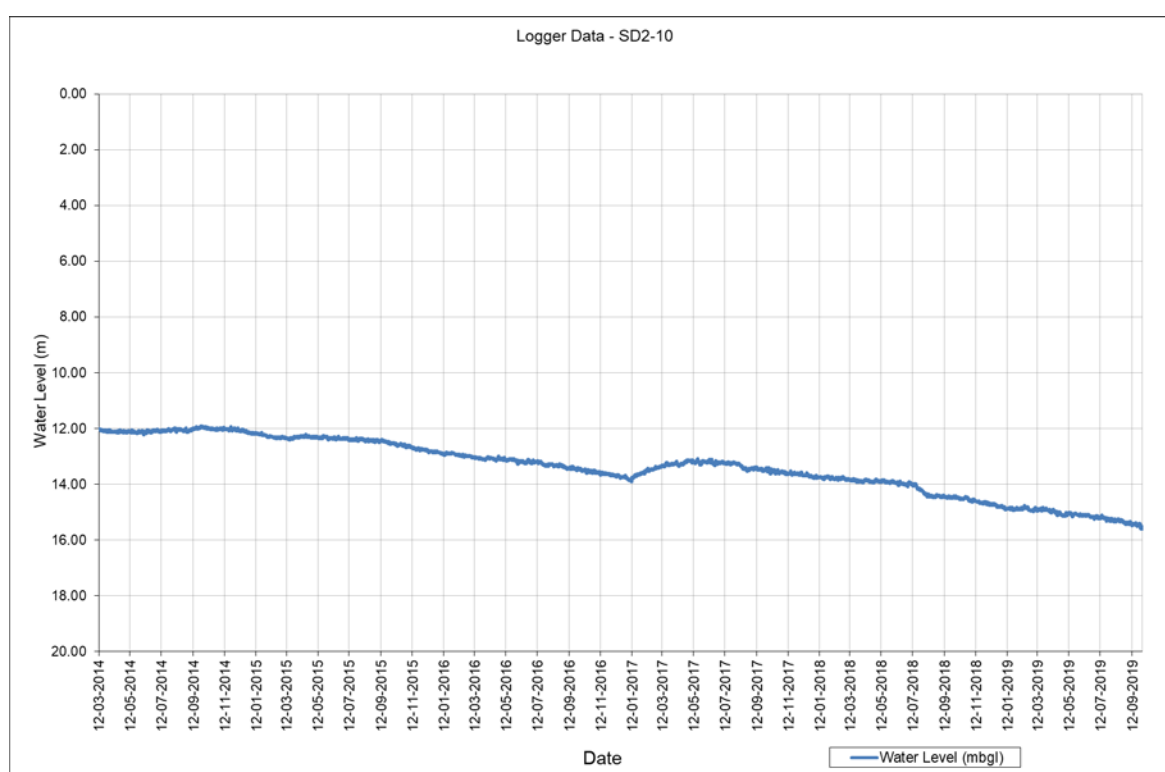


Figure 144: Water level trend in the deeper MAS (dolomite aquifer) observed at monitoring site SD2-10 in the SD2 Area

The hydraulic connection between the two aquifer subsystems (i.e. the T-Qk–BIF Gravel) and the Dolomite Aquifer) is probably high as the water level trends in the two systems, monitored over a distance of ~3.4 km's apart, are similar.

In closing, the current monitoring site selection needs to be maintained as it represents the important parts of both well field areas with a good background exposure. However, as the water supply programme runs over time, additional monitoring sites will have to be incorporated which necessitates boreholes situated on private land as well.

7.5 Natural Features Related to Hydrological Cycle

7.5.1 Depressions/Pans/Wetlands

There are several natural features present especially on the SD1 Area, which lies in the head water regions of the Ghaap Plateau drainage system. Important features such as the Groot Pan and linear drainage depressions/channels of the Steenbok and Kleinriet Rivers are part of the hydrological flow regime in the SD1 Area. These drainages tend to become non-perennial flow systems further east – although during wetter seasons, these channel depressions sustain local wetland systems.

There is a significant hydraulic link between accumulated surface runoff during wetter seasons in the existing depressions and drainage channels, i.e. feeding into the underlying highly permeable [karst] dolomite aquifer system and reversing this phenomenon a few kilometres downstream where water flows at a significant rate from the shallow aquifer system into pans and large depressions, i.e. the Daniëlskuil Pan and the Groot Pan. This phenomenon was specifically observed during the 1989-1990 [extreme] wet season in the area when a large pan formed which slowly dissipated over the years – mainly due to evaporation from the pan surface.

7.5.2 Dolomite Eyes and Springs

During the 2013 Hydrocensus Survey a total of 6 springs/shallow pools were identified in the SD1 Area. These sites are situated towards the east and northeast of the area and represent a “downstream” discharge area (Figure 19). An important aspect related to the positions of these Springs is that except the Klein Papkuil Springs, they are situated in different groundwater management units demarcated by a network of groundwater barriers in the SD1 Area, i.e. secondary intrusive dyke systems.

Only one spring were located [physically] during the 2013 Hydrocensus Survey on the SD2 Area, however, a total of six springs were indicated on the groundwater database – representing springs from a historic perspective of the area. These “non-perennial” springs are probably active flowing following extreme wet seasons (i.e. after the 1974-'76 “extraordinary wet season”) and therefore not regarded as contributing to long-term water supply sustainability. The position of these springs is illustrated in Figure 71.

The elevations of these springs over time (viz. time series trends) will have to be included in the monitoring programme as they will provide a good long-term background status of the water resources in and adjacent to the wellfield terrains.

7.6 Resource Sustainability over LoS

The summaries of the 2019 SD1 and SD2 Area's Model Update provides results of mitigated predictive simulations based on the (i) aquifer hydraulic parameters (obtained from several borehole test pumping results), (ii) assessment of recent rainfall-aquifer recharge scenarios, (iii) re-calibrations to limit the long-term aquifer saturation level (viz. water level trends). This modelling exercise was done to mitigate (viz. limit) the water level drawdown in both Areas to be within a <6 m limit by reducing the annual abstraction rates

The mitigated simulated results illustrate that long-term yield from the two Areas of 4.17 and 3.0 Mm³/a would result in an average drawdown on the Areas of just below 6 m (viz. 5.6 and 5.7 m respectively). Higher drawdowns in the wellfield terrains will take place, however, the long-term predictive modelling indicates values will still be below 8 m.

8.0 GROUNDWATER RESOURCE MANAGEMENT PROGRAMME

The sustainability and potential environmental impacts that could manifest due to the long-term groundwater abstraction from the SD1 and SD2 Areas requires that a specific resource management programme is designed and implemented before scheme development takes place. The impact that long-term climate variability might have on the sustainability of the water resources requires that a pro-active management plan is put in place and maintained as part of the daily scheme management operations.

The following crucial attributes with regard to a sustainable water resource management programme is predicted.

8.1 Abstraction Management Programme

8.1.1 Well field design

The final wellfield design will be based on the outcome of the 2019-2020 numerical modelling upgrade; however, no new production boreholes are planned and only those boreholes selected with an economical abstraction potential will be proposed as production sites.

During the numerical modelling upgrade of the SD1 and SD2 Areas specific care was taken to minimize water level drawdown-interference between nearby production boreholes. In such cases, a specific pumping schedule will be designed whereby the production yields will be altered to minimize the borehole interferences.

Special care was taken to place the production sites as far as possible from other large bulk water supply boreholes, i.e. in the case of the municipal water supply boreholes for Daniëlskuil and Postmasburg.

The SD1 and SD2 Areas have been demarcated into individual wellfield areas consisting of a number of proposed production boreholes (see section 8.1.3 below).

8.1.2 Abstraction volumes

The 2019 numerical modelling update are based on critical climate conditions and scenarios limiting the long-term aquifer saturation levels (i.e. water level trends). The following sustainable annual abstraction rates have been estimated from the 2019 update:

- SD1: 4.2 Mm³/a – Long-term median recharge based on hydrochemical mass balance is ~14 Mm³/a (existing use water use is ~4.2 Mm³/a); and
- SD2: 3.0 Mm³/a – Long-term median recharge based on hydrochemical mass balance is ~9 Mm³/a (existing use is ~2.1 Mm³/a).

Based on the individual borehole yield potential as per SD1 and SD2 well field assessments and geometry of each well field, abstraction rates will have to be specified in support of the engineering requirements of the scheme's infrastructure and optimal operation. These abstraction rates will have to be controlled to prevent over utilization of the borehole/aquifer system in specific areas. It is foreseen that for a scheme like this, special schemes operation modules will be available to manage individual borehole yields as depicted in the 2019-2020 numerical modelling scenarios.

It should be noted that the scheme's abstraction rates, expressed either as weekly/monthly/annual volumes will represent the most important management attribute in the public domain, i.e. with regard to the function of the Monitoring Committees [for example].

However, during wetter seasons, borehole abstraction schedules could be altered to allow aquifer storage recovery (viz. recharge/replenish) from long-term abstraction effects. It might indicate that [for example] SD1

Area might be operated at a lower than “recommended capacity” and SD2 Area at a higher than “recommended capacity” for short periods.

8.1.3 Production boreholes

Follow from the 2019-2020 numerical modelling upgrades, the following boreholes will be selected as final production boreholes:

Follow from the 2019-2020 numerical modelling upgrades, the following wellfield terrains have been identified as the optimum (viz. Mitigated 2019 Scenario):

- SD1 Terrain consists of four (4) Wellfield Terrains; they are as follows:
 - WF1 (4 h's)
 - WF2 (7 bh's)
 - WF3 (2 bh's)
 - WF4 (2 bh's) – Total: 17 boreholes.
- SD2 Terrain consists of four (4) Wellfield Terrains; they are as follows:
 - Northern Wellfield (4 bh's)
 - North-West Wellfield (2 Bh's)
 - Southern Wellfield (7 Bh's); and
 - Southern (N) Wellfield (3 Bh's) – Total: 16 boreholes.

The SD1 and SD2 wellfield terrain demarcations and proposed production boreholes are illustrated in Figure 40 and Figure 98 respectively.

8.1.4 Dynamic to critical water level drawdowns in SD 1 & –2 Areas

Based on the outcome of the 2019 numerical modelling (viz. 2019 Mitigated Scenario) of the SD1 and SD2 Wellfield Terrains so-called Dynamic and Critical water levels (viz. depth to the water table measured in monitoring and abstraction boreholes by means of a dip meter and /or a programmed data logger). These are explained as follows:

- Dynamic aquifer water levels depths are proposed as that level where the aquifer system is in balance with the effective rainfall recharge. Annual variances from this level of ~3.5 m could [for example] be proposed in highly sensitive areas and ~5.0 m in less sensitive areas; and
- Critical aquifer water levels represent the absolute maximum limit to which the aquifer can be dewatered. In the case of SD1 and SD2, this limit has been set at 7.0 m from a long-term average water level depth before certain risk factors such as the initiation of ground instability and/or vegetation growth might be impacted. This limit (viz. 7 m) is applicable on dolomite outcrop areas and where the calcrete cover is less than 6 thick. Area where the Kalahari Group and associated calcrete horizons are >6 m, a critical water level drawdown of 10 m is regarded as the critical figure.
- The 2019 Mitigation Scenario allows for a re-evaluation of the critical drawdown value and the following drawdown depths have been established:

- SD1 Terrain: Between 4.49 and 6.97 m with the average drawdown value at 5.8 m (Table 52). In the surrounding aquifer area, the drawdown values vary between 3.94 and 5.79 m with the average value ~5.6 m, and
- SD2 Terrain: Between 2.22 and 10.94 m with the average drawdown value at 6.6 m (Table 56). In the surrounding aquifer area, the drawdown values vary between 3.09 and 9.04 m with the average value ~5.7 m.

It should be noted that areas where the overlying Kalahari Group Aquifer System is present, these drawdown values could increase to between 10 and 15 m as the Kalahari Group “shields” the underlying dolomite aquifer system against ground stability deteriorations.

8.1.5 Well field operating rules

The proposed operating rules for production boreholes in SD1 (17 boreholes) and SD2 (16 boreholes) wellfields are:

- Proposed annual abstraction from each borehole should not be exceeded. To meet annual peak demands or for maintenance the daily pumping can be extended to 24 hours provided annual abstraction per borehole is not exceeded. This means that a reduced abstraction during low demand months will apply to not exceed the annual abstraction.
- Boreholes to be equipped with pumps operating on a maximum duty cycle of 20 hrs/day for SD1 and 18 hours per day for SD2 to abstract the proposed annual abstraction
- The predicted/simulated water level drawdowns (referencing the 2019 static levels) as shown in Appendix J and N) for each production borehole should not exceed the maximum annual drawdown. If reached or exceed the daily abstraction must be reduced by 20% or 4 hours less pumping per day.
- To protect the aquifer from excessive abstraction and limit long term water level drawdowns to mitigate the risk of sinkholes formation, it is recommended that:
 - If the maximum predicted drawdown for each borehole for the period ending 2043 is exceeded, the following reduced pumping schedule must be followed:
 - > 1.0m reduce abstraction by 20 % ~ 4 hours per day less pumping
 - > 1.5m reduce abstraction by 40 % ~ 8 hours per day less pumping
 - > 2.0m reduce abstraction by 60 % ~ 12 hours per day less pumping
 - > 2.5m reduce abstraction by 80 % ~ 16 hours per day less pumping
 - > 3.0m reduce abstraction by 100 % ~ Stop pumping

8.2 Hydrological monitoring:

8.2.1 Objectives/Protocols of Monitoring Programme

Due to the environmental and hydrological sensitivity of the Ghaap Plateau (SD1) and the Groenwaterspruit (SD2) areas, the objective would be to design and implement a comprehensive hydrological monitoring network and program covering the proposed well field areas as well as a significant coverage of the background areas representing a large portion of the D73A Quaternary Catchment. During the initial groundwater investigation, so-called Groundwater Management Units have been mapped – each with its characteristic hydrogeological features and demarcations. These GMU's will form the basis of the

hydrological monitoring programme. – 3 GMU's in the SD1 Area and 4 GMU's in the SD2 Area. The number of monitoring boreholes varies between one (1) for distant GMU's and eleven (11) for "well field" GMU's.

Monitoring protocols would cover the following aspects:

- Representative coverage of the well field areas and surrounding effected and propose un-effected areas (as per numerical modelling demarcations);
- Inclusion of SD1 and SD2 exploratory boreholes tapping all aquifer systems with specific focus on the shallow aquifer system in environmental sensitive areas, i.e. the Wild Olive "Forest Area"; and
- A dedicated monitoring and infrastructure administration including sufficient funding thereof. It is foreseen that costs for maintenance of the monitoring infrastructure (instruments and data loggers) will have to be secured as part of the long-term administration responsibility of the scheme managers.
- Establishment of SD1 and SD2 Monitoring Committees with a dedicated constitution and membership.
- A scheme monitoring reporting system whereby a categorised group of officials and individuals (public) could have access for (i) reporting (scheme operators/members of the monitoring committees) and (ii) general observations (public as part of I&AP's).

8.2.2 Monitoring network proposed for SD1 and SD2 Areas

The proposed monitoring network for SD1 and SD2 Areas wellfield were proposed and Figure 145 and Figure 146 and entails an initial baseline monitoring period of up to three years followed by a long-term monitoring program during the LoS (Life of Scheme)

The groundwater monitoring programme must comprise of:

- Quarterly water level monitoring of all accessible exploration boreholes for period of up to three years,
- Continuous water level monitoring at present installed electronic data loggers for period of up to three years,
- Rainfall monitoring should cover each of the proposed wellfields and an electronic data logging unit is required for each wellfield. Daily rainfall data is required. Quarterly bulk rainwater sampling is required to optimize annual recharge estimations for each wellfield.
- During well field implementation the proposed production and designated monitoring boreholes should be equipped with real time water level loggers and incorporated with DWA's resource monitoring program,
- Specific monitoring programme(s) for sensitive environmental areas, i.e. springs, wetlands and natural forests (i.e. the Wilf Olive forest in the SD1 Area) should be established.
- Monitoring of weekly abstraction rates at each production and standby borehole is required. These figures could be summarized into monthly/quarterly volumes as needed.
- After well field implementation, quarterly sampling of well field boreholes and analysis of samples for macro chemical elements as well as bacteriological analysis.
- During the 2019 Mitigation Scenario modelling review, 18 and 10 monitoring boreholes were selected as prime monitoring sites in the SD1 and SD2 Areas (Table 53 and Table 57) respectively. It is foreseen that at least 25% of the respective [reference] monitoring sites for the SD1 and SD2 Areas are equipped with "real-time" water level logging devices.

The proposed monitoring network for SD1 and SD2 Areas wellfield were proposed and Figure 145 and Figure 146 and entails an initial baseline monitoring period of up to three years followed by a long-term monitoring program during the LoS (life of Scheme)

- Quarterly water level monitoring of all accessible exploration boreholes for period of up to three years,
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- During well field implementation the proposed production and designated monitoring boreholes should be equipped with real time water level loggers and incorporated with DWA's resource monitoring program,
- Specific monitoring programme(s) for sensitive environmental areas, i.e. springs, wetlands and natural forests (i.e. the Wilf Olive forest in the SD1 Area) should be established.
- Monitoring of weekly abstraction rates at each production and standby borehole is required. These figures could be summarized into monthly/quarterly volumes as needed.

- After well field implementation, quarterly sampling of well field boreholes and analysis of samples for macro chemical elements as well as bacteriological analysis.
- During the 2019 Mitigation Scenario modelling review, 18 and 10 monitoring boreholes were selected as prime monitoring sites in the SD1 and SD2 Areas (Table 53 and Table 57) respectively. It is foreseen that at least 25% of the respective [reference] monitoring sites for the SD1 and SD2 Areas are equipped with “real-time” water level logging devices.

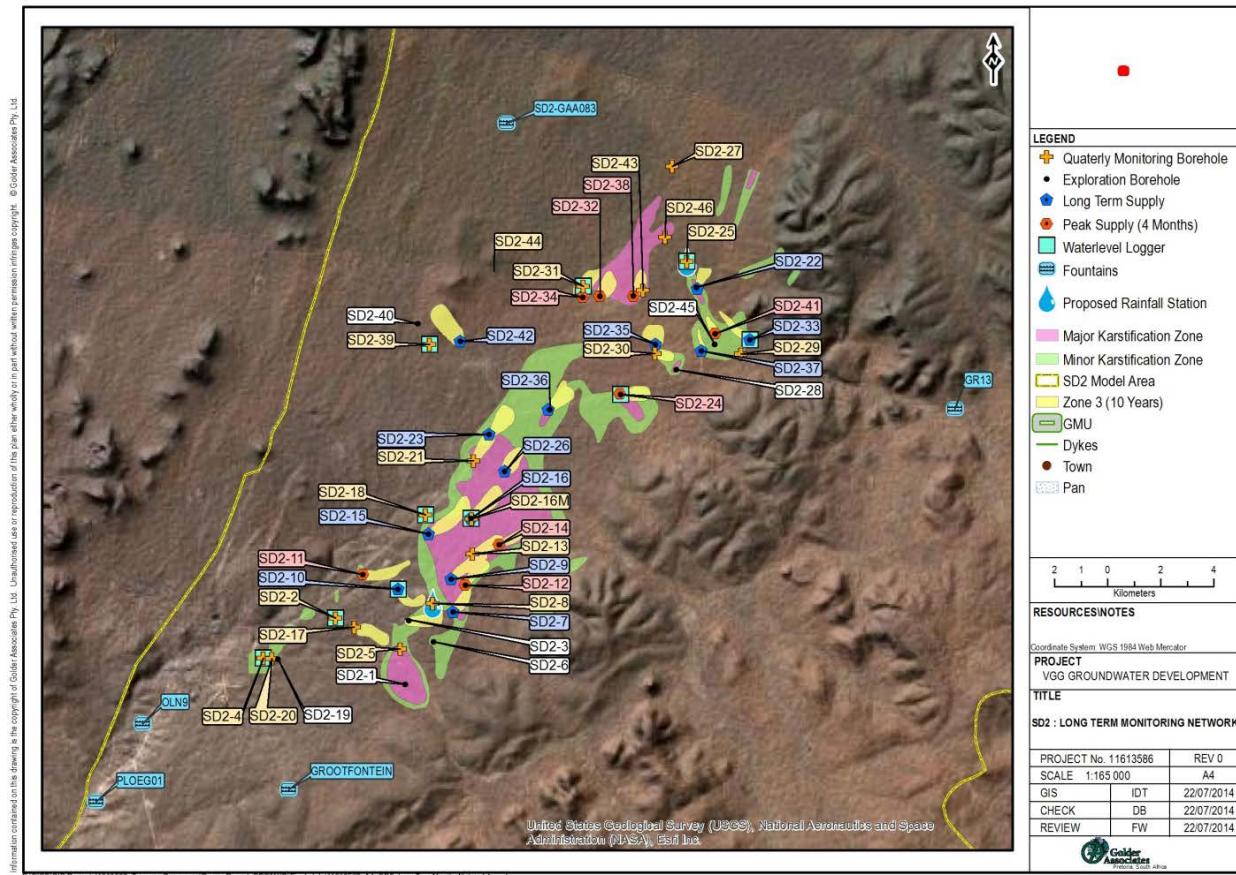


Figure 146: SD2 Area Long-term groundwater monitoring network

In closing, the designated monitoring boreholes, should be equipped for real time water level monitoring, to minimize private land access and to be incorporated with DWA's resource monitoring program. Real time water level monitoring data loggers should also be linked to Tshping Water User Association database to make monitoring data accessible to all groundwater users and interested parties.

8.2.3 Monitoring programme (Attributes)

The objective of the SD1 and SD2 Area's Monitoring Programme will be to design and implement a representative monitoring network supported by a dedicate monitoring programme operated and maintained by a group of responsible persons. The VGRWSS operators will have to take responsibility for the administration and financial procurement of the monitoring programme.

The following attributes are required to ensure that representative data and information are generated to guide and support the resource sustainability and limit the environmental status of the scheme and terrains.

8.2.3.1 *Baseline Conditions*

It is proposed that a set of quarterly water level measurements at (i) all the SD1 and SD2 Areas exploration borehole sites and (ii) a specific selection from private boreholes should be operational at least One-Hydrological-Cycle prior to the scheme development.

8.2.3.2 *Intervals*

The following monitoring intervals for Baseline Conditions are proposed:

- Rainfall: Event with hourly totals
- Abstraction figures: Weekly with monthly totals
- Water levels, as follows:
 - Weekly: Demarcated well field areas (impacted areas as per 2019 Model Updates in SD1 and SD2 Areas) –
 - Monthly: Within the GMU's demarcations, viz. a specific selection of boreholes
 - Quarterly: A specific selected group of monitoring boreholes including boreholes used for agricultural water supplies and municipal water supplies.

8.2.3.3 *Rainfall Depths*

- Rainfall input at 3 (three) positions in each of the SD Area (link to a GPRS system for continuous observations, i.e. hourly totals to daily totals). Annual bulk sampling of the rainwater to verify the actual aquifer recharge estimates (first three years of LoS).

8.2.3.4 *Water Quality*

Quarterly water quality sampling/analysis from a selected group of boreholes, including the production boreholes will be conducted. The background water quality of the SD1 and SD2 well field area is regarded as Ideal water quality; therefore, only a limited number of quarterly monitoring sites will be selected, viz, 5 per well field area.

8.2.3.5 *Abstraction Rates*

Monitoring at abstraction boreholes is regarded as a special monitoring protocol and should address the following hydrological attributes:

- Abstraction figures available on a weekly interval preferably by means of GPRS downloading to a suitable server system,
- Pumping and rest water levels (special water level data logger recommended with GPRS daily download facility).

8.2.3.6 *Water Levels*

Water level depths logging and dip measurements at a selected group of boreholes consisting of VGWSS boreholes, Municipal boreholes (Daniëlskuil and Postmasburg) and several boreholes on the surrounding private properties.

8.2.4 *Recommendation for WUL Conditions (Monitoring Attributes)*

The above-mentioned monitoring attributes and intervals will become part of the water use license conditions. A specific set of monitoring sites, i.e. abstraction boreholes, monitoring boreholes, wetland monitoring sites and rainfall sites will represent the proposed monitoring network. Intervals, as presented above (

8.2.5 Reporting format (Webpage Option)

It is foreseen that a Web-page system will be developed where all relevant monitoring results and important issues will be submitted. This activity should merge with the system currently operated by the Tshiping Water Users Association.

Bi-annual reporting of the hydrological monitoring programmes outcome is foreseen through a Webpage application. This reporting format will become the responsibility of the Scheme Monitoring Committees and therefore not discussed further in this BAR.

8.3 Reporting Community

8.3.1 Tshiping WUA

Although a groundwater information management system (IMS) based on the proposed critical attributes [as mentioned in section 8.2.3] will be operated by the scheme operating facility, monitor data will ultimately be submitted to the local WUA to update their information system. It would be good practice to supplement the dataset(s) between the two facilities to design a representative quaternary catchment wide monitoring network to assess the long-term regional groundwater flow pattern and climate impacts on a Quaternary Catchment scale, i.e. SD1 Area (central part of C92A & C92C) and SD2 Area (upper part of D73A).

For the SD2 Area, the Tshiping WUA would be the only Water User Association option responsible for the D73A (Groenwaterspruit) quaternary catchment. The SD1 Area, on the other hand, could become part of the Tshiping WUA's management area.

8.3.2 Agric Agricultural/Farmers Unions Representatives

It is foreseen that a representative from each of the SD area's agricultural unions/branches will be incorporated into the Scheme Monitoring Committees.

8.3.3 Regulators

As per water use licensing conditions, a set of monitoring boreholes will be identified as special purpose monitoring boreholes with a range of hydrological attributes, i.e. water levels and hydrochemical constituents monitored on a time series interval. Production boreholes will be part of the monitoring group and abstraction rates will be closely monitored and regulated. It is foreseen that for the first 5-years of the scheme operations period, bi-annual audits and assessments of the groundwater responses will be required by the regulators.

8.4 Proposed Hydrological Monitoring Committee

Due to the environmental concerns and sensitivity towards the abstraction of groundwater from a local resource in the Danielskuil-Papkuil and [upstream] Postmasburg Areas. It is expected that monitoring committees for SD1 and SD2 Terrains are established. Due to the differences between SD1 and SD2 ITO hydrogeological and environmental differences, it is proposed that two monitoring committees are established to deal with the SD1 and SD2 Areas separately.

8.4.1 Management Protocols

Firstly, the establishment of an executive committee is proposed consisting of representatives from (i) Scheme Operations, (ii) Water Resources Regulator (DWS), (iii) Agricultural Union, and (iv) Municipalities to select a larger group of representatives to represent an Areal Scheme Monitoring Committee (2x). The main objectives of a scheme monitoring committee is to (i) regulate the monitoring network/program aspects, (ii) acknowledge/discuss monitoring results/trends, (iii) high-light concerns/risks WRT the water resources & environment, and (iv) propose mitigation measures & implementation scenarios.

Subsidiary objectives of the Areal Scheme Monitoring Committees should address the following aspects of the monitoring programme:

- Establish a Code of Practice based on similar committees established in SA, i.e. The Langebaan Road Hydrological Monitoring Committee.
- Consists of a group of representatives with the following disciplines:
 - 1x Scheme Operation Manager (Water requirements, infrastructure and water demand trends),
 - 1x Representative from Water Resources Regulator, e.g. DWS (Legislation and Water Use Licence Audit),
 - 1x Representative from local Water Users Association (Monitoring information management and catchment hydrological status),
 - 1x Monitoring Programme Manager (Status and logistics of monitoring operations/programme/network),
 - 1x Agricultural/Farmers Union representative (Interests of the private landowners/farmers),
 - 1x Municipalities Water Resources Manager (Status of municipal water supply resource(s)),
 - 1x Scheme Hydrogeologist (Groundwater resource behaviour, impacts and potential risks), and
 - 1x Representative from agricultural community (Representing local farmers in wellfield terrains).
- Nominees required to address specific disciplines related to the environmental and water resources status of the SD1 and SD2 Areas –
 - Consultation/presentation by a specific discipline should be allowed only if arranged and authorised by the monitoring committee representatives for a specific committee meeting.
- Other issues ITO the committee's management criteria:
 - Chairperson should be from a regulating authority, i.e. Department of Water and Sanitation; and
 - Secretarial/administrative support should be from the Scheme Operating Body.

Objective nr. (iv) above, viz. “propose mitigation measures & implementation scenarios” could be regarded as the main objective of the monitoring committee, however, it should be designed within the operational jurisdiction of the scheme operators.

8.4.2 Proposed level of consent/control

Each monitoring committee should have the prerogative to (i) have insight to the monitoring data/information, (ii) preliminary review of applicable scientific evaluation(s) related to the water resource dynamics/environmental status based on expert scientific assessment of the water resource/scheme monitoring results, (iii) call for additional consultation(s) from experts on issues that requires further monitoring and assessments, and (iv) proposing mitigation procedures to limit risks and impacts on the water resources and environmental status.

In the case of extreme measures, i.e. shutdown of certain Production Sites to limit over-abstraction of a water source, a higher level of consent/control will have to be established, i.e. involving a higher level of regulation and scientific acknowledgement to design/implement measures that would balance the impact of abstraction versus local groundwater resource/environmental deterioration.

9.0 POTENTIAL RISKS AND PROPOSED MITIGATION MEASURES.

The CRR (comments and response report) assessment of the proposed scheme, specifically highlights the following aspects as general concerns/risks opted during the Public Participation process for the Environmental Impact Assessment during meetings on Delporthoop, Daniëlskuil, Postmasburg and Olifantshoek in 2019. The main topics of concern were as follows.

- a) Impact on Fauna and Flora (e.g. Wild Olive “Olienhout” trees in SD1 Area)
- b) Impacts on groundwater resources (viz. aquifer systems):
 - i) Regional lowering of shallow, and to a lesser degree deep aquifer saturation levels (i.e. long-term water level recession impacting on domestic and stock water supplies),
 - ii) Irregular aquifer recharge events due to [medium-term] climate variation(s),
 - iii) Abstraction (or production yield) management,
 - iv) Impacts on domestic and stock watering groundwater resources,
 - v) Sustainability of wetlands and springs, and
 - vi) Potential groundwater and surface water quality deterioration.
- c) Ground stability is a concern for infrastructure.
- d) Lack of catchment-wide hydrological monitoring and data management.
- e) Illegal Availability of annual auditing information of prescribed WUL conditions, and
- f) Protection of scheme infrastructure and private property security arrangements.

The above-mentioned risks and preliminary mitigation measures are listed in Table 61.

Table 61: Listing of potential risks and mitigation measures for SD1 and SD2 Areas

Risk #	Physical impact	Impacted by....	Recurrence Rate ¹	Level of Impact ²	Comments
					<i>Preliminary Mitigation Measures</i>
a)	Water level decline to below tree root system.	Long-term abstraction overrides annual recharge volume.	Cyclic	Medium (specific areas within SD1 only).	Not a phreatophyte, unsaturated zone replenished annually. Annual growth rate may not be impacted. • <i>Site specific monitoring programme for study cases.</i>
b) i)	Water level declines to below private borehole water strikes. (domestic and stock watering bh's).	Production yield of scheme overrides annual replenishment of aquifer system	Cyclic	Medium (wet-dry seasons) to High (drought cycle)	Many domestic and stock water boreholes are shallow boreholes (<20 m). Water level declines of <0.5 m might impact wetlands and spring flows. • <i>Limits for annual abstraction rates specified see Section</i> • <i>Limits for long-term water level decline set for SD1 and SD2 at ~6 m</i> • <i>Re-drilling of affected boreholes an option; and</i> • <i>Adjustment of Scheme Production Yield in affected wellfield terrains.</i>
b) ii)	Effective rainfall depths <35 mm/event – can't generate rainwater infiltration.	Variation in rainfall event depths due chaotic weather patterns.	Cyclic	Sporadic during stormy weather patterns; Medium during normal rainfall patterns; and Permanent during drought periods.	Recharge is highly variable in the Northern Cape Region; however, a few high intensity rainfall events can generate a significant recharge pulse causing water level rebounds of several meters lasting up to 2-years. • <i>Effective management of the production yields to cover periods of lower recharge.</i>

Risk #	Physical impact	Impacted by....	Recurrence Rate ¹	Level of Impact ²	Comments ----- Preliminary Mitigation Measures
b) iii)	Depleting water level in wellfield terrains.	Low groundwater recharge and overriding sustainable yield.	Medium-term	High	Due to a season with low rainfall the aquifer recharge may not replenish the aquifer storage to secure a sustainable yield for the coming years. <i>An Abstraction Management Programme is proposed whereby the production yields will be adjusted according to replenishment of the aquifer storage. May also require a partial, or total wellfield shutdown.</i>
b) iv)	Lowering of water table in private boreholes.	Scheme abstraction within 2 km's from private boreholes.	Cyclic to long-term (>7 yrs).	High	Water tables in the wellfield terrains will oscillate due to hydrological conditions and abstraction. Higher, seasonal water table recessions are expected due to groundwater abstractions, but rebounds take place (see Figure 105 to Figure 107). <i>The monitoring programme needs to prematurely identify such cases and addressed by a hydrogeological assessment.</i> <i>Measures in the worst case (viz. depleting aquifer storage) could include a [temporary] wellfield shutdown.</i>
b) v)	Shallow water borne systems driven by groundwater are not replenished and could "dry-out".	Negative water balance between recharge and water use.	Sporadic.	Medium to High.	Medium to long-term water level recession trend lower natural water supplies to wetlands and springs. Wellfields demarcated to have limited, if any effect on wetlands and springs and groundwater compartment boundaries create manageable drawdown scenarios.

Risk #	Physical impact	Impacted by....	Recurrence Rate ¹	Level of Impact ²	Comments ----- Preliminary Mitigation Measures
					Wetlands and springs (environmental concern) will be included in hydrological monitoring program.
b) v)	Water quality deterioration (groundwater and surface water sources).	Local, surface pollution in wellfield areas and due to some agricultural practices.	Sporadic		Dolomite aquifer systems are significantly vulnerable for pollution; especially surface generated. ----- Wellfield protection delineations will be implemented,
c)	Development of dolines and sinkholes in shallow (e.g. <50 m) dolomite rock formations.	Depleting groundwater level elevations.	Sporadic.	Low	A sporadic phenomenon during high rainwater run-off following prolonged drought cycles. Low impact foreseen due to limited infrastructure in wellfield terrains. Expected to become a concern when water levels drop >6 m in “open” dolomite terrains and >12 m in areas covered by >6 m Kalahari Group sediments and calcrete. ----- A high-level dolomite stability review was conducted.
d)	Insufficient assessment of medium/long-term impacts.	Lack of infrastructure, logistics and funding.	Sporadic.	High	Several aspects responsible for resource sustainability risk, i.e.: - Current hydrological networks/programmes not integrated - No catchment-wide hydrological monitoring program established – expect large gaps

Risk #	Physical impact	Impacted by....	Recurrence Rate ¹	Level of Impact ²	Comments ----- <i>Preliminary Mitigation Measures</i>
					• Lack of actual abstraction figures in most levels of water use; and • SD1 and SD2 Areas hydrological monitoring programme to report to catchment regulating authority, i.e. Tshiping WUA. • <i>Scheme hydrological monitoring programme and network need to be implemented at least 2x hydrological cycle pre-LoS;</i> • <i>Hydrological monitoring programme logistic and funding structure to be established and implemented (operated by Scheme managers); and</i> • <i>Biannual (6-month interval) assessment and annual water resources status review for scheme monitoring programme.</i> • <i>A Scheme Monitoring Committee is foreseen with consisting of a group of representatives from various disciplines.</i>
e)	Sustainable management of scheme production yield.	Illegal water users.	Sporadic.	High	A water balance for each of the demarcated production areas need to be established. The SD1 and SD2 Areas consists of several “so-called” Groundwater Management Units where scheme and private production will occur concurrently. Abstractions by surrounding users is an important aspect of the overall catchment water balance/sustainability.

Risk #	Physical impact	Impacted by....	Recurrence Rate ¹	Level of Impact ²	Comments ----- Preliminary Mitigation Measures
					- The Scheme Hydrological Monitoring Programme needs to be integrated with surrounding water use cases, i.e. mines and municipalities; and - Delegates selected for the proposed Scheme's Monitoring Committees will have to participate and present water resource information.
f)	Deterioration of monitoring infrastructure.	Loss of monitoring equipment and subsequently information.	Sporadic.	High	Monitoring equipment that was installed in the SD2 Area were stolen since installing them in 2013/'14. The monitoring infrastructure required for the proposed hydrological monitoring network will consist of sensitive equipment, i. e' weather stations and rainwater samplers. Limited infrastructure funding for the required monitoring logistics prohibited short-term replace of vandalised/stolen equipment. An appropriate security arrangement is required.
		¹ <u>S</u> poradic (unconditional), <u>C</u> yclic (seasonal), or Medium-term (i.e. ~5 to 7 yr.). ² <u>L</u> ow (reset immediately), <u>M</u> edium (within 1x hydrologic cycle), High (require a 1-in-5 yr. extraordinary event to recover/lack of Scheme Management)			

9.1 Abstraction Impacts on Areas Outside SD1 & SD2 Areas

The impact on aquifer saturation levels, i.e. water levels in the wellfield terrains have been modelled in initially in 2014 (2014 Scenario) and in 2019 (predictive simulations). The latter modelling addressed a long-term, forward simulation applying predicted rainfall based on an observed period between 1993 and 2016 (up to 2044).

As noted, the original abstraction volumes of the SD1 and SD2 Areas were decreased from 6.6 to 4.2 Mm³/a and 4.3 to 3.0 Mm³/a, respectively. A significant decrease in the special distribution of the higher 6-8 m drawdown zone between the 2014 and 2019 scenarios is predicted as discussed and illustrated in Figure 118 and Figure 119 and Figure 129 and Figure 130 respectively.

In closing, it is important to note that no drawdown values below 2 meters are visualised to account for the inaccuracy in the model calibration, which is within the expected seasonal variability of water table elevations. It is likely that any drawdown below 2 meters is within the range of natural water table fluctuations and therefore any potentially affected groundwater dependent ecosystem therefore adapted to it. Similarly, potential groundwater users are unlikely to recognise such drawdown as borehole yields are typically not significantly impacted by such seasonal fluctuations.

9.2 Area(s) of Concern

The scheme's annual abstraction rate falls within the long-term groundwater reserve determination values estimated by external studies, viz. GRDM and GYMR for the two quaternary catchments, i.e. C92A (SD1 Area) and D73A 9SD2 Area). However, long-term water level trends in the wellfield terrains may fall into short-term (viz. hydrological seasons) to ½-medium term (i.e. 3±1 yr.) recessions that could drop the water level in the wellfield terrains to the beyond the predicted drawdown range of 6 to 8 m. This is mainly due to seasonal variations in the groundwater recharge input. Complete reverse of these negative trends occurs "naturally" and medium-term aquifer storage losses could be "recovered" within a few weeks/months following good rainfall input.

In closing, due to the compartmentalization of the SD1 and SD2 Areas into Groundwater Management Units, the different wellfield terrains are hydraulically isolated from the surrounding aquifer systems and it is expected that water level trends in the areas outside these terrains would remain within the predicted range of <6 m over the LoS.

10.0 RECOMMENDATIONS

The following recommendation for the groundwater assessment and management requirements are proposed:

10.1 Groundwater Management Programme

A groundwater management programme describing the following components is recommended:

- An Abstraction Management Programme for (i) the Wellfield design, (ii) proposed Abstraction Volumes (based in an updated scenario of the 2019 Modelling Update for SD1 and SD2 Areas), and (iii) a list of Proposed Long-term Production Boreholes as directed by the outcome of the 2019 Modelling Update.

Furthermore:

- A Dynamic water level drawdown scenario in the SD1 and SD2 Areas have been estimated at ~6 m below a background reference water level depth (i.e. reference elevation); thus, meaning this level will a long-term management limit for the scheme operations; and

- A Critical water level drawdown scenario in the different wellfield terrains have been estimated which is in the order of ~7 m below an average background reference water level elevation. This drawdown may be as high as 10 m in the areas where the deeper dolomite/banded iron formation aquifer system is overlain by more than 6 m Kalahari Group sediments, including the calcrete horizon present in large parts of the wellfield terrains.

In closing, an applicable data manager system will have to be developed for storage and evaluation of datasets on a prescribed interval, i.e. weekly bases for at least “one-Hydrological-Cycle” after the first abstraction takes place. The information generated from the different datasets should be made accessible on a public network, i.e. Webpage system.

10.2 Hydrological Monitoring Programme and Committee

A dedicated hydrological monitoring programme (and network) is foreseen that will generate (i) rainfall depths, (ii) rainwater hydrochemistry, (iii) abstraction figures, (iv) water levels, and (v) groundwater quality. Representative hydrological monitoring networks for the SD1 and SD2 Areas have been suggested in the initial SD1 and SD2 hydrogeological studies.

In addition, private and scheme exploration boreholes, viz. not solely abstraction boreholes, will be assigned for long-term monitoring in SD1 and SD2 Areas and should be implemented at least two years prior to the implementation of the abstraction scheme.

In closing it is recommended that a site specific, i.e. SD1 and SD2 Area representative Monitoring Committee is established during the scheme implementation phase to observe and guide [where necessary] the proposed monitoring programme. Members of the committee should be able to support the logistical and juridical aspects of the monitoring programme – specifically access to private land to monitor the background hydrological attributes required to manage the groundwater resources in the production areas.

10.3 Implementation of Mitigation Measures

A description of the impacts and related (preliminary) mitigation measures are discussed in section 9.0 and summarised in Table 61. References of the mitigation measures are provided as included in more descriptive sections the BAR. Refinement, and obviously of these mitigation measures are required in future.

11.0 REGULATORY MEASURES

The abstractions for the Scheme will have to be authorised and licensed by the regulation authority, i.e. the Department of Water and Sanitation. Although many other environmental aspects are included in the proposed activity, i.e. design, development and implementation of the Scheme, this BAR deals with the issues pertaining to the local water resources in the said SD1 and SD2 Areas. It is therefore recommended that the following water use attributes needs to address as *specific conditions* in the water use license application:

11.1 Water Use License & Auditing Attributes

The following aspects of a Water Use License related to the Vaal-Gamagara Rural Water Supply Scheme – Phase II should be included in the application:

- A complete geohydrological report (as per Government Notice GN. R 267 (Annexure B) including the following high-level assessments of :
 - Methodology Applied: hydro-census, geophysical surveys, drilling & test pumping, chemical analyses, recharge calculations, [numerical] modelling, availability assessment and aquifer

characterization – all of these aspects have been addressed in the 2014 hydrogeological study and the 2019 Update;

- Geohydrological Impacts: based on quantity, quality and groundwater management – all of these aspects have been addressed in the BAR, but further refinement is required, i.e. specific mitigation measures as the scheme abstraction progresses in future; and
- Groundwater monitoring system: a comprehensive monitoring programme and representative network will be developed with significant emphasis on the wellfields, surrounding private lands, quantity/quality trend analyses, collation of hydrological time series attributes (i.e. specific emphasis on rainfall/water characteristics). A representative Monitoring Committee is envisaged that will assess and guide the short-term monitoring logistics and activities. A Webpage link to an applicable data managing/evaluation system is foreseen.
- A comprehensive set of water resources attributes should be included in the Water Use License Conditions as objectives for annual audits of the activity.

Signature Page

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APPENDIX A

SD1 Hydrocensus

Borehole Number	Farm Name	Owner	Latitude	Longitude	BH Depth (m)	Discharge Rate (l/s)	BH Yield (l/s)	WL (mbgl)	Field EC (mS/m)	Field measured pH	Equipment	Use	Date Surveyed
SD1-GAA001	ROOIPAN PTN. OLIENSPRUIT	KOKKIE YORK	-28.3687	23.65721	50.39	6.03	-	-	79	6.74	S	AS	20120203
SD1-GAA002	ROOIPAN PTN. OLIENSPRUIT	KOKKIE YORK	-28.3687	23.65719	52.48	4.33	-	-	-	-	W	DA	20120203
SD1-GAA003	ROOIPAN PTN. OLIENSPRUIT	KOKKIE YORK	-28.3875	23.64321	43.13	0.52	-	-	54	7.5	W	AS	20120203
SD1-GAA004	ROOIPAN PTN. OLIENSPRUIT	KOKKIE YORK	-28.3767	23.62931	16.24	0.53	-	-	-	-	N	-	20120203
SD1-GAA005	ROOIPAN PTN. OLIENSPRUIT	KOKKIE YORK	-28.3894	23.62023	38.31	3.03	-	-	-	-	N	DA	20120203
SD1-GAA006	ROOIPAN PTN. OLIENSPRUIT	KOKKIE YORK	-23.3893	28.62065	45	-	-	8.89	-	-	N	-	20120203
SD1-GAA007	CARTERBLOCK PTN. DIKBOS	KOKKIE YORK	-28.35	23.61845	-	-	-	9.44	-	-	N	-	20120203
SD1-GAA008	CARTER BLOCK PTN. PAPKUIL	KOKKIE YORK	-28.3555	23.53243	130	-	-	-	78	7.93	N	-	20120203
SD1-GAA009	LANGVERWAGHT	G.P. DU PLESSIS	-28.3577	23.63797	-	-	-	5.22	112	6.57	W	AS	20120203
SD1-GAA010	LANGVERWAGHT	G.P. DU PLESSIS	-28.3576	23.63796	-	-	-	4.99	-	-	M	-	20120203
SD1-GAA011	LANGVERWAGHT	G.P. DU PLESSIS	-28.3574	23.63833	-	-	-	4.54	-	-	N	-	20120203
SD1-GAA012	ROOIPAN PTN. WITPUT	G.P. DU PLESSIS	-28.3737	23.67906	-	-	-	2.2	87	6.32	W	AS	20120203
SD1-GAA013	ROOIPAN PTN. WITPUT	G.P. DU PLESSIS	-28.3731	23.68378	-	-	-	-	-	-	W	-	20120203
SD1-GAA014	ROOIPAN PTN. WITPUT	G.P. DU PLESSIS	-28.4118	23.67877	-	-	-	-	162	6.2	W	AS	20120203
SD1-GAA015	ENGLAND	I.H. VERMEULEN	-28.3242	23.62187	31.6	0.55	-	-	75	6.58	W	DA	20120203
SD1-GAA016	ENGELAND	I.H. VERMEULEN	-28.30435	23.65370	-	-	-	-	111	6.4	W	AS	20120206
SD1-GAA017	CARTER BLOCK PTN. DIKBOS	KOKKIE YORK	-28.3223	23.61353	23	0.55	-	-	140	6.14	W	AS	20120206

Borehole Number	Farm Name	Owner	Latitude	Longitude	BH Depth (m)	Discharge Rate (l/s)	BH Yield (l/s)	WL (mbgl)	Field EC (mS/m)	Field measured pH	Equipment	Use	Date Surveyed
SD1-GAA018	CARTER BLOCK PTN. DIKBOS	KOKKIE YORK	-28.3538	23.59059	30.1	0.51	-	10.21	-	-	W	AS	20120206
SD1-GAA019	CARTER BLOCK PTN. DIKBOS	KOKKIE YORK	-28.3596	23.60183	29	0.51	-	-	-	-	W	AS	20120206
SD1-GAA020	CARTER BLOCK PTN. DIKBOS	KOKKIE YORK	-28.3779	23.61085	37.33	1.23	-	-	-	-	W	-	20120206
SD1-GAA021	CARTER BLOCK PTN. DIKBOS	KOKKIE YORK	-28.3784	23.61022	25.82	1.25	-	-	110	5.85	S	AS	20120206
SD1-GAA022	CARTER BLOCK PTN. DIKBOS	KOKKIE YORK	-28.3782	23.61039	-	-	-	12.07	-	-	W	AS	20120206
SD1-GAA023	CARTER BLOCK PTN. DIKBOS	KOKKIE YORK	-28.4095	23.59912	37.48	0.54	-	-	93	5.87	W	AS	20120206
SD1-GAA024	CARTER BLOCK PTN. LAUGHING WATERS	STEFAANS PRENS	-28.3115	23.5477	-	-	-	-	-	-	N	-	20120206
SD1-GAA025	CARTER BLOCK PTN. LAUGHING WATERS	STEFAANS PRENS	-28.3112	23.54797	25	-	-	16.19	91	7.03	W	DA	20120206
SD1-GAA026	CARTER BLOCK PTN. LAUGHING WATERS	STEFAANS PRENS	-28.311	23.5479	36.35	1	-	16.05	-	-	N	-	20120206
SD1-GAA027	CARTER BOX PTN. LAUGHING WATERS	STEFAANS PRENS	-28.3013	23.57529	75.2	6.21	-	-	-	-	M	DA	20120206
SD1-GAA028	CARTER BLOCK PTN. LAUGHING WATERS	STEFAANS PRENS	-28.3024	23.57499	-	3.2	-	-	69	6.61	W	AS	20040921
SD1-GAA029	CARTER BLOCK PTN. LAUGHING WATERS	STEFAANS PRENS	-28.3267	23.5845	-	-	-	2.4	75	7.21	N	-	20120206
SD1-GAA030	SEEKOEIVLEI	ADELE RENIER	-28.3607	23.72521	-	-	-	-	-	-	W	-	20120206
SD1-GAA031	SEEKOEIVLEI	ADELE RENIER	-28.3534	23.72964	-	-	-	5.32	103	7.26	W	-	20120206
SD1-GAA032	SEEKOEIVLEI	ADELE RENIER	-28.3535	23.73209	-	-	-	2.0	96	7.35	N	-	20120206
SD1-GAA033	SEEKOEIVLEI	ADELE RENIER	-28.3719	23.69451	-	-	-	-	-	-	W	-	20120206

Borehole Number	Farm Name	Owner	Latitude	Longitude	BH Depth (m)	Discharge Rate (l/s)	BH Yield (l/s)	WL (mbgl)	Field EC (mS/m)	Field measured pH	Equipment	Use	Date Surveyed
SD1-GAA034	SEEKOEIVLEI	ADELE RENIER	-28.3721	23.6949	33	1.3	-	-	84	7.41	W	AS	20120206
SD1-GAA035	SEEKOEIVLEI	ADELE RENIER	-28.3798	23.72443	9.83	6.05	-	-	-	-	W	DA	20120206
SD1-GAA036	SEEKOEIVLEI	ADELE RENIER	-28.3799	23.72452	-	-	-	1.64	-	-	W	DA	20120206
SD1-GAA037	SEEKOEIVLEI	ADELE RENIER	-28.38	23.72436	-	-	-	-	-	-	W	DA	20120206
SD1-GAA038	SEEKOEIVLEI	ADELE RENIER	-28.38	23.72434	-	-	-	2.27	83	7.2	S	DA	20120206
SD1-GAA039	ROOIPAN PTN. WITPUT	G.P. DU PLESSIS	-28.3729	23.68365	-	-	-	-	-	-	N	-	20120206
SD1-GAA040	TREWILL	ARRIE FOURIE	-28.3174	23.68554	-	-	-	5.21	-	-	W	AS	20120206
SD1-GAA041	TREWILL	ARRIE FOURIE	-28.3239	23.68731	-	-	-	6	-	-	W	AS	20120206
SD1-GAA042	TREWILL	ARRIE FOURIE	-28.3231	23.68888	-	-	-	-	-	-	W	-	20120206
SD1-GAA043	TREWILL	ARRIE FOURIE	-28.3133	23.70315	-	-	-	2.76	-	-	W	-	20120206
SD1-GAA044	TREWILL	ARRIE FOURIE	-28.3133	23.70326	-	-	-	2.84	-	-	W	AS	20120206
SD1-GAA045	CONTENT	ARRIE FOURIE	-28.3196	23.71148	-	-	-	2.45	89	7.43	W		20120206
SD1-GAA046	CONTENT	ARRIE FOURIE	-28.3194	23.73094	-	3.79	-	-	91	6.95	W	AS	20040921
SD1-GAA047	CONTENT	ARRIE FOURIE	-28.3193	23.73007	-	-	-	-	169	8.52	N	AS	20120206
SD1-GAA048	CONTENT	ARRIE FOURIE	-28.304	23.73417	-	-	-		137	6.98	W	AS	20120207
SD1-GAA049	TREWILL	ARRIE FOURIE	-28.2894	23.71482	-	-	-	3.27	-	-	M	AS	20120207
SD1-GAA050	TREWILL	ARRIE FOURIE	-28.2861	23.71331	-	-	-	8.81	-	-	W	AS	20120207

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SD1-GAA051	TREWILL	ARRIE FOURIE	-28.2809	23.6902	-	-	-	2.29	113	7.27	W	AS	20120207
SD1-GAA052	TREWILL	ARRIE FOURIE	-28.2947	23.68815	-	-	-	3.69	-	-	W	AS	20120207
SD1-GAA053	NIE TE VER	ARRIE FOURIE	-28.2857	23.65	-	-	-	-	-	-	W	AS	20120207
SD1-GAA054	NIE TE VER	ARRIE FOURIE	-28.2947	23.66068	100	8.89	-	-	-	-	M	DA	20120207
SD1-GAA055	NIE TE VER	ARRIE FOURIE	-28.2966	23.65955	-	-	-	-	91	7.59	W	DA	20120207
SD1-GAA056	AANDRUS	DAAN VAN	-28.2754	23.63783	-	-	-	-	100	7.12	W	AS	20120207
SD1-GAA057	CARTER BLOCK	KOKKIE YORK	-28.3562	23.53227	85	-	-	-	134	7.41	S		20120207
SD1-GAA058	HINTON GEORGE	LENNOX CLOETE	-28.2556	23.58974	-	-	-	15.76	-	-	W	AS	20120207
SD1-GAA059	HINTON GEORGE	LENNOX CLOETE	-28.2556	23.58979	-	-	-	15.84	-	-	W		20120207
SD1-GAA060	EXCELSIOR	LENNOX CLOETE	-28.2365	23.60668	-	-	-	-	-	-	W	AS	20120207
SD1-GAA061	EXCELSIOR	LENNOX CLOETE	-28.2403	23.58656	-	-	-	-	79	6.79	W	DA	20120207
SD1-GAA062	EXCELSIOR	LENNOX CLOETE	-28.2406	23.58659	-	-	-	12.66	-	-	W		20120207
SD1-GAA063	HINTON GEORGE	LENNOX CLOETE	-28.2701	23.56058	-	-	-	21.73	123	7.08	W	AS	20120207
SD1-GAA064	HINTON GEORGE	LENNOX CLOETE	-28.2826	23.57483	-	-	-	7.53	84	7.17	W	AS	20120207
SD1-GAA065	TEVREDE	COBUS VAN NIEKERK	-28.2699	23.68386	-	-	-	-	-	-	W	AS	20120207
SD1-GAA066	TEVREDE	COBUS VAN NIEKERK	-28.2718	23.67379	-	-	-	4.41	187	7.86	W	DA	20120207
SD1-GAA067	TEVREDE	COBUS VAN NIEKERK	-28.2747	23.67204	-	-	-	-	232	6.69	W	AS	20120207

Borehole Number	Farm Name	Owner	Latitude	Longitude	BH Depth (m)	Discharge Rate (l/s)	BH Yield (l/s)	WL (mbgl)	Field EC (mS/m)	Field measured pH	Equipment	Use	Date Surveyed
SD1-GAA068	TEVREDE	COBUS VAN NIEKERK	-28.2803	23.66856	-	-	-	4.92	114	7.12	W		20120207
SD1-GAA069	CARTER BLOCK PTN. MURRAY	MARIKA DE JAGER	-28.3811	23.58045	-	-	-	-	230	6.4	S	DA	20120207
SD1-GAA070	CARTER BLOCK PTN. MURRAY	MR A DE JAGER	-28.3731	23.58975	30	0.444	-	-	91	7.33	W	AS	20120207
SD1-GAA071	CARTER BLOCK PTN. MURRAY	MR A DE JAGER	-28.4155	23.57559	30	0.444	-	-	75	7.03	W	AS	20120207
SD1-GAA072	CARTER BLOCK PTN. BEADLE	HENNIE VAN ZYL	-28.3205	23.56594	50	0.02	-	6.53	102	7.17	N		20120207
SD1-GAA073	CARTER BLOCK PTN. BEADLE	HENNIE VAN ZYL	-28.3216	23.56481	50	0.05	3.6	-	137	7.0	S		20120207
SD1-GAA074	CARTER BLOCK PTN. BEADLE	HENNIE VAN ZYL	-28.3247	23.56469	50	-	0.1	-	111	7.2	N		20120207
SD1-GAA075	CARTER BLOCK PTN. BEADLE	HENNIE VAN ZYL	-28.318	23.54644	46	2.8	16.7	-	74	7.36	N		20120207
SD1-GAA076	CARTER BLOCK PTN. BEADLE	HENNIE VAN ZYL	-28.3186	23.54597	24.34	9.05	-	-	51	7.27	N		20120207
SD1-GAA077	CARTER BLOCK PTN. BEADLE	HENNIE VAN ZYL	-28.3189	23.54586	23	28	27.8	-	73	7.1	S	DA	20120207
SD1-GAA078	CARTER BLOCK PTN. BEADLE	HENNIE VAN ZYL	-28.3194	23.54573	46	8.3	27.8	-	69	7.74	M	DA	20120207
SD1-GAA079	CARTER BLOCK PTN. BEADLE	HENNIE VAN ZYL	-28.3238	23.54548	38	22	5.6	-	73	7.37	M	AI	20120207
SD1-GAA080	CARTER BLOCK PTN. BEADLE	HENNIE VAN ZYL	-28.3182	23.53948	50	8.3	5.6	-	72	7.11	S	DA	20120207
SD1-GAA081	CARTER BLOCK PTN. ROLPAN	HANNES MEYER	-28.4171	23.53039	-	-	-	-	93	6.89	W	AS	20120208
SD1-GAA082	CARTER BLOCK PTN. ROLPAN	HANNES MEYER	-28.4445	23.56155	-	-	-	-	114	7.03	W	AS	20120208
SD1-GAA083	ARBEIDSLOON	KEITH WILLIAMS	-28.3168	23.75672	30	-	-	4.48	144	7.28	W	AS	20120208
SD1-GAA084	CARTER BLOCK PTN. ROLPAN	HANNES MEYER	-28.4447	23.56174	-	-	-	6.55	-	-	W	AS	20120208

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SD1-GAA085	CARTER BLOCK PTN. ROLPAN	HANNES MEYER	-28.4455	23.56315	-	-	-	9.93	107	7.16	S	DA	20120208
SD1-GAA086	ARBEIDSLOON	KEITH WILLIAMS	-28.3169	23.75673	5	-	-	4.12	-	-	W		20120208
SD1-GAA087	ARBEIDSLOON	KEITH WILLIAMS	-28.3189	23.76824	18	-	-	3.69	131	7.24	W	AS	20120208
SD1-GAA088	ARBEIDSLOON	KEITH WILLIAMS	-28.3304	23.74239	30	-	-	-	107	6.91	W	AS	20120208
SD1-GAA089	ARBEIDSLOON	KEITH WILLIAMS	-28.332	23.73883	-	-	-	3.36	-	-	N		20120208
SD1-GAA090	ARBEIDSLOON	KEITH WILLIAMS	-28.3259	23.75706	18	-	-	-	154	7.23	W	DA	20120208
SD1-GAA091	GROOTVLEI	PIET AUSTIN	-28.3318	23.78396	30.15	0.52	-	-	169	7.02	W	AS	20120208
SD1-GAA092	GROOTVLEI	PIET AUSTIN	-28.3427	23.77807	14.2	0.71	-	3.37	115	7.2	W	AS	20120208
SD1-GAA093	GROOTVLEI	PIET AUSTIN	-28.3661	23.7657	17.12	8.01	-	-	91	7.12	W	AS	20120208
SD1-GAA094	GROOTVLEI	PIET AUSTIN	-28.3815	23.74695	-	-	-	-	-	-	W	DA	20120208
SD1-GAA095	GROOTVLEI	PIET AUSTIN	-28.3821	23.74723	-	-	-	1.48	-	-	N		20120208
SD1-GAA096	GROOTVLEI	PIET AUSTIN	-28.3826	23.74786	28.04	1.8	-	-	-	-	W	DA	20120208
SD1-GAA097	GROOTVLEI FOUNTAIN SMALL	PIET AUSTIN	-28.382	23.74756	-	-	-	-	78	8.17	N		20120208
SD1-GAA098	GROOTVLEI FOUNTAIN LARGE	PIET AUSTIN	-28.3798	23.74455	-	-	-	0.45	88	7.87	W	AS	20120208
SD1-GAA099	GROOTVLEI	PIET AUSTIN	-28.3761	23.73451	35.6	0.45	-	4.51	192	7.67	W	DA	20120208
SD1-GAA100	CARTER BLOCK PTN. SILVER STREAMS	JOHAN FAIHST	-28.3478	23.57931	40	-	-	-	-	-	W		20120208

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SD1-GAA101	CARTER BLOCK PTN. SILVER STREAMS	JOHAN FAIHST	-28.3605	23.56518	23.65	0.5	-	-	-	-	W		20120208
SD1-GAA102	CARTER BLOCK PTN. SILVER	JOHAN FAIHST	-28.3527	23.5834	40	-	-	-	-	-	W		20120208
SD1-GAA103	CARTER BLOCK PTN. SILVER STREAMS	JOHAN FAIHST	-28.3537	23.581	-	0.117	-	-	101	7.23	W	DA	20120208
SD1-GAA104	CARTER BLOCK PTN. SILVER STREAMS	JOHAN FAIHST	-28.3537	23.58082	-	-	-	-	113	6.96	N		20120208
SD1-GAA105	CARTER BLOCK PTN. SILVER STREAMS	JOHAN FAIHST	-28.3537	23.58079	56.04	1.41	-	-	146	6.8	S	AS	20120208
SD1-GAA106	CARTER BLOCK PTN. SILVER STREAMS	JOHAN FAIHST	-28.3529	23.58158	35	0.33	-	-	102	7.53	S	AD	20120208
SD1-GAA107	CARTER BLOCK PTN. OUTPOST	JOHAN FAIHST	-28.3451	23.56997	30.2	0.53	-	-	175	7.44	S	DA	20120208
SD1-GAA108	CARTER BLOCK PTN. SILVER	JOHAN FAIHST	-28.3407	23.5332	39	2.83	-	-	96	7.12	S	AS	20120208
SD1-GAA109	JONAS BANK	SAKKIE VAN	-28.2411	23.68916	-	-	-	3.62	124	7.3	W	DA	20050801
SD1-GAA110	JONAS BANK	SAKKIE VAN	-28.2421	23.68865	-	-	-	4.1	122	7.13	S	DA	20050801
SD1-GAA111	AANDRUS	DAAN VAN	-28.2581	23.62467	-	-	-	-	90	7.16	W	AS	20120208
SD1-GAA112	AANDRUS	DAAN VAN	-28.2625	23.64191	-	-	-	-	104	7.07	W	AS	20120208
SD1-GAA113	WEYMOUTH	DAAN VAN	-28.2937	23.62004	-	-	-	-	83	6.87	W	AS	20120208
SD1-GAA114	WEYMOUTH	DAAN VAN	-28.2982	23.59917	-	-	-	12.46	84	6.99	W	AS	20120208
SD1-GAA115	WEYMOUTH	DAAN VAN	-28.2822	23.59318	-	-	-	-	-	-	W	AS	20120208

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SD1-GAA116	WEYMOUTH	DAAN VAN	-28.2824	23.59311	17	-	-	11.66	84	7.05	N		20120208
SD1-GAA117	HARTEBEESPUT	JOHAN VISSER	-28.283	23.76047	17.6	-	-	2.54	137	-	W	AS	20040921
SD1-GAA118	HARTEBEESPUT	JOHAN VISSER	-28.2809	23.76026	-	-	-	-	89	-	W	DA	20040921
SD1-GAA119	HARTEBEESPUT	JOHAN VISSER	-28.2806	23.76014	-	1.5	-	3.3	89	7.17	S	DA	20120208
SD1-GAA120	HARTEBEESPUT	JOHAN VISSER	-28.2742	23.74522	-	-	-	11.7	189	-	W	AS	20040921
SD1-GAA121	HARTEBEESPUT	JOHAN VISSER	-28.2545	23.76097	-	-	-	4.8	-	-	W	AS	20040921
SD1-GAA122	HARTEBEESPUT	JOHAN VISSER	-28.2546	23.76092	-	-	-	2.97	-	-	S	DA	20120208
SD1-GAA123	HARTEBEESPUT	JOHAN VISSER	-28.2403	23.76648	-	-	-	11.7	147	7.02	W	AS	20120208
SD1-GAA124	HARTEBEESPUT	JOHAN VISSER	-28.2243	23.77303	-	-	-	6.61	115	6.24	W	AS	20120208
SD1-GAA125	HARTEBEESPUT	JOHAN VISSER	-28.256	23.75955	-	-	-	-	-	-	W		20120208
SD1-GAA126	HARTEBEESPUT	JOHAN VISSER	-28.2726	23.76978	-	-	-	-	151	7.03	W	AS	20120209
SD1-GAA127	HARTEBEESPUT	JOHAN VISSER	-28.2893	23.7517	-	-	-	-	-	-	W	AS	20040921
SD1-GAA128	CARTER BLOCK PTN. WALKER	JOHAN VISSER	-28.3762	23.56141	41.45	-	-	-	92	6.99	W	AS	20040921
SD1-GAA129	CARTER BLOCK PTN. WALKER	JOHAN VISSER	-28.3762	23.56164	-	-	-	-	95	7.14	W		20120209
SD1-GAA130	CARTER BLOCK PTN. WALKER	JOHAN VISSER	-28.3798	23.5266	24	-	-	19.05	103	6.99	W		20120209
SD1-GAA131	POENSKOPKRAAL	JOHAN DU PLESSIS	-28.5054	23.65206	-	-	-	5.04	202	7.0	S	DA	20120209
SD1-GAA132	POENSKOPKRAAL	JOHAN DU PLESSIS	-28.5052	23.65158	-	-	-	-	-	-	W	DA	20120209

Borehole Number	Farm Name	Owner	Latitude	Longitude	BH Depth (m)	Discharge Rate (l/s)	BH Yield (l/s)	WL (mbgl)	Field EC (mS/m)	Field measured pH	Equipment	Use	Date Surveyed
SD1-GAA133	POENSKOPKRAAL	JOHAN DU PLESSIS	-28.5026	23.64985	-	-	-	-	111	6.99	W	AS	20120209
SD1-GAA134	POENSKOPKRAAL	JOHAN DU PLESSIS	-28.5144	23.63826	-	-	-	5.46	166	6.93	W	AS	20120209
SD1-GAA135	ENGELAND	THEUNS	-28.3443	23.62028	30	-	-	-	-	-	W	DA	20120209
SD1-GAA136	ENGELAND	THEUNS	-28.3454	23.62038	25	-	-	-	-	-	W	AS	20120209
SD1-GAA137	ENGELAND	THEUNS	-28.3473	23.62114	30.78	-	-	-	-	-	M	AS	20120209
SD1-GAA138	ENGELAND	THEUNS	-28.3275	23.63677	40	-	1.0	-	-	-	W	AS	20120209
SD1-GAA139	ROCKLANDS	THINUS VAN DER	-28.4725	23.57099	27	2	-	9.3	-	-	W	DA	20040921
SD1-GAA140	ROCKLANDS	THINUS VAN DER	-28.4725	23.57102	-	-	-	-	91	7.27	W	DA	20120213
SD1-GAA141	ROCKLANDS	THINUS VAN DER	-28.4731	23.57524	-	-	-	-	84	7.35	W	AS	20040921
SD1-GAA142	ROCKLANDS	THINUS VAN DER	-28.4736	23.56889	-	-	-	-	-	-	W	AS	20040921
SD1-GAA143	INGLEWOOD PTN. ROCKLANDS	THINUS VAN DER SPUY	-28.4583	23.55253	55	0.3	-	-	81	8.31	W	AS	20040921
SD1-GAA144	INGLEWOOD	THINUS VAN DER	-28.4526	23.54254	-	-	-	18.44	106	6.85	W	AS	20120213
SD1-GAA145	INGLEWOOD PTN. ROCKLANDS	THINUS VAN DER	-28.4526	23.54246	-	-	-	18.44	-	-	W	AS	20120213
SD1-GAA146	STRYPAN	THINUS VAN DER	-28.4483	23.58052	-	-	-	-	86	7.46	W	AS	20120213
SD1-GAA147	ROCKLANDS	THINUS VAN DER	-28.4743	23.56881	-	-	-	8.66	-	-	S	DA	20120213
SD1-GAA148	ARRIESFONTEIN	GERRIE CLOETE	-28.2802	23.76801	40	-	-	3.42	89	7.23	S	DA	20120213
SD1-GAA149	ARRIESFONTEIN	GERRIE CLOETE	-28.2801	23.76747	9.14	-	-	3.74	-	-	W	DA	20120214

Borehole Number	Farm Name	Owner	Latitude	Longitude	BH Depth (m)	Discharge Rate (l/s)	BH Yield (l/s)	WL (mbgl)	Field EC (mS/m)	Field measured pH	Equipment	Use	Date Surveyed
SD1-GAA150	ARRIESFONTEIN FOUNTAIN	GERRIE CLOETE	-28.2796	23.76896	-	-	-	0.1	103	8.03	N	AS	20120214
SD1-GAA151	ARRIESFONTEIN	GERRIE CLOETE	-28.276	23.7802	-	-	-	-	113	7.2	W	AS	20120214
SD1-GAA152	ARRIESFONTEIN	GERRIE CLOETE	-28.285	23.77538	-	-	-	2.31	76	7.4	N		20120214
SD1-GAA153	ARRIESFONTEIN	GERRIE CLOETE	-28.3012	23.76636	-	-	-	30.5	94	7.15	W	AS	20120214
SD1-GAA154	CARTER BLOCK PTN. ELIM	DRIES SCHEEPERS	-28.3276	23.5423	40	-	6.7	-	73	7.43	S	DA	20120405
SD1-GAA155	STRYDPAN PTN. SELFHELP	THINUS VAN DER	-28.4139	23.62567	-	-	-	-	74	7.18	W	AS	20120214
SD1-GAA156	STRYDPAN PTN. SELFHELP	THINUS VAN DER	-28.4138	23.62559	-	-	-	-	-	-	W	AS	20120214
SD1-GAA157	STRYDPAN PTN. SELFHELP	THINUS VAN DER	-28.4265	23.60632	-	0.83	-	5.12	253	7.44	S	DA	20120214
SD1-GAA158	STRYDPAN PTN. SELFHELP	THINUS VAN DER	-28.4271	23.60638	-	-	-	4.81	-	-	N		20120214
SD1-GAA159	STRYDPAN PTN. SELFHELP	THINUS VAN DER	-28.4273	23.60636	-	-	-	-	183	7	W	AS	20120214
SD1-GAA160	STRYDPAN PTN. SELFHELP	THINUS VAN DER	-28.4281	23.60682	-	-	-	-	158	7.15	W	AS	20120214
SD1-GAA161	STRYDPAN PTN. SELFHELP	THINUS VAN DER	-28.436	23.61479	-	-	-	-	-	-	W	AS	20120214
SD1-GAA162	STRYDPAN PTN. SELFHELP	THINUS VAN DER	-28.4366	23.61514	-	-	-	-	87	7.54	W	AS	20120214
SD1-GAA163	HUISTENBOSCH	JACQUES JACOBS	-28.5381	23.61518	-	-	-	5.03	173	7.0	N		20120214
SD1-GAA164	HUISTENBOSCH	JACQUES JOCAOBS	-28.5377	23.61544	-	-	-	-	-	-	W	AS	20120214
SD1-GAA165	HUISTENBOSCH	JACQUES JACOBS	-28.5375	23.61546	-	-	-	4.77	-	-	S	DA	20120214
SD1-GAA166	HUISTENBOSCH	JACQUES JACOBS	-28.5326	23.63141	-	-	-	4.74	121	7.94	W	AS	20120214

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SD1-GAA167	HUISTENBOSCH	JACQUES JACOBS	-28.523	23.62258	-	-	-	-	165	7.08	W	AS	20120214
SD1-GAA168	HUISTENBOSCH	JACQUES JACOBS	-28.5358	23.61678	-	-	-	-	-	-	W		20120214
SD1-GAA169	NOOITGEDACHT	THINUS VAN DER	-28.4451	23.63744	-	-	-	-	113	7.2	W	AS	20120214
SD1-GAA170	NOOITGEDACHT	THINUS VAN DER	-28.445	23.63725	-	-	-	4.0	-	-	N		20120214
SD1-GAA171	NOOITGEDACHT	THINUS VAN DER	-28.4416	23.63848	-	-	-	-	-	-	W		20120214
SD1-GAA172	NOOITGEDACHT	THUNIS VAN DER	-28.4416	23.63868	-	-	-	4.26	87	7.2	N		20120214
SD1-GAA173	SWARTDAM	THUNIS VAN DER	-28.4858	23.60299	-	-	-	10.89	116	7.02	W	AS	20120214
SD1-GAA174	SWARTDAM	THUNIS VAN DER	-28.4864	23.60309	-	-	-	-	108	6.93	W	AS	20120214
SD1-GAA175	SWARTDAM	THUNIS VAN DER	-28.529	23.58341	-	-	-	-	88	7.4	W	AS	20120216
SD1-GAA176	ROCKLANDS	THINUS VAN DER	-28.4727	23.56829	-	-	-	9.61	130	7.06	N		20120216
SD1-GAA177	INGLEWOOD	HANNES	-28.4763	23.5309	30	-	-	17.1	96	7.12	W	AS	20120216
SD1-GAA178	INGLEWOOD	HANNES	-28.4775	23.53133	-	-	-	17.13	-	-	N		20120216
SD1-GAA179	INGLEWOOD	HANNES	-28.4997	23.52854	-	-	-	20.18	74	7.4	W	AS	20120216
SD1-GAA180	INGLEWOOD	HANNES	-28.494	23.54731	40	-	-	-	160	6.94	W	AS	20120216
SD1-GAA181	INGLEWOOD	HANNES	-28.494	23.54744	40	-	-	-	147	6.93	W	AS	20120216
SD1-GAA182	INGLEWOOD	HANNES	-28.4931	23.54769	40	-	-	10.94	93	7.1	N		20120216
SD1-GAA183	INGLEWOOD	HANNES	-28.4929	23.54795	-	-	-	11.87	106	7.3	W	DA	20120216

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SD1-GAA184	NOOITGEDAGHT	GERT FABER	-28.4642	23.64622	21	-	-	-	83	7.44	W	AS	20040921
SD1-GAA185	NOOITGEDAGHT	GERT FABER	-28.4638	23.64679	42	1	-	9.1	158	7.1	Q	DA	20040921
SD1-GAA186	NOOITGEDAGHT	GERT FABER	-28.4816	23.64072	14	-	-	2.57	-	-	Q	AS	20040921
SD1-GAA187	NOOITGEDAGHT	GERT FABER	-28.4818	23.64053	-	-	-	5.32	-	-	W	AS	20040921
SD1-GAA188	CARTER BLOCK PTN. ELIM	DRIES SCHEEPERS	-28.3284	23.54857	40	-	-	21.9	-	-	W		20120405
SD1-GAA189	CARTER BLOCK PTN. BEADLE	DRIES SCHEEPERS	-28.3392	23.55776	30	-	0.4	-	488	7.43	W	AS	20120410
SD1-GAA190	CARTER BLOCK PTN. ELIM	DRIES SCHEEPERS	-28.3367	23.57397	-	2.8	8.3	1.66	470	7.2	S	AS	20120410
SD1-GAA191	PADDAFONTEIN	CHRISTO	-28.3825	23.7168	30.48	1.82	-	-	80	7.05	S	DA	20040921
SD1-GAA192	PADDAFONTEIN	CHRISTO	-28.3826	23.71689	-	-	-	2.01	-	-	N		20120410
SD1-GAA193	PADDAFONTEIN	CHRISTO	-28.3827	23.71704	-	-	-	2.41	-	-	W	AS	20120410
SD1-GAA194	PADDAFONTEIN	CHRISTO	-28.3828	23.71713	-	-	-	-	-	-	W	DA	20120410
SD1-GAA195	PADDAFONTEIN	CHRISTO	-28.382	23.74681	-	-	-	-	-	-	W	AS	20120410
SD1-GAA196	PADDAFONTEIN	CHRISTO	-28.4142	23.68984	78.6	2.02	-	-	119	6.61	S	AS	20120410
SD1-GAA197	PADDAFONTEIN	CHRISTO	-28.4183	23.7241	47.18	1.23	-	-	83	6.7	S	AS	20120410
SD1-GAA198	FARM 523	LUCAS BURGER	-28.544	23.58809	-	-	-	7.0	132	7.17	W	AS	20040921
SD1-GAA199	FARM 515	LUCAS BURGER	-28.5137	23.56132	73	0.11	-	17.85	-	-	S	AS	20120410
SD1-GAA200	FARM 515	LUCAS BURGER	-28.5114	23.56269	73	0.11	-	21.9	112	7.52	S	AS	20120410

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SD1-GAA201	FARM 515	LUCAS BURGER	-28.5052	23.56528	-	-	-	28.3	-	-	S	AS	20120410
SD1-GAA202	FARM 515	LUCAS BURGER	-28.4876	23.57287	61	0.25	-	17.8	-	-	W	AS	20040921
SD1-GAA203	FARM 515	LUCAS BURGER	-28.4754	23.57414	-	-	-	-	105	7.17	W	AS	20040921
SD1-GAA204	KLEIN PAPKUIL	J GERS	-28.494	23.69337	-	-	-	7.59	102	6.78	W	AS	20040921
SD1-GAA205	KLEIN PAPKUIL	J GERS	-28.4844	23.71893	-	-	-	7.7	-	-	W	AS	20040921
SD1-GAA206	POENSKOPKRAAL-TBC	J GERS	-28.489	23.64554	-	-	-	-	106	6.8	W	AS	20040921
SD1-GAA207	PAPKUIL	J GERS	-28.4795	23.67383	-	-	-	0.56			W	DA	20040921
SD1-GAA208	ROOIPAN PTN. OLIENSPRUIT	KOKKIE YORK	-28.3717	23.65812	-	-	-	5.87	163	8.14	N		20121022
SD1-GAA209	PAPKUIL	J GERS	-28.4657	23.66907	14.7	-	-	3.8	92	7.41	W	AS	20040921
SD1-GAA210	PAPKUIL	J GERS	-28.4814	23.67608	-	-	-	-	-	-	W	AS	20040921
SD1-GAA211	KLEIN PAPKUIL	J GERS	-28.4991	23.69065	-	-	-	-	88	7.25	S	DA	20040921
SD1-GAA212	KLEIN PAPKUIL	J GERS	-28.4968	23.69196	-	-	-	5.74	90	7.4	W	DA	20040921
SD1-GAA213	PAPKUIL	VAUGHN MARAIS	-28.4789	23.67368	15.24	-	-	1.62	-	-	W		20040921
SD1-GAA214	PAPKUIL	VAUGHN MARAIS	-28.4793	23.674	-	0.83	-	0.56	75	7.6	N		20040921
SD1-GAA215	VLEIPLAAS	BOTHA MARKRAM	-28.3717	23.69357	48	-	-	-	-	-	W	DA	20120410
SD1-GAA216	VLEIPLAAS	BOTHA MARKRAM	-28.3685	23.69189	-	-	-	-	75	6.76	W	DA	20120410
SD1-GAA217	VLEIPLAAS	BOTHA MARKRAM	-28.3697	23.68975	-	-	-	2.84	-	-	N		20120410

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SD1-GAA218	VLEIPLAAS	BOTHA MARKRAM	-28.3538	23.68306	51.18	5.03	-	-	-	-	N	DA	20120410
SD1-GAA219	VLEIPLAAS	BOTHA MARKRAM	-28.3541	23.68582	-	-	-	-	111	7.33	W	AS	20120410
SD1-GAA220	ROOIPAN PTN. OLIENSPRUIT	KOKKIE YORK	-28.3692	23.65492	52.24	0.53	-	-	-	-	W	AS	20040921
SD1-GAA221	ROOIPAN PTN. OLIENHOUT	KOKKIE YORK	-28.3716	23.65812	-	-	-	10.04	-	-	N		20121022
SD1-GAA222	PADDAFONTEIN	CHRISTO STEENKAMP	-28.4143	23.68997	-	-	-	-	-	-	W	AS	20121023
SD1-GAA223	VLEIPLAAS	BOTHA MAKRAM	-28.3538	23.68314	90.7	-	-	-	-	-	N		20121023
SD1-GAA224	VLEIPLAAS	BOTHA MAKRAM	-28.3553	23.6803	7	-	-	5.4	263	4.82	N		20121023
SD1-GAA225	DANIELSKUIL ALLOTMENT	MUNICIPALITY BH - JAN BARNARD	-28.1948	23.58557	-	-	-	14.86	192	5.85	W	DA	20121113
SD1-GAA226	DANIELSKUIL ALLOTMENT	MUNICIPALITY BH - JAN BARNARD	-28.1806	23.58988	-	-	-	-		-	W	DA	20121113
SD1-GAA227	JONASBANK	SAKKIE VAN DER MERWE	-28.2357	23.67536	11.2	-	-	3.45	203	7.37	N		20050801
SD1-GAA228	FREDERIK	THEUNS CLOETE	-28.1664	23.60016	-	-	-	-	-	-	S	DA	20121113
SD1-GAA229	FREDERIK	THEUNS CLOETE	-28.164	23.6099	-	-	-	-	-	-	S	AS	20121113
SD1-GAA230	FREDERIK	THEUNS CLOETE	-28.1642	23.61069	-	-	-	-	-	-	W	AS	20121113
SD1-GAA231	FREDERIK	THEUNS CLOETE	-28.1827	23.61573	-	-	-	-	-	-	W	AS	20121113
SD1-GAA232	WELGEVONDEN	THEUNS CLOETE	-28.1768	23.65305	-	-	-	-	73	6.86	W	AS	20121113
SD1-GAA233	WELGEVONDEN	THEUNS CLOETE	-28.1881	23.65149	-	-	-	-	-		W	AS	20121113
SD1-GAA234	WELGEVONDEN	THEUNS CLOETE	-28.188	23.6515	-	-	-	3.76	-	-	N		20121113

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SD1-GAA235	WELGEVONDEN	THEUNS CLOETE	-28.1869	23.64454	-	-	-	-	-	-	W	AS	20121113
SD1-GAA236	WELGEVONDEN	THEUNS CLOETE	-28.1759	23.65259	-	-	-	2.19	-	-	N		20121113
SD1-GAA237	DANIELS ALLOTMENT PTN. DANLIME 1	MUNICIPALITY BH - RIKKIE ALVELD	-28.1797	23.5367	68	-	-	25.2	33	7.9	S		20050801
SD1-GAA238	DANIELSKUIL PTN. INVAL (BACKUP)	MUNICIPALITY BH	-28.1806	23.53622	-	-	-	-	-	-	S		20121113
SD1-GAA239	DANIELSKUIL (APIE SE GAT 4) PTN. DANLIME 2	MUNICIPALITY BH	-28.1848	23.56658	83	-	50.0	8.07	58	8.35	S	DA	20050801
SD1-GAA240	DANIELSKUIL MEENT PTN. DANLIME 4 (BACKUP)	MUNICIPALITY BH	-28.1957	23.57514	60	-	12.0	9.98	51	7.8	S	DA	20050801
SD1-GAA241	DANIELSKUIL MEENT PTN. DANLIME 3 (BACKUP)	MUNICIPALITY BH	-28.1957	23.57467	33	-	10.0	9.04	-	-	S	DA	20050801
SD1-GAA242	DANIELSKUIL (PILOT BH)	MUNICIPALITY BH	-28.1837	23.567	-	-	-	8.87	-	-	N		20121113
SD1-GAA243	DANIELSKUIL(APIE SE GAT2)	MUNICIPALITY BH	-28.1826	23.56692	90	-	39.0	9.58	58	6.99	N		20050801
SD1-GAA244	DANIELSKUIL MEENT (APIE SE GAT)	MUNICIPALITY BH	-28.1827	23.56603	102	-	24.0	9.31	58	7.8	N	DA	20050801
SD1-GAA245	DANIELSKUIL MEENT (APIE SE GAT3)	MUNICIPALITY BH	-28.1817	23.56622	90	-	1.0	9.84	-	-	N	DA	20050801
SD1-GAA246	WELGEVONDEN	MATHUIS BEESLAAR	-28.22	23.6221	-	-	-	9.56	86	7.47	W	AS	20121113
SD1-GAA247	WELGEVODEN	MATHUIS BEESLAAR	-28.2101	23.61479	-	-	-	12.17	127	7.57	N		20121113
SD1-GAA248	WELGEVONDEN	MATHUIS BEESLAAR	-28.2016	23.64582	-	-	-	-	88	7.91	W	AS	20121113
SD1-GAA249	JONASBANK	MATHUIS BEESLAAR	-28.2306	23.64811	4.2	-	-	4.2	105	7.59	W	AS	20050801

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SD1-GAA250	JONASBANK	MATHUIS BEESLAAR	-28.2288	23.65292	4.6	-	-	2.85	-	-	N		20050801
SD1-GAA251	JONASBANK	MATHUIS BEESLAAR	-28.1999	23.68968	5.3	-	-	5.3	122	9.07	W	AS	20050801
SD1-GAA252	JONASBANK	MATHUIS BEESLAAR	-28.2109	23.70194	-	-	-	-	121	8.82	W	AS	20050801
SD1-GAA253	JONASBANK	MATHUIS BEESLAAR	-28.2281	23.69509	6.9	-	-	5.1	157	8.97	W	AS	20050801
SD1-GAA254	JONASBANK	MATHUIS BEESLAAR	-28.2281	23.69501	6.4	-	-	5.1	-	-	N	-	20050801
SD1-GAA255	KAIS	ALLIE SYLLIMAN	-28.1919	23.72548	19.8	-	-	5.7	157	8.52	W	AS	20050801
SD1-GAA256	JONASBANK	MATHUIS BEESLAAR	-28.2127	23.66276	6	-	-	6	100	8.35	W	AS	20050801
SD1-GAA257	OUPLAAS	DANIELSKUIL	-28.2236	23.56998	14.44	-	-	6.93	-	-	N	-	20050801
SD1-GAA258	DANIELSKUIL	DANIELSKUIL	-28.2195	23.56912	-	-	-	-	-	-	W	DA	20130311
SD1-GAA259	DANIELSKUIL ALLOTMENT	DANIELSKUIL	-28.1762	23.53238	70.6	1.8	-	12.6	-	-	N	DA	20050801
SD1-GAA260	DANIELSKUIL OOG	DANIELSKUIL	-28.1659	23.55263	-	-	-	43.87	27	6.87	N	-	20050606
SD1-GAA261	OUPLAAS - MAIN WATER	ELRINA - IDWALA	-28.2125	23.52394	-	-	-	12.045	-	-	S	DA	20130311
SD1-GAA262	OUPLAAS - MAIN WATER	IDWALA MINE	-28.2089	23.52606	36	-	-	10.94	-	-	S	DA	20050801
SD1-GAA263	CARTER BLOCK	KOKKIE YORK	-28.319	23.60093	54.8	20.55	-	-	-	-	N	-	20130604
SD1-GAA264	CARTER BLOCK PTN. KOLBE	PPC/BOTHA	-28.2982	23.51539	-	-	-	7.34	73	9.3	W	AS	20140204
SD1-GAA265	CARTER BLOCK PTN. KOLBE	PPC/BOTHA	-28.3104	23.52384	-	-	-	-	79	6.74	W	AS	20140204
SD1-GAA266	KAIS FOUNTAIN	ALLIE SYLLIMAN	-28.169440	23.741680	-	0.5	0.5	-	-	-	W	DA	20140220

Borehole Number	Farm Name	Owner	Latitude	Longitude	BH Depth (m)	Discharge Rate (l/s)	BH Yield (l/s)	WL (mbgl)	Field EC (mS/m)	Field measured pH	Equipment	Use	Date Surveyed
Min					4.2	0.02	0.1	0.45	27.0	4.8			
Max					130.0	28.0	50.0	43.9	488.0	9.3			
Average					38.7	3.3	14.0	8.2	115.7	7.2			
SANS 241:2011 Max Allowable Limit									<170	5 - 9.7			
DWAF 1998 Class I Drinking Water Limit									70-150	5-10			

APPENDIX B

SD1 Summarised Drilling Results

Borehole Number	Farm Name	Landowner	Latitude	Longitude	Altitude (mamsl)	Geophysical. Traverse No	Drilling Depth (m)	Casing Depth (m)	Final Diam.	Water Strike Depth (mbgl)	Water strike (l/s)	Final Blow yield (l/s)	Measured WL (mbgl)	Measured WL	Aquifer Type Geological Formation	Date Completed	BH Status
SD1-01	DANIELSKUIL	Danielskuil Municipality	-28.22787	23.58190	1447.07	LM23/775	82	58	165	27;44;52-58	8,0; 2; 17	12.50	10.6	1436.45	Fractured Dolomite at contact with dolerite	07/03/2013	Production
SD1-02	DANIELSKUIL	Danielskuil Municipality	-28.23577	23.58102	1445.68	LM24/170	30	30	165	18;28	0.2; >10	20.00	9.9	1435.79	Fractured Dolomitic-limestone	07/03/2013	Production
SD1-03	DANIELSKUIL	Danielskuil Municipality	-28.23446	23.57317	1448.1	LM24/950	80	80	203	18,70	7.6,1	12.00	12.0	1436.07	Fractured Dolomitic-limestone	21/02/2013	Production
SD1-04	DANIELSKUIL	Danielskuil Municipality	-28.22185	23.58840	1448.99	LM22/700	61	42	203	19	18.0	18.00	11.6	1437.41	Fractured Dolomitic-limestone	18/03/2013	Production
SD1-05	DANIELSKUIL	Danielskuil Municipality	-28.21119	23.59939	1457.23	LM21/500	40	31	165	20-27	2.0	20.00	17.3	1439.98	Fractured Dolomitic-limestone	25/03/2013	Production
SD1-06	DANIELSKUIL	Danielskuil Municipality	-28.20901	23.58192	1449.8	LM21/2260	70	25	203	22	1.8	1.8	11.7	1438.10	Fractured Dolomitic-limestone	23/03/2013	Monitoring
SD1-07	DANIELSKUIL	Danielskuil Municipality	-28.21856	23.57834	1450.11	LM22/1750	50	24	165	Seepage (30-36)	Seepage	0.1	13.0	1437.13	Fractured Dolomitic-limestone	22/03/2013	Monitoring
SD1-08	HINTON GEORGE	Lennox Cloete	-28.25789	23.58555	1449.15	L17/2100	40	36	254	22;27-31	8;30	38.0	13.7	1435.47	Fractured Dolomitic-limestone	25/04/2013	Production
SD1-09	CARTER BLOCK	Lennox Cloete	-28.25527	23.59748	1444.01	L17/3300	40	36	203	10-19;32-36	25;13	38.0	6.8	1435.48	Fractured Dolomitic-limestone	16/04/2013	Production
SD1-10	CARTER BLOCK	Kokkie York/Killian	-28.33522	23.60812	1444.5	LM15/5100	28	28	254	22;25-28	0.1;20	20.0	11.9	1432.09	Fractured BIF	29/05/2013	Production
SD1-11	CARTER BLOCK	Lena Kok	-28.29988	23.57918	1435.9	LM14/2700	70	61	165	43;67-70	3.8;10.2	14.0	13.4	1432.93	Fractured Dolomitic-limestone	07/04/2013	Production
SD1-12	CARTER BLOCK	Lena Kok	-28.32459	23.59331	1442.51	LM13/4900	112	36	254	19	4.0	5.9	3.3	1432.63	Fractured Dolomitic-limestone	29/04/2013	Monitoring
SD1-13	ROOIPAN	Wynand De Jager	-28.39381	23.54737	1437.63	LM2/2500	60	60	165	49	4.4	5.0	18.3	1424.20	Fractured Dolomitic-limestone	04/07/2013	Monitoring
SD1-14	ROOIPAN	Kokkie York	-28.38532	23.64480	1437.54	LM9/1900	67	67	254	56	14.0	14.0	13.1	1424.52	Fractured BIF	26/05/2013	Production
SD1-14S	CARTER BLOCK PTN. 19	Kokkie York	-28.38538	23.64476	1443.08	LM9/1900	18	18	165	Seepage	Seepage	Seepage	12.6	1424.90	Calcrete	23/05/2013	Monitoring
SD1-15	LIME ACRES	Wynand De Jager	-28.39334	23.54794	1441.14	LM2/2600	64	64	165	36	1.6	1.60	18.7	1424.34	Calcrete dolerite contact	22/06/2013	Monitoring
SD1-16	LIME ACRES	Kokkie York/Killian	-28.36428	23.59780	1441.14	LM10/2450	69	59	165	23;40;53-55	0.1;2;10	10.5	9.6	1431.53	BIF/ Fractured Dolomitic-limestone	24/05/2013	Production
SD1-16S	CARTER BLOCK	Kokkie York/Killian	-28.36441	23.59788	1435.15	LM10/2450	16	16	165	Seepage	Seepage	Seepage	9.7	1431.47	Calcrete	24/05/2013	Monitoring
SD1-17	CARTER BLOCK	Lena Kok	-28.31607	23.58026	1436.9	T1/3600	58	53	203	40;52	10;>20	50.0	2.3	1432.86	Fractured Dolomitic-limestone	25/04/2013	Production
SD1-17M	CARTER BLOCK PTN. 19	Lena Kok	-28.31614	23.58062	1443.18	T1/3640	24	24	165	17;21	6.6;5	10.0	2.3	1432.83	Fractured Dolomitic-limestone	18/08/2013	Monitoring
SD1-18	CARTER BLOCK PTN. 19	Lena Kok	-28.38957	23.58370	1443.18	TB4/0	72	72	165	29;50	0.1;0.1	0.2	16.2	1426.96	Fractured Dolomitic-limestone	19/06/2013	Monitoring
SD1-19	CARTER BLOCK	Lena Kok	-28.31002	23.57928	1434.82	T2/3300	40	34	203	13-31	>20	20.0	2.4	1432.42	Fractured Dolomitic-limestone	15/04/2013	Production
SD1-20	CARTER BLOCK	Lena Kok	-28.31478	23.59588	1435	T2/5050	48	48	203	6;19;32;44-47	0.1;2;2;>20	33.0	2.2	1432.80	Fractured BIF and Dolomitic-limestone	01/05/2013	Production
SD1-21	CARTER BLOCK	Lena Kok	-28.30433	23.58906	1434.86	T3/3200	103	90	165	21;73;101-103	2;5.2;25.8	33.0	2.0	1432.82	Fractured BIF and Dolomitic-limestone	12/04/2013	Production
SD1-22	CARTER BLOCK	Lena Kok	-28.29738	23.58331	1435.87	T4/2400	49	49	203	19;38;46	3;7;10	20.0	2.9	1432.94	Fractured BIF and Dolomitic-limestone	26/04/2013	Production
SD1-23	CARTER BLOCK PTN. 19	Lena Kok	-28.39005	23.58404	1442.91	TB4/60	76	76	165	Seepage	Seepage	Seepage	18.1	1424.84	Calcrete/ Fractured BIF - Dolomitic-limestone	17/06/2013	Monitoring
SD1-24	ROOIPAN	Kokkie York	-28.39055	23.62879	1437.27	LM5/5620	68	68	203	67	>25	34.0	12.7	1424.57	Calcrete/ Fractured Dolomitic-limestone	02/06/2013	Production
SD1-25	DANIELSKUIL	Danielskuil Municipality	-28.22309	23.56914	1446.64	Re-drill /OP058	51	52	203	49	>50	62.0	7.0	1439.62	Fractured Dolomitic-limestone	29/04/2013	Production

Borehole Number	Farm Name	Landowner	Latitude	Longitude	Altitude (mamsl)	Geophysical. Traverse No	Drilling Depth (m)	Casing Depth (m)	Final Diam.	Water Strike Depth (mbgl)	Water strike (l/s)	Final Blow yield (l/s)	Measured WL (mbgl)	Measured WL	Aquifer Type Geological Formation	Date Completed	BH Status
SD1-26	LIME ACRES	Kokkie York/Killian	-28.35129	23.59879	1441.82	LM11/330	69	61	203	38-39;56-58;66-69	1;3;8	14.1	10.41	1431.41	Calcrete/ Fractured BIF - Dolomitic-limestone	28/05/2013	Production
SD1-27	CARTER BLOCK PTN. ROOIPAN	Kokkie York	-28.37868	23.62470	1437.42	LM17/1800	104	104	203	85;101	11;>25	40.0	12.9	1424.49	Calcrete/ Fractured Dolomitic-limestone	15/06/2013	Production
SD1-27S	ROOIPAN	Kokkie York	-28.37873	23.62472	1437.38	LM17/1800	18	18	165	Seepage	Seepage	Seepage	12.1	1425.30	Calcrete	02/05/2013	Monitoring
SD1-28	CARTER BLOCK	Wynand De Jager	-28.38563	23.58745	1444.43	TG3/30	64	56	165	34;52	0.2;2.0	2.0	14.2	1430.28	Calcrete/ Fractured Dolomite at dolerite contact	15/06/2013	Monitoring
SD1-29	FARM 301	Daan van Deventer	-28.28456	23.58589	1442.75	LM12/8000	68	68	165	16;63-68	4;>10	14.0	9.6	1433.14	Fractured BIF and Dolomitic-limestone	05/04/2013	Production
SD1-30	CARTER BLOCK PTN. 19	Wynand De Jager	-28.38575	23.58834	1444.45	TG3/120	71	71	165	40	0.8	0.8	17.4	1427.03	Calcrete/ Fractured Dolomitic-limestone	14/06/2013	Monitoring
SD1-31	CARTER BLOCK PTN. 19	Wynand De Jager	-28.37524	23.59744	1444.41	TL4/150	120	72	203	23	0.1	0.8	13.1	1431.35	Calcrete/ Fractured Dolomitic-limestone	21/06/2013	Monitoring
SD1-32	ROOIPAN	Kokkie York	-28.40082	23.65853	1436.43	LM8/1000	73	73	203	71-73	>25	36.00	12.6	1423.78	Calcrete/ Fractured Dolomitic-limestone	31/05/2013	Production
SD1-32S	ROOIPAN	Kokkie York	-28.40079	23.65846	1435.9	LM8/1000	16	16	165	Seepage	Seepage	Seepage	14.1	1422.47	Calcrete	27/05/2013	Monitoring
SD1-32M	ROOIPAN	Kokkie York	-28.40039	23.65872	1436.59	LM8/1040	72	72	165	16-17;70-71	0.1;10	10.00	12.2	1423.71	Calcrete/ Fractured Dolomitic-limestone	25/07/2013	Monitoring
SD1-33	DANIELSKUIL	Danielskuil Municipality	-28.17310	23.51860	1494.17	D1/2530	74	74	203	33;73-78	0.2;>10	18.00	26.1	1468.05	Fractured BIF and Dolomitic-limestone	08/07/2013	Production
SD1-34	DANIELSKUIL	Danielskuil Municipality	-28.17447	23.53161	1493.4	D2/2850	137	137	203	60;97	6;2	17.00	25.6	1467.81	Fractured BIF and Dolomitic-limestone	23/06/2013	Production
SD1-35	CARTER BLOCK	Lennox Cloete	-28.34501	23.58328	1442.33	LM4/5000	28	28	254	16;22;26	0.2;2;>20	34.00	9.6	1432.75	Calcrete/ Fractured Dolomitic-limestone	01/05/2013	Production
SD1-35M	CARTER BLOCK	Lennox Cloete	-28.34544	23.58276	1442.16	LM4/4960	30	30	165	27	>20	10.00	9.7	1432.48	Calcrete/ Fractured Dolomitic-limestone	29/07/2013	Monitoring
SD1-36	LIME ACRES	Kokkie York/Killian	-28.33717	23.60471	1443.95	LM4/7350	88	36	254	28	2.0	2.00	11.9	1432.03	Calcrete/ Fractured Dolomitic-limestone	25/05/2013	Monitoring
SD1-37	ROOIPAN	Kokkie York	-28.38772	23.62333	1436.74	LM5/5000	81	81	203	81	20.0	20.00	12.3	1424.47	Calcrete/ Fractured Dolomitic-limestone	02/06/2013	Production
SD1-38	CARTER BLOCK	Hannes Meyer	-28.40251	23.53199	1443.05	TC08/60	70	70	165	Seepage	Seepage	Seepage	66.8	1376.23	Calcrete at contact at dolerite	05/07/2013	Monitoring
SD1-39	CARTER BLOCK	Hannes Meyer	-28.40240	23.53262	1442.98	TC08/120	72	72	165	41	1	1.00	20.8	1422.21	Fractured Dolomitic-limestone	06/07/2013	Monitoring
SD1-40	CARTER BLOCK	PPC	-28.30157	23.49494	1468.72	D9/1850	97	93	165	52;60-61	2;4	10.00	30.2	1438.48	Fractured BIF	15/07/2013	Production
SD1-40M	CARTER BLOCK	PPC	-28.30125	23.49500	1467.00	D9/1810	100	64	165	51;61	0.4;0.4	0.90	30.1	1438.67	Fractured BIF	04/08/2013	Monitoring
SD1-41	CARTER BLOCK	PPC	-28.30427	23.49428	1467.44	D9/1550	97	91	203	73-91	12	16.00	43.4	1423.46	Fractured BIF and Dolomitic-limestone	15/07/2013	Production
SD1-42	CARTER BLOCK	PPC	-28.29786	23.48335	1477.226	D8/2050	112	110	165	70-71;107-110	2;10	10.00	53.5	1423.77	Fractured BIF and Dolomitic-limestone	11/08/2013	Production
SD1-43	CARTER BLOCK	Kokkie York/Killian	-28.36883	23.62928	1437.83	LM2/11900	64	64	203	23;60	0.2;22	23.00	14.8	1423.02	Calcrete/ Fractured Dolomitic-limestone	15/06/2013	Production
SD1-44	DANIELSKUIL	Danielskuil Municipality	-28.21134	23.59929	1457.283	LM21/500	34	29	203	24-29	>10	8.90	17.8	1439.45	Fractured Dolomitic-limestone	27/07/2013	Production
SD1-45	DANIELSKUIL	Danielskuil Municipality	-28.19284	23.55202	1453.9	LM23/775	44	44	203	25;35;38-42	2.5;20;20	41.00	12.8	1434.25	Fractured Dolomitic-limestone	03/07/2013	Production
Min						-	16	16	-	6	0.1	0.2	2.0	1376.23	-	-	32 Production
Max						-	137	137	-	110	50	62	66.8	1468.05	-	-	21 Monitoring

Borehole Number	Farm Name	Landowner	Latitude	Longitude	Altitude (mamsl)	Geophysical. Traverse No	Drilling Depth (m)	Casing Depth (m)	Final Diam.	Water Strike Depth (mbgl)	Water strike (l/s)	Final Blow yield (l/s)	Measured WL (mbgl)	Measured WL	Aquifer Type Geological Formation	Date Completed	BH Status
Average						-	63.3	56.1	-	45.9	8.9	18.6	14.0	1431.19	-	-	53 Total

APPENDIX C

SD1 Summarised Test Pumping Programme

Borehole Number	Borehole Coordinates		Borehole Information			Pump Testing Details								
	Latitude	Longitude	Completion Date	Borehole Depth (mbgl)	Static Water level (mbgl)	Pump Installation Depth (mbgl)	No of SDT's	PI Yield (l/s)	Final Yield of SDT (l/s)	Duration of CDT (min)	Yield of CDT (l/s)	CDT Drawdown (m)	WL Recovery (m)	WL Recovery (Min)
Existing Boreholes														
SD1-GAA001	-28.36874	23.65721	28/09/2012	50.39	10.64	48	4	Not Reached	6.98	60	6.03	6.98	0	3
SD1-GAA002	-28.36866	23.65719	01/10/2012	52.48	9.78	48	3	-	4.33	No CDT	-	0.17	0	40
SD1-GAA003	-28.38748	23.64321	02/10/2012	43.13	12.56	41.5	1	0.24	0.52	No CDT	-	-	0	50
SD1-GAA004	-28.37671	23.62931	01/10/2012	16.24	11.84	14.8	Cal Test	0.12	0.53	No CDT	-	-	0	50
SD1-GAA005	-28.38934	23.62031	30/09/2012	38.31	17.71	35.8	4	4.02	5.22	720	3.03	5.22	0	3
SD1-GAA015	-28.32417	23.62187	04/10/2012	31.6	11.7	29.5	1	0.27	0.55	No CDT	-	-	0	-
SD1-GAA017	-28.32231	23.61353	03/10/2012	23	13.71	20.5	1	0.25	0.55	No CDT	-	-	0	-
SD1-GAA018	-28.35382	23.59059	05/10/2012	30.1	7.15	29.5	1	0.42	0.51	No CDT	-	-	0	-
SD1-GAA019	-28.35966	23.60185	02/10/2012	29	14.29	26.1	3	1.38	1.5	720	0.51	16.54	2.35	3
SD1-GAA020	-28.37794	23.61085	05/10/2012	37.33	2.09	32.8	Cal Test 4	0.54	1.23	No CDT	-	-	0	-
SD1-GAA021	-28.37837	23.61022	03/10/2012	25.82	2.6	23.8	3	1.68	2	720	1.25	3.96	0.02	12
SD1-GAA023	-28.40951	23.59912	06/10/2012	37.48	2.91	32.8	2	0.63	1.05	720	0.54	8.69	0.46	12
SD1-GAA026	-28.31103	23.54790	22/10/2012	36.35	3.36	32.8	2	0.69	1	No CDT		16.75	0.1	1.33
SD1-GAA027	-28.30131	23.57529	23/10/2012	75.2	2.46	72	4	Not Reached	6.3	720	6.21	0.24	0	5
SD1-GAA034	-28.3721	23.6949	18/10/2012	33	3.3	30	4	1.73	3.03	720	1.3	5.25	0.27	12
SD1-GAA035	-28.37980	23.72443	16/10/2012	9.83	10.22	9	4	Not Reached	6.24	960	6.05	0.31	0	2
SD1-GAA076	-28.31857	23.54597	23/10/2012	24.3	7.36	23.8	3	Not Reached	10.65	720	9.05	3.11	0.09	12
SD1-GAA091	-28.33180	23.78396	15/10/2012	30.15	9.58	27	1	0.38	0.52	No CDT	-	22.61	0.2	1
SD1-GAA092	-28.34273	23.77807	13/10/2012	14.2	11.92	12	2	0.56	0.71	No CDT	-	-	-	-
SD1-GAA093	-28.36610	23.76570	13/10/2012	17.12	9.61	14.8	4	Not Reached	9.43	1440	8.01	2.59	0	4
SD1-GAA096	-28.38259	23.74786	08/10/2012	28.04	10	26.8	3	2.63	4.05	720	1.8	0.78	0	5

Borehole Number	Borehole Coordinates		Borehole Information			Pump Testing Details								
	Latitude	Longitude	Completion Date	Borehole Depth (mbgl)	Static Water level (mbgl)	Pump Installation Depth (mbgl)	No of SDT's	PI Yield (l/s)	Final Yield of SDT (l/s)	Duration of CDT (min)	Yield of CDT (l/s)	CDT Drawdown (m)	WL Recovery (m)	WL Recovery (Min)
SD1-GAA099	-28.37610	23.73451	11/10/2012	35.6	13.55	32.1	2	0.55	1	258	0.45	27.42	0.25	5
SD1-GAA101	-28.36046	23.56518	17/10/2012	23.65	11.92	23.1	1	0.12	0.5	No CDT	-	5.34	0.08	1
SD1-GAA105	-28.35374	23.58079	18/10/2012	56.04	13.06	50.8	4	1.97	3.14	720	1.41	9.74	0.46	12
SD1-GAA107	-28.34507	23.56997	20/10/2012	30.2	13.06	26.1	1	0.09	0.53	No CDT	-	11.41	0	40
SD1-GAA108	-28.34071	23.53320	20/10/2012	39	13.77	36	4	3.06	5.22	720	2.83	1.24	0	3
SD1-GAA196	-28.41422	23.68984	11/10/2012	78.6	14.81	65.5	3	1.04	2.02	No CDT	-	-	-	-
SD1-GAA197	-28.41831	23.72410	09/10/2012	47.18	15.45	44.5	3	1.74	2.04	480	1.23	8.19	0.03	2
SD1-GAA218	-28.35383	23.68306	11/10/2012	51.18	25.08	48	4	3.29	6.02	240	3.29	41.87	0.68	8
SD1-GAA220	-28.36919	23.65492	07/10/2012	52.24	25.43	50.5	2	0.63	1.02	720	0.53	13.81	0.01	8
SD1-GAA259	-28.17634	23.53239	22/07/2013	70.6	13.45	64.8	2	0.80	1.8	No CDT	-	-	0	120(SDT)
SD1-GAA263	-28.31905	23.60095	28/05/2013	54	18.76	46.8	4	Not Reached	20.5	No CDT	-	-	0	20(SDT)
Exploration Boreholes														
SD1-01	-28.22785	23.58191	20/04/2013	82	19.15	70.5	4	not reached	20.2	1440	15.02	4.16	0	300
SD1-02	-28.23577	23.58101	17/04/2013	30	13.8	28.5	4	not reached	20.14	1440	15.12	3.36	0	240
SD1-03	-28.23445	23.57317	14/04/2013	82.6	34.91	70.5	4	not reached	24.01	1440	12.08	18.27	0.48	1440
SD1-04	-28.22183	23.58841	23/04/2013	61.55	44.07	28.5	4	not reached	20.09	1440	20.08	1.31	0	960
SD1-05	-28.21118	23.59941	26/04/2013	40	30.05	28.5	4	not reached	22.5	2880	20.02	0.61	0	60
SD1-06	-28.20899	23.58191	27/04/2013	70.26	29.77	58.8	3	4.90	10	No CDT	No CDT	39.8(sdt)	0(sdt)	180(sdt)
SD1-08	-28.25787	23.58558	02/05/2013	39.85	2.13	34.8	4	not reached	30.21	1440	30.08	0.71	0	10
SD1-09	-28.25526	23.59750	29/04/2013	40.3	10.64	34.8	4	not reached	30.13	1440	25.09	3.42	0	150
SD1-10	-28.33522	23.60812	14/06/2013	27	10.22	22.8	4	not reached	30.21	1440	25.08	3.24	0	150
SD1-11	-28.29988	23.57916	05/05/2013	70	9.78	58	4	not reached	20	1440	20.0	0.73	0	30

Borehole Number	Borehole Coordinates		Borehole Information			Pump Testing Details								
	Latitude	Longitude	Completion Date	Borehole Depth (mbgl)	Static Water level (mbgl)	Pump Installation Depth (mbgl)	No of SDT's	PI Yield (l/s)	Final Yield of SDT (l/s)	Duration of CDT (min)	Yield of CDT (l/s)	CDT Drawdown (m)	WL Recovery (m)	WL Recovery (Min)
SD1-12	-28.32463	23.59330	09/05/2013	110	17.71	34.6	3	5.40	7.26	No CDT	No CDT	29.21(sdt)	0.02	180
SD1-13	-28.39381	23.54737	02/08/2013	60	13.06	58.8	4	5.00	7.1	1440	3.5	8.67	0	240
SD1-14	-28.38532	23.64478	08/06/2013	67.5	3.3	58.8	3	8.40	12.04	2880	6.13	7.17	0	360
SD1-16	-28.36429	23.59782	02/06/2013	59.4	3.36	52.8	4	not reached	20.52	2880	20.09	3.07	0	240
SD1-17	-28.31607	23.58024	09/05/2013	57.6	11.84	34.8	4	not reached	30.53	1440	30.02	0.74	0	90
SD1-17	-28.31607	23.58026	04/09/2013	57.6	9.58	34.8	No SDT	not reached	No SDT	4320	30	1.25	0	5
SD1-19	-28.31003	23.57927	06/05/2013	40.22	12.56	28.8	4	not reached	30.1	1440	25.02	0.74	0	60
SD1-20	-28.31477	23.59588	11/05/2013	49.4	11.7	45.8	4	not reached	30.33	1440	30.13	0.77	0	30
SD1-21	-28.30433	23.58906	13/05/2013	103	13.71	82.8	4	not reached	21.55	1440	20.11	2.7	0	150
SD1-22	-28.29763	23.58330	15/05/2013	49	7.15	46.8	4	not reached	25.12	1440	20.04	11.59	0	120
SD1-24	-28.39051	23.62882	16/06/2013	68.5	9.58	64.5	4	not reached	30.21	1440	30.1	1.16	0	180
SD1-25	-28.22307	23.56911	22/05/2013	51.5	2.09	51.5	4	not reached	30.3	2880	30.29	1.83	0	30
SD1-26	-28.35129	23.59878	05/06/2013	69	2.46	52.8	4	not reached	20.21	1440	15.06	3.79	0	210
SD1-27	-28.37868	23.62470	26/07/2013	104	13.06	82.8	4	not reached	30.1	2880	30.1	4.12	0	300
SD1-28	-28.38561	23.58744	25/06/2013	71.8	10	64.8	3	3.40	5.49	720	2.4	11.8	0	350
SD1-29	-28.28454	23.58590	19/05/2013	68.65	14.29	58.8	4	17.10	20.12	1440	10.1	21.98	0	300
SD1-32	-28.40087	23.65860	12/06/2013	73.85	7.36	70.8	4	not reached	30.1	2880	25.08	3.91	0	120
SD1-32	-28.40082	23.65853	31/07/2013	73	13.77	70.8	No SDT	not reached	No SDT	4320	30.2	5.33	0	40
SD1-33	-28.17310	23.51860	21/07/2013	78.7	13.55	64.8	4	18.20	20.1	4320	12.0	15.74	0	1080
SD1-34	-28.17447	23.53161	14/07/2013	137	11.92	76.8	4	18.20	20.1	4320	12.0	13.47	0	2160
SD1-35	-28.34501	23.58329	26/05/2013	28.7	2.6	22.5	4	not reached	30.2	2880	30.0	1.55	0	120
SD1-35	-28.34501	23.58328	03/08/2013	28.7	14.81	22.8	No SDT	not reached	No SDT	4320	30.0	2.37	0	60

Borehole Number	Borehole Coordinates		Borehole Information			Pump Testing Details								
	Latitude	Longitude	Completion Date	Borehole Depth (mbgl)	Static Water level (mbgl)	Pump Installation Depth (mbgl)	No of SDT's	PI Yield (l/s)	Final Yield of SDT (l/s)	Duration of CDT (min)	Yield of CDT (l/s)	CDT Drawdown (m)	WL Recovery (m)	WL Recovery (Min)
SD1-36	-28.33714	23.60471	29/05/2013	70.9	2.91	34.8	3	4.60	7.64	No CDT	No CDT	22.16(SDT)	0	40(SDT)
SD1-37	-28.38772	23.62334	22/06/2013	82	11.92	70.8	4	21.75	26.19	1440	15.0	12.63	0	90
SD1-40	-28.30157	23.49494	30/08/2013	97.6	13.62	82.8	4	not reached	20	4320	10.08	14.47	0	1320
SD1-40M	-28.30125	23.49500	25/08/2013	64.44	13.45	58.8	3	2.44	3.52	No CDT	No CDT	27.30(SDT)	0	100
SD1-41	-28.30427	23.49428	24/08/2013	97	18.76	82.8	4	18.10	20	4320	12.0	14.21	0	600
SD1-42	-28.29786	23.48335	18/08/2013	112	25.43	76.8	4	14.50	16.3	2880	10.1	10.38	0	360
SD1-43	-28.36883	23.62930	24/06/2013	68	9.61	64.8	4	not reached	20.01	1440	15.0	6.27	0	1440
SD1-44	-28.21134	23.59929	09/08/2013	34.42	15.45	28.8	4	not reached	30.21	4320	30.0	1.14	0	20
SD1-45	-28.19284	23.55202	14/08/2013	44.9	25.08	40.8	4	not reached	30.03	2880	30.0	2.05	0	540

APPENDIX D

**SD2 Summarised Hydrocensus
Borehole Information**

Borehole Number	Farm Name/Property	Owner/Representative	Latitude	Longitude	Reported Borehole Depth (m)	Discharge Rate (l/s)	Reported Yield (l/s)	Measured WL (mbgl)	Measured EC (mS/m)	Measured pH	Equipment	Use	Date Surveyed
SD2-GAA001	GOEDGEDACHT PTN. JEN-HAVEN	JEN HAVEN COMMUNITY	-28.21998	23.25417	113.00	-	-	36.52	-	-	M	DA	2013/01/18
SD2-GAA002	GOEDGEDACHT PTN. JEN-HAVEN	JEN HAVEN COMMUNITY	-28.22272	23.24516	86.00	-	-	41.74	68	7.63	S	DA	2012/05/17
SD2-GAA003	GOEDGEDACHT PTN. JEN-HAVEN	JEN HAVEN COMMUNITY	-28.22123	23.24266	-	-	-	46.64	61	7.68	N	-	2012/04/13
SD2-GAA004	GOEDGEDACHT PTN. JEN-HAVEN	JEN HAVEN COMMUNITY	-28.21604	23.24010	88.55	20.41	-	45.34	-	-	N	-	2014/04/01
SD2-GAA005	GOEDGEDACHT PTN. JEN-HAVEN	JEN HAVEN COMMUNITY	-28.21577	23.24045	80.00	-	-	44.5	-	-	N	-	2012/04/13
SD2-GAA006	GOEDGEDACHT PTN. JEN-HAVEN	JEN HAVEN COMMUNITY	-28.23760	23.23915	-	-	-	48.2	-	-	W	AS	2012/04/13
SD2-GAA007	GOEDGEDACHT PTN. JEN-HAVEN	JEN HAVEN COMMUNITY	-28.24943	23.22040	-	-	-	53.73	35	8.1	W	AS	2012/04/13
SD2-GAA008	FARM 442 PTN. GELUK	C OLIVIER	-28.21557	23.21815	60.96	-	-		-	-	W	DA	2012/04/13
SD2-GAA009	FARM 442 PTN. GELUK	C OLIVIER	-28.20826	23.21069	-	-	-	12.65	74	7.77	W	AS	2012/04/13
SD2-GAA010	FARM 442 PTN. ELLENDALE	WILLIAM JARVIS	-28.22652	23.20682	79.24	4.02	-	32	-	-	W	DA	2014/04/01
SD2-GAA011	FARM 442 PTN. ELLENDALE	WILLIAM JARVIS	-28.21529	23.19622	69.00	1.02	-	14.51	66	7.19	W	AS	2014/04/01
SD2-GAA012	FARM 442 PTN. ELLENDALE	WILLIAM JARVIS	-28.21611	23.19569	-	-	-	9.42	-	-	N	-	2012/04/13
SD2-GAA013	GOEDGEDACHT PTN. JEN-HAVEN	JEN HAVEN COMMUNITY	-28.23764	23.23948	88.20	0.84	-	49.05	-	-	N	-	2014/04/01
SD2-GAA014	FARM 442 PTN. HEUNINGVLEI	J.A. CLOETE	-28.23902	23.18340	-	-	-	-	91	7.14	W	DA	2012/04/13
SD2-GAA015	FARM 442 PTN. HEUNINGVLEI	J.A. CLOETE	-28.23891	23.18299	75.00	-	-	7.44	362	7.18	N	-	2012/04/13
SD2-GAA016	FARM 442 PTN. HEUNINGVLEI	J.A. CLOETE	-28.23857	23.18257	60.00	-	-	7.47	-	-	N	-	2012/04/13
SD2-GAA017	FARM 442 PTN. HEUNINGVLEI	J.A. CLOETE	-28.23791	23.18299	-	-	-	-	-	-	N	-	2012/04/13
SD2-GAA018	GROENWATER	Groenwater Community (James Koloje)	-28.24769	23.27466	110.00	-	3.3	44.64	72	7.84	N	-	2013/01/18
SD2-GAA019	GROENWATER	Groenwater Community (James Koloje)	-28.24812	23.27069	-	-	-	54.22	159	6.43	N	-	2012/04/13
SD2-GAA020	GROENWATER	Groenwater Community (James Koloje)	-28.25769	23.27490	-		-	26.83	9	7.01	N	-	2012/05/17
SD2-GAA021	GROENWATER	Groenwater Community (James Koloje)	-28.24604	23.27655	-	1.0	-	39.43	40	7.5	Q	DA	2013/01/18
SD2-GAA022	GROENWATER PTN. TAFELKOP	Groenwater Community (James Koloje)	-28.29536	23.27086	-	-	-	19.75	-	-	Q	DA	2012/04/13
SD2-GAA023	GROENWATER	Groenwater Community (James Koloje)	-28.30173	23.26853	-	-	-	18.10	77	7.25	W	AS	2013/01/17

Borehole Number	Farm Name/Property	Owner/Representative	Latitude	Longitude	Reported Borehole Depth (m)	Discharge Rate (l/s)	Reported Yield (l/s)	Measured WL (mbgl)	Measured EC (mS/m)	Measured pH	Equipment	Use	Date Surveyed
SD2-GAA024	VAALPOORT	ROUX VAN DER MERWE	-28.28436	23.16785	-	-	-	19.89	-	-	S	-	2012/04/16
SD2-GAA025	VAALPOORT	ROUX VAN DER MERWE	-28.28426	23.16801	-	-	-	20.04	-	-	S	DA	2012/04/16
SD2-GAA026	VAALPOORT	ROUX VAN DER MERWE	-28.28450	23.16786	-	-	-	-	-	-	W	DA	2012/04/16
SD2-GAA027	POSTMASBURG GATKOPPIES	NOENOE FOURIE	-28.28233	23.15231	-	2.0	-	-	108	7.85	S	DA	2012/05/17
SD2-GAA028	POSTMASBURG GATKOPPIES	NOENOE FOURIE	-28.28005	23.15207	12.00	-	-	6.35	-	-	N	-	2013/01/18
SD2-GAA029	POSTMASBURG PTN. KLEIN SION	BERTIE MULLER	-28.28210	23.15022	100.00	-	-	-	-	-	M	DA	2012/04/16
SD2-GAA030	POSTMASBURG PTN. DIE NAWEEK	PIET LE ROUX	-28.28217	23.15024	36.00	-	-	8.11	-	-	S	DA	2013/01/18
SD2-GAA031	POSTMASBURG PTN. DIE NAWEEK	PIET LE ROUX	-28.28218	23.15030	176.00	-	-	-	-	-	N	-	2013/01/18
SD2-GAA032	POSTMASBURG PTN. KLEIN SION	BERTIE MULLER	-28.28276	23.14827	50.00	-	-	8.67	-	-	S	DA	2012/04/16
SD2-GAA033	POSTMASBURG PTN. DIE GREWE	JOHAN GREEFF	-28.28422	23.14174	30.00	-	-	7.63	-	-	S	DA	2012/04/16
SD2-GAA034	POSTMASBURG PTN. DIE GREWE	JOHAN GREEFF	-28.28292	23.14616	-	-	-	4.2	-	-	S	DA	2012/04/16
SD2-GAA035	POSTMASBURG PTN. DIE GREWE	JOHAN GREEFF	-28.28315	23.14461	-	-	-	6.11	-	-	W	AS	2012/04/16
SD2-GAA036	VAALPOORT (GATKOPPIES1)	Postmasburg municipality borehole	-28.27968	23.15286	50.00	-	-	9	-	-	S	DA	2013/01/17
SD2-GAA037	VAALPOORT	W COETZEE - Municipality Use BH	-28.27928	23.15313	15.00	-	-	9.69	69	7.27	N	DA	2013/01/16
SD2-GAA038	VINCI	AUTHER OLIVIER (Jen Haven Community)	-28.22853	23.16411	-	-	-	-	79	7.41	W	AS	2012/04/13
SD2-GAA039	ROOIPOORT PTN. ROOIDAM	BENNIE BREDENKAMP	-28.33045	23.14897	-	0.8	-	19.65	-	-	W	DA	2012/05/17
SD2-GAA040	ROOIPOORT PTN. ROOIDAM	BENNIE BREDENKAMP	-28.33037	23.14840	51.81	1.26	-	19.54	-	-	W	DA	2012/04/16
SD2-GAA041	ROOIPOORT PTN. ROOIDAM	BENNIE BREDENKAMP	-28.33056	23.14827	36.57	-	-	16.12	-	-	Q	DA	2012/04/16
SD2-GAA042	ROOIPOORT PTN. ROOIDAM	BENNIE BREDENKAMP	-28.34478	23.15257	51.81	0.37	-	28.43	67	6.98	W	AS	2012/05/17
SD2-GAA043	ROOIPOORT PTN. ROOIDAM	BENNIE BREDENKAMP	-28.32947	23.17871	71.62	2.52	-	48.47	-	-	W	AS	2012/04/16
SD2-GAA044	ROOIPOORT PTN. VAALPOORT	ROUX VAN DER MERWE	-28.29630	23.18000	-	-	-	-	65	7.25	M	AS	2012/05/17
SD2-GAA045	ROOIPOORT PTN. VAALPOORT	ROUX VAN DER MERWE	-28.30635	23.18943	-	-	-	-	-	-	W	AS	2012/04/16
SD2-GAA046	ROOIPOORT PTN. VAALPOORT	ANDRIES CORDIER	-28.31966	23.15574	30.48	-	-	21.35	-	-	S	-	2012/04/16

Borehole Number	Farm Name/Property	Owner/Representative	Latitude	Longitude	Reported Borehole Depth (m)	Discharge Rate (l/s)	Reported Yield (l/s)	Measured WL (mbgl)	Measured EC (mS/m)	Measured pH	Equipment	Use	Date Surveyed
SD2-GAA047	ROOIPOORT PTN. VAALPOORT	ANDRIES CORDIER	-28.31950	23.15625	51.80	-	-	19.96	-	-	N	-	2012/04/16
SD2-GAA048	ROOIPOORT PTN. VAALPOORT	ANDRIES CORDIER	-28.31981	23.15598	-	-	-	24.69	-	-	W	DA	2012/04/16
SD2-GAA049	ROOIPOORT PTN. VAALPOORT	ANDRIES CORDIER	-28.32107	23.15547	-	-	-	23.74	62	7.28	W	DA	2012/05/17
SD2-GAA050	POSTMASBURG	MUNICIPALITY BOREHOLE	-28.28048	23.15353	30.00	-	-	-	-	-	N	-	2014/04/02
SD2-GAA051	POSTMASBURG PTN. GATKOPPIES	MARIANNA MATHEE	-28.28522	23.13888	-	-	-	0.32	-	-	N	-	2012/04/16
SD2-GAA052	POSTMASBURG PTN. GATKOPPIES	MARIANNA MATHEE	-28.28534	23.13804	-	-	-	5.32	-	-	N	-	2012/04/16
SD2-GAA053	POSTMASBURG PTN. GATKOPPIES	MARIANNA MATHEE	-28.28508	23.13914	-	-	-	5.96	103	6.56	S	DA	2012/05/17
SD2-GAA054	POSTMASBURG	Postmasburg Municipality - NOOI DE BRUIN	-28.30610	23.12586	30.00	-	5.56	16.17	-	-	S	DA	2013/01/18
SD2-GAA055	POSTMASBURG	Postmasburg Municipality - HANS VAN WYK	-28.30746	23.13713	-	-	-	-	65	7.34	W	DA	2012/04/16
SD2-GAA056	POSTMASBURG	Postmasburg Municipality - VYTJIE NEELS	-28.30083	23.16884	-	-	-	21.33	-	-	W	AS	2012/04/16
SD2-GAA057	POSTMASBURG PTN. REDLANDS	PIETER STAFFORD	-28.31209	23.11838	-	-	-	11.59	-	-	S	-	2012/04/16
SD2-GAA058	POSTMASBURG PTN. REDLANDS	PIETER STAFFORD	-28.31212	23.11843	-	8.19	-	-	-	-	M	DA	2012/04/16
SD2-GAA059	FARM 442 PORTION 5 KLEIN GOEDGEDACHT	ATTIE BRITS	-28.25612	23.19102	-	-	-	33.36	-	-	N	-	2013/01/18
SD2-GAA060	FARM 445 PORTION 5 KLEIN GODEGEDACHT	ATTIE BRITS	-28.26128	23.19161	83.00	1.39	-	-	77	7.6	M	DA	2012/10/23
SD2-GAA061	POSTMASBURG	Postmasburg Municipality - BOOI PIETERSE	-28.34024	23.12997	-	-	-	-	120	7.58	W	DA	2012/10/23
SD2-GAA062	POSTMASBURG	TOWNSON	-28.32473	23.12700	-	-	-	-	84	7.77	W	DA	2012/10/23
SD2-GAA063	PLAAS 441 PTN. JO-DIEN	JHONNY CLOETE	-28.17880	23.23988	-	-	-	17.18	65	9.21	W	AS	2013/07/08
SD2-GAA064	GOEDGEDACHT PTN. JO-DIEN	JHONNY CLOETE	-28.17888	23.23999	-	-	-	32.65	-	-	W	-	2013/06/06
SD2-GAA065	GOEDGEDACHT PTN. JO-DIEN	JHONNY CLOETE	-28.17894	23.24010	-	-	-	21.85	-	-	N	-	2013/06/06
SD2-GAA066	GOEDGEDACHT PTN. JO-DIEN	JHONNY CLOETE	-28.17929	23.24013	-	-	-	-	-	-	N	-	2013/06/06
SD2-GAA067	FARM 441	MARTIENS WILLEMSE	-28.17843	23.24040	-	-	-	-	-	-	N	-	2013/06/06
SD2-GAA068	FARM 441	MARTIENS WILLEMSE	-28.17841	23.24042	-	-	-	-	-	-	W	DA	2013/06/06
SD2-GAA069	FARM 441 PTN. 5	MARTIENS WILLEMSE	-28.17681	23.26721	76.20	-	-	64.12	-	-	N	-	2013/06/06

Borehole Number	Farm Name/Property	Owner/Representative	Latitude	Longitude	Reported Borehole Depth (m)	Discharge Rate (l/s)	Reported Yield (l/s)	Measured WL (mbgl)	Measured EC (mS/m)	Measured pH	Equipment	Use	Date Surveyed
SD2-GAA070	FARM 441	MARTIENS WILLEMSE	-28.17686	23.26540	146.00	0.51	-	56.26	73	9.34	M	DA	2014/04/01
SD2-GAA071	MIMOSA	JACOLIEN MATHYS	-28.18727	23.30852	-	-	-	-	-	-	W	DA	2014/03/10
SD2-GAA072	MIMOSA	JACOLIEN MATHYS	-28.18756	23.30760	-	-	-	-	-	-	N	-	2013/06/06
SD2-GAA073	MIMOSA PTN. KOEDOESHOEK	JACOLIEN MATHYS	-28.18026	23.30169	-	-	-	10.46	-	-	W	-	2013/06/06
SD2-GAA074	MIMOSA PTN. KOEDOESHOEK	JACOLIEN MATHYS	-28.18052	23.30025	-	-	-	-	19	9.19	W	DA	2013/07/08
SD2-GAA075	MIMOSA PTN. MICH-WILL	MICHEAL WILLEMSE	-28.20852	23.30737	-	-	-	33.39	-	-	W	AS	2013/06/06
SD2-GAA076	MIMOSA PTN. MICH-WILL	MICHEAL WILLEMSE	-28.19886	23.31667	-	-	-	6.77	-	-	W	DA	2013/06/06
SD2-GAA077	SERETSESENCHO PTN. SION	JOHN STAPLETON	-28.15734	23.18757	138.38	1.01	-	12.46	-	-	N	-	2014/04/01
SD2-GAA078	SERETSESENCHO PTN. SION	JOHN STAPLETON	-28.15735	23.18725	81.76	0.74	-	16.36	-	-	N	-	2014/04/01
SD2-GAA080	SERETSESENCHO PTN. SION	JOHN STAPLETON	-28.16254	23.18262	39.70	0.4	-	31.22	-	-	N	-	2014/04/01
SD2-GAA081	SERETSESENCHO PTN. SION	JOHN STAPLETON	-28.16328	23.18346	76.80	4.05	-	32.07	-	-	W	AS	2014/04/01
SD2-GAA082	SERETSESENCHO PTN. SION	JOHN STAPLETON	-28.16546	23.18267	68.56	1.23	-	5.95	148	9.22	M	DA	2014/04/01
SD2-GAA083	SERETSESENCHO PTN. SION	SAMUEL WILLEMSE	-28.17045	23.17517	-	-	-	-	88	9.39	N	-	2013/07/08
SD2-GAA084	SERETSESENCHO PTN. SWARTMODDER	SAMUEL WILLEMSE	-28.16276	23.15214	-	4.44	-	10.57	73	8.89	W	DA	2014/04/01
SD2-GAA085	SERETSESENCHO PTN. SWARTMODDER	SAMUEL WILLEMSE	-28.16388	23.15252	-	0.92	-	14.06	-	-	N	-	2014/04/01
SD2-GAA086	SERETSESENCHO PTN. SWARTMODDER	SAMUEL WILLEMSE	-28.17986	23.18057	78.68	0.52	-	8.47	-	-	N	-	2014/04/01
SD2-GAA087	SERETSESENCHO PTN. SWARTMODDER	SAMUEL WILLEMSE	-28.18767	23.17433	45.90	1.06	-	9.36	-	-	W	AS	2014/04/01
SD2-GAA088	SERETSESENCHO PTN. WELTEVREDEN	ANDRIES WILLEMSE	-28.19296	23.17101	-	-	-	-	-	-	W	DA	2013/06/06
SD2-GAA089	FARM 442 PTN. (8) GELUK	Christo OLIVER	-28.18957	23.19783	-	-	-	5.75	-	-	W	AS	2013/06/06
SD2-GAA090	FARM 442 PTN. KWAAITSAND	JANIE NEELS	-28.17862	23.19847	-	-	-	-	-	-	W	AS	2013/06/06
SD2-GAA091	FARM 442 PTN. KWAAITSAND	JANIE NEELS	-28.19255	23.21065	-	-	-	11.46	-	-	W	DA	2013/06/06
SD2-GAA092	FARM 442 PTN. KWAAITSAND	JANIE NEELS	-28.19797	23.21387	-	-	-	26.07	65	8.54	W	DA	2013/07/09

Borehole Number	Farm Name/Property	Owner/Representative	Latitude	Longitude	Reported Borehole Depth (m)	Discharge Rate (l/s)	Reported Yield (l/s)	Measured WL (mbgl)	Measured EC (mS/m)	Measured pH	Equipment	Use	Date Surveyed
SD2-GAA093	FARM 442 PTN. JO-DIEN	JHONNY CLOETE	-28.18300	23.22549	-	-	-	11.63	-	-	W	AS	2013/06/06
SD2-GAA094	FARM 440 PTN. MOEDHOU	WINSTON/VAUGHN AYTON	-28.17041	23.23339	-	-	-	13.32	-	-	W	AS	2013/06/06
SD2-GAA095	FARM 440 PTN. MOEDHOU	WINSTON/VAUGHN AYTON	-28.16184	23.22736	-	-	-		-	-	W	DA	2013/06/06
SD2-GAA096	FARM 440 PTN. MOEDHOU	WINSTON/VAUGHN AYTON	-28.15974	23.21468	41.50	-	-	3.69	-	-	N	-	2013/06/06
SD2-GAA097	FARM 440 PTN. MOEDHOU	WINSTON/VAUGHN AYTON	-28.15966	23.21461	-	-	-		95	8.69	M	DA	2013/07/08
SD2-GAA098	FARM 457 PTN. OWENDALE	PIET DU TOIT	-28.26528	23.42261	80.00	0.63	-	25.50	-	-	S	DA	2014/01/22
SD2-GAA099	FARM 469 PTN. HUMANSRUS	ALAN SCHOLTZ	-28.27900	23.36409	-	-	-	42.65	-	-	S	DA	2013/07/03
SD2-GAA100	FARM 469 PTN. HUMANSRUS	ALAN SCHOLTZ	-28.29153	23.37533	-	-	-	35.37	-	-	W	AS	2013/07/03
SD2-GAA101	FARM 469 PTN. HUMANSRUS	ALAN SCHOLTZ	-28.32083	23.35034	20.33	-	-	20.15	-	-	W	-	2013/07/03
SD2-GAA102	GROENWATER	Groenwater Community (C Hatting)	-28.27703	23.33520	-	-	-	6.64	-	-	H	DA	2013/07/03
SD2-GAA103	GROENWATER	Groenwater Community (C Hatting)	-28.27719	23.33526	10.66	-	-	6.52	-	-	W	DA	2013/07/03
SD2-GAA104	GROENWATER	Groenwater Community (C Hatting)	-28.27188	23.34001	79.24	18.94	-	5.20	-	-	N	-	2013/07/03
SD2-GAA105	GROENWATER	Groenwater Community (C Hatting)	-28.27122	23.34066	27.43	-	-	6.14	-	-	N	-	2013/07/03
SD2-GAA106	GROENWATER	Groenwater Community (C Hatting)	-28.28774	23.34242	-	-	-	8.15	-	-	N	-	2013/07/03
SD2-GAA107	GROENWATER	Groenwater Community (C Hatting)	-28.27771	23.33893	27.43	-	-	4.04	-	-	W	AS	2013/07/03
SD2-GAA108	GROENWATER	Groenwater Community (C Hatting)	-28.26626	23.33827	8.53	-	-	3.63	-	-	H	DA	2013/07/03
SD2-GAA109	GROENWATER	Groenwater Community (C Hatting)	-28.25240	23.35118	51.81	10.1	-	25.48	-	-	W	AS	2013/07/03
SD2-GAA110	GROENWATER	Groenwater Community (C Hatting)	-28.25111	23.34034	48.76	-	-	11.34	-	-	M	DA	2013/07/03
SD2-GAA111	GROENWATER	Groenwater Community (C Hatting)	-28.24887	23.29572	-	-	-	13.92	-	-	S	AS	2013/07/03
SD2-GAA112	GROENWATER	Groenwater Community (C Hatting)	-28.27539	23.31678	54.86	-	-	23.98	-	-	H	DA	2013/07/03
SD2-GAA113	GROENWATER	Groenwater Community (C Hatting)	-28.28211	23.31066	64.00	-	-	26.32	-	-	S	DA	2013/07/03
SD2-GAA114	GROENWATER	Groenwater Community (C Hatting)	-28.27742	23.30573	-	-	-	14.96	-	-	S	AS	2013/07/03
SD2-GAA115	GROENWATER	Groenwater Community (C Hatting)	-28.27740	23.30571	-	-	-	14.84	-	-	N	-	2013/07/03

Borehole Number	Farm Name/Property	Owner/Representative	Latitude	Longitude	Reported Borehole Depth (m)	Discharge Rate (l/s)	Reported Yield (l/s)	Measured WL (mbgl)	Measured EC (mS/m)	Measured pH	Equipment	Use	Date Surveyed
SD2-GAA116	GROENWATER PNT 4	Groenwater Community (C Hatting)	-28.29228	23.31897	73.00	-	4.0	24.35	-	-	N	AD	2013/07/03
SD2-GAA117	FARM 455 PTN. DAREHOPE	MIENKIE STEENKAMP	-28.23607	23.34082	-	-	-	23.03	-	-	M	DA	2013/07/03
SD2-GAA118	FARM 455 PTN. DAREHOPE	MIENKIE STEENKAMP	-28.23735	23.34450	-	-	-	27.44	-	-	W	DA	2013/07/03
SD2-GAA119	FARM 455 PTN. DAREHOPE	MIENKIE STEENKAMP	-28.23753	23.34429	-	-	-	21.69	-	-	S	DA	2013/07/03
SD2-GAA120	GROENWATER	Groenwater Community(C Hatting)	-28.24237	23.34112	102.00	-	-	21.89	-	-	N	-	2013/07/03
SD2-GAA121	GROENWATER	Groenwater Community(C Hatting)	-28.24259	23.34100	150.00	-	-	19.9	-	-	N	AD	2013/07/03
SD2-GAA122	SOETFONTEIN	ALBERTUS VILJOEN	-28.37205	23.03445	128.00	-	-	5.08	-	-	S	DA	2013/07/03
SD2-GAA123	SOETFONTEIN	ALBERTUS VILJOEN	-28.37197	23.03421	-	-	-	5.94	-	-	S	DA	2013/07/03
SD2-GAA124	SOETFONTEIN	ALBERTUS VILJOEN	-28.37150	23.03444	-	-	-	5.73	-	-	S	DA	2013/07/03
SD2-GAA125	ROOIPAN	ALBERTUS VILJOEN	-28.37155	23.63461	-	-	-	5.5	-	-	N	-	2014/01/22
SD2-GAA126	SOETFONTEIN	ALBERTUS VILJOEN	-28.37401	23.03591	-	-	-	6.74	-	-	N	-	2013/07/03
SD2-GAA127	VAALPOORT	LOEKIE VAN DER MERWE	-28.27681	23.16467	-	-	-	15.89	-	-	S	AS	2013/11/04
SD2-GAA128	VAALPOORT	LOEKIE VAN DER MERWE	-28.27637	23.15168	-	-	-	-	-	-	S	DA	2013/11/04
SD2-GAA129	VAALPOORT	LOEKIE VAN DER MERWE	-28.27753	23.15546	-	-	-	10.33	-	-	S	DA	2013/11/04
SD2-GAA130	GOEDGEDACHT	LOEKIE VAN DER MERWE	-28.25723	23.20215	-	5.556	-	-	-	-	W	AS	2014/01/27
SD2-GAA131	GOEDGEDACHT	LOEKIE VAN DER MERWE	-28.25864	23.21376	-	5.556	-	46.04	-	-	S	AS	2014/01/27
SD2-GAA132	GOEDGEDACHT	LOEKIE VAN DER MERWE	-28.26804	23.21092	-	-	-	41.73	-	-	N	-	2014/01/27
SD2-GAA133	GOEDGEDACHT PTN. JEN-HAVEN	JEN HAVEN COMMUNITY	-28.23768	23.23951	88.00	-	-	48.78	-	-	N	-	2013/11/1
SD2-GAA134	METSEATEN	JOSEPH ISAACS	-28.20203	23.13888	28.60	0.74	-	13.95	-	-	W	DA	2014/04/01
SD2-GAA135	METSEATEN	JOSEPH ISAACS	-28.20202	23.13838	54.60	1.06	-	13.18	-	-	W	DA	2014/04/01
SD2-GAA136	METSEATEN	JOSEPH ISAACS	-28.20200	23.13788	36.80	4.0	-	10.89	-	-	M	DA	2014/04/01
SD2-GAA137	METSEATEN	JOSEPH ISAACS	-28.20198	23.13844	-	-	-	-	-	-	M	DA	2014/01/31
SD2-GAA138	SERETSESENCHO PTN. SION	JOHN STAPLETON	-28.15685	23.18598	119.80	0.62	-	6.57	-	-	W	AS	2014/04/01

Borehole Number	Farm Name/Property	Owner/Representative	Latitude	Longitude	Reported Borehole Depth (m)	Discharge Rate (l/s)	Reported Yield (l/s)	Measured WL (mbgl)	Measured EC (mS/m)	Measured pH	Equipment	Use	Date Surveyed
SD2-GAA139	VINCI	JEN HAVEN COMMUNITY	-28.22712	23.16404	90.60	1.56	-	12.04	-	-	N	-	2014/04/01
SD2-GAA140	METSEATEN	LUCAS KOTZE	-28.21038	23.13560	58.20	0.5	-	14.21	-	-	N	DA	2014/04/02
SD2-GAA141	METSEATEN	LUCAS KOTZE	-28.21363	23.16592	2.80	-	-	-	-	-	N	-	2014/04/02
SD2-GAA200	SEDIBENG MINE	SEDIBENG MINE	-28.19149	23.11113	94.16	30	-	39.18	-	-	N	-	2012/04/13
SD2-GAA201	SEDIBENG MINE	SEDIBENG MINE	-28.18380	23.12162	103.08	15.12	-	35.79	-	-	N	-	2012/04/13
Min					2.8	0.37	3.33	0.32	9.0	6.43			
Max					176.0	30.0	5.56	64.12	362.0	9.39			
Average					67.30	5.04	4.30	20.12	85.13	7.81			
SANS 241:2011 Max Allowable Limit									<170	5 - 9.7			
DWAF 1998 Class I Drinking									70-150	5-10			

APPENDIX E

SD2 Summarised Drilling Results

Borehole Number	Farm Name	Land-owner	Latitude	Longitude	Altitude (mamsl)	Traverse No/Station No	Drilling Depth (m)	Casing Depth (m)	Final Diam. (mm)	Water Strike (m)	Water strike (l/s)	Final Blow yield (l/s)	Measured WL (mbgl)	Measured WL (mamsl)	Geological Formation/Aquifer Type	Date Completed	BH Status
SD2-1	Municipality	Postmasburg	-28.337554	23.140891	1354.66	P2/1000	106	60	254	Seepage only	Seepage only	Seepage only	21.63	1333.03	Khalahari sediments	25/08/2013	Monitoring
SD2-2	Municipality	Postmasburg	-28.317828	23.117227	1339.53	P20/720	74	3	254	Seepage only	Seepage only	Seepage only	20.79	1318.74	Khalahari sediments/dolerite	19/08/2013	Monitoring
SD2-3	Municipality	Postmasburg	-28.318590	23.142107	1351.84	P4/3500	118	106	165	23;68;73;99;110	0.1;0.3;2;10;6	22.00	19.02	1332.82	Khalahari sediments/dolomite	23/08/2013	Production
SD2-4	Municipality	Postmasburg	-28.329855	23.092867	1320.11	P1/300	74	60	165	Seepage only	Seepage only	Seepage only	13.78	1306.33	Khalahari sediments/dolomite	21/08/2013	Monitoring
SD2-5	Municipality	Postmasburg	-28.327050	23.139120	1348.07	P20/3100	105	104	165	52;97	0.2;4	4.00	15.24	1332.83	Khalahari sediments/dolomite	03/09/2013	Monitoring
SD2-6	Municipality	Postmasburg	-28.324972	23.150426	1353.38	P2/2700	89	84	165	Seepage only	Seepage only	Seepage only	20.48	1332.90	Khalahari sediments	07/09/2013	Monitoring
SD2-7	Municipality	Postmasburg	-28.316072	23.157200	1353.88	P21/3350	52	52	203	37-42;50-52	3;23	26.00	21.13	1332.75	Khalahari sediments/dolomite	05/09/2013	Production
SD2-8	Municipality	Postmasburg	-28.313490	23.150118	1353.62	P21/2600	120	61	165	51	0.2	0.20	20.67	1332.95	Khalahari sediments/dolomite	09/09/2013	Monitoring
SD2-9	Municipality	Postmasburg	-28.306271	23.156516	1351.26	P22/2350	66	64	165	39-40;53-54;61	0.6;1.0;20	20.00	18.52	1332.74	Khalahari sediments/dolomite	12/09/2013	Production
SD2-10	Municipality	Postmasburg	-28.309325	23.138496	1345.85	P21/1370	60	70	165	39;43;58;62;67-70	0.2;0.3;6;4;10	23.00	13.00	1332.85	Khalahari sediments/dolomite	13/09/2013	Production
SD2-11	Municipality	Postmasburg	-28.304981	23.126510	1337.65	P21/100	34	33	203	22;27-28	20;10	33.00	10.99	1326.66	Dolomite	12/09/2013	Production
SD2-12	Municipality	Postmasburg	-28.308063	23.161201	1353.00	P22/2850	75	75	165	41;72	1.3;20	20.00	20.51	1332.49	Khalahari sediments/dolomite	14/09/2013	Production
SD2-13	Municipality	Postmasburg	-28.298704	23.163611	1353.17	P23/2150	55	52	203	30;38;50	2;10;4	16.00	20.28	1332.89	Khalahari sediments	24/09/2013	Production
SD2-14	Municipality	Postmasburg	-28.296017	23.172748	1357.17	P7/2450	100	100	165	98	15.5	14.00	24.26	1332.91	Khalahari sediments/dolomite	26/09/2013	Production
SD2-15	Municipality	Postmasburg	-28.292804	23.148754	1349.10	P23/550	83	82	165	79-83	20.0	20.00	16.28	1332.82	Khalahari sediments/dolomite	28/09/2013	Production
SD2-16M	Municipality	Postmasburg	-28.288303	23.163341	1352.48	P7/1100	74	56	203	40	2.0	1.70	19.75	1332.73	Khalahari sediments	02/10/2013	Monitoring
SD2-16	Municipality	Jen Haven - PM	-28.288158	23.163097	1352.45	P7/1070	97	97	165	97	30.0	23.0	19.75	1332.70	Khalahari sediments/dolomite	20/10/2013	Production
SD2-17	Municipality	Postmasburg	-28.320661	23.123741	1339.81	P20/1430	59	59	165	19;32;43	0.2;2;8	8.00	13.46	1326.35	Khalahari sediments/dolomite	30/09/2013	Production
SD2-18	Municipality	Postmasburg	-28.287230	23.147742	1345.35	P5/7700	73	3	254	43;63	0.1;01	0.20	12.41	1332.94	Khalahari sediments/dolomite	30/09/2013	Monitoring
SD2-19	Municipality	Postmasburg	-28.330032	23.097718	1324.82	P1/780	61	61	165	Seepage only	Seepage only	Seepage only	18.21	1306.61	Khalahari sediments/dolomite	02/10/2013	Monitoring

Borehole Number	Farm Name	Land-owner	Latitude	Longitude	Altitude (mamsl)	Traverse No/Station No	Drilling Depth (m)	Casing Depth (m)	Final Diam. (mm)	Water Strike (m)	Water strike (l/s)	Final Blow yield (l/s)	Measured WL (mbgl)	Measured WL (mamsl)	Geological Formation/Aquifer Type	Date Completed	BH Status
SD2-20	Municipality	Jen Haven - PM	-28.330009	23.095777	1319.07	P1/600	61	61	165	35-39	0.2	0.20	13.44	1305.63	Khalahari sediments/dolomite	05/10/2013	Monitoring
SD2-21	Vaalpoort	Loekie van der	-28.270995	23.163933	1352.7	P5/10200	94	94	165	89	20	20.0	19.81	1332.92	Khalahari sediments/dolomite	17/10/2013	Production
SD2-22	Goedgedaght	Jen Haven - PM	-28.219793	23.239764	1388.8	P19/600	73	73	165	53;68-73	2;5	4.30	45.8	1342.96	BIF/Dolomite	19/10/2013	Production
SD2-23	Vaalpoort	Loekie van der Merwe	-28.263208	23.169254	1354.7	P5/11300	73	73	203	50;72	0.2;20	20.00	21.79	1332.88	Khalahari sediments/dolomite	21/10/2013	Production
SD2-24	Goedgedaght	Jen Haven - PM	-28.25106	23.21368	1381.5	P5/16100	119	119	165	94;119	2;10	15.50	48.01	1333.45	BIF/Dolomite	27/10/2013	Production
SD2-25	Goedgedaght	Jen Haven - PM	-28.21163	23.23613	1385.10	P24/3300	66	61	203	60-66	0.7	0.70	42.17	1342.93	BIF/Dolomite	25/10/2013	Monitoring
SD2-26	Vaalpoort	Loekie van der	-28.27414	23.17470	1356.3	P6/5400	75	75	203	50;68;72	1;5;15	40.0	23.23	1333.10	BIF/Dolomite	26/10/2013	Production
SD2-27	Farm 442	Jen Haven - PM	-28.18323	23.23123	1385.0	P27/1650	61	61	165	25;57;59	0.2;2;10	13.50	16.84	1368.14	Khalahari sediments/dolomite	28/10/2013	Production
SD2-28	Goedgedaght	Jen Haven - PM	-28.24391	23.23268	1391.2	P17/2700	85	53	203	Seepage only	Seepage only	Seepage only	50.52	1340.70	BIF	10/11/2013	Monitoring
SD2-29	Goedgedaght	Jen Haven - PM	-28.23921	23.25441	1401.5	P9/4800	73	73	165	61	0.2	0.20	48.33	1353.21	BIF	14/11/2013	Monitoring
SD2-30	Goedgedaght	Jen Haven - PM	-28.23913	23.22550	1387.12	P16/2150	98	98	165	66;91	2;25	30	52.79	1334.33	BIF/Dolomite	15/11/2013	Production
SD2-31	Farm 442	Jen Haven - PM	-28.21907	23.20114	1368.5	P13/150	85	66	203	16;27;39	0.2; 4	4.10	11.38	1357.15	Dolomite	15/11/2013	Production
SD2-32	Farm 442	Jen Haven - PM	-28.22200	23.20683	1374.8	P12/1300	90	90	203	80-84	11.0	11.00	31.63	1343.12	BIF/Dolomite	21/11/2013	Production
SD2-33	Goedgedaght	Jen Haven - PM	-28.23506	23.25756	1402.96	P9/5350	104	102	165	84;90	1.0;4.0	1.50	59.86	1343.10	BIF	05/12/2013	Production
SD2-34	Farm 442	Jen Haven - PM	-28.22229	23.20101	1369.54	P13/500	34	32	203	23;29	20;7.0	26.00	12.31	1357.23	BIF/Dolomite	28/11/2013	Production
SD2-35	Goedgedaght	Jen Haven - PM	-28.23638	23.22553	1384.4	P16/1850	100	82	203	68;73;86	0.8;21.2;2.0	22	50.5	1333.87	BIF/Dolomite	04/12/2013	Production
SD2-36	Farm 442	Jen Haven - PM	-28.25574	23.18940	1367.00	P5/13600	97	97	203	83;95	8.0;12.0	20	33.92	1333.08	BIF/Dolomite	02/12/2013	Production
SD2-37	Goedgedaght	Jen Haven - PM	-28.23833	23.24114	1394.02	P18/2625	85	85	165	71;83	1;3	4.00	57.47	1336.55	BIF/Dolomite	07/02/2014	Production
SD2-38	Goedgedaght	Jen Haven - PM	-28.22198	23.21828	1381.44	P14/3600	89	89	165	88	10.0	10.80	37.95	1343.49	BIF/Dolomite	25/02/2014	Production
SD2-39	Metseaten	Jen Haven - PM	-28.23636	23.14901	1386.70	P33/4225	70	70	203	34;41	0.1;1.0	1.10	16.1	1370.60	Dolomite	22/02/2014	Monitoring
SD2-40	Metseaten	Jen Haven - PM	-28.23020	23.14522	1392.31	P33/3450	60	14	203	Seepage only	Seepage only	Seepage only	52.99	1339.32	Dolomite	22/02/2014	Monitoring
SD2-41	Goedgedaght	Jen Haven - PM	-28.23316	23.24583	1394.32	P48/1300	72	72	203	63;67	2;11	13.00	51.04	1343.28	BIF/Dolomite	28/02/2014	Production
SD2-42	Metseaten	Jen Haven - PM	-28.23549	23.15964	1375.8	P34/1150	39	39	165	13;20;26;28;29;37;39	10;12	17.00	5.21	1370.55	Dolomite	25/02/2014	Production
SD2-43	Metseaten	Jen Haven - PM	-28.22022	23.22136	1382.20	P56/3250	121	35	203	Seepage only	Seepage only	Seepage only	38.46	1343.74	BIF/Dolomite	05/03/2014	Monitoring
SD2-44	Metseaten	Jen Haven - PM	-28.21448	23.17077	1397.80	P34/3725	60	13	203	seepage only	seepage only	Seepage only	28.23	1369.57	Dolomite	01/03/2014	Monitoring
SD2-45	Goedgedaght	Jen Haven - PM	-28.23630	23.24567	1395.5	P48/950	130	48	203	94	0.1	0.10	52.18	1343.36	BIF/Dolomite	06/03/2014	Monitoring
SD2-46	Goedgedaght	Jen Haven - PM	-28.20446	23.22878	1382.8	P54/4850	125	32	254	Seepage only	Seepage only	Seepage only	39.4	1343.37	BIF/Dolomite	07/03/2014	Monitoring
Min						-	34	3	-	13.0	0.1	0.1	5.21	1305.6	-	-	28 Production

Borehole Number	Farm Name	Land-owner	Latitude	Longitude	Altitude (mamsl)	Traverse No/Station No	Drilling Depth (m)	Casing Depth (m)	Final Diam. (mm)	Water Strike (m)	Water strike (l/s)	Final Blow yield (l/s)	Measured WL (mbgl)	Measured WL (mamsl)	Geological Formation/Aquifer Type	Date Completed	BH Status
Max						-	130	119	-	119.0	30.0	40	59.86	1370.6	-	-	19 Monitoring
Average						-	81.1	65.7	-	57.4	6.8	13.7	28.12	1337.6	-	-	47 Total

APPENDIX F

**SD2 Exploration Boreholes Pump
Tested**

Borehole Number	Borehole Coordinates		Borehole Information			Pump Testing Details								
	Latitude	Longitude	Completion Date	Borehole Depth (m)	Static Water level (mbgl)	Pump Installation Depth (m)	No of SDT's	PI Yield (l/s)	Final Yield of SDT	Duration of CDT (min)	Yield of CDT (l/s)	CDT Drawdown (m)	WL Recovery (m)	WL Recovery (min)
Exploration Boreholes														
SD2-03	-28.31856	23.14214	2013/09/08	118	18.6	101	4	-	20.1	48	20.1	18.7	0	480
SD2-04	-28.32982	23.09288	2014/01/22	74	13.38	62	2	0.13	0.6	-	-	-	36.5	120
SD2-05	-28.32705	23.13926	2013/09/09	104	14.3	101	3	1.3	2.5	-	-	-	0	110(SDT)
SD2-06	-28.32501	23.15042	2014/01/24	77	20.0	62	1	-	0.51	-	-	-	32.34	60
SD2-07	-28.31605	23.15721	2013/09/13	52	20.8	47	4	-	30.3	48	30.0	15.8	0	10
SD2-08	-28.31349	23.15012	2014/01/25	121	20.3	85	3	0.43	1.3	-	-	-	6.48	180
SD2-09	-28.30627	23.15653	2013/09/16	66	18.2	59	4	-	20.6	24	20.1	1.0	0	90
SD2-09(2)	-28.30627	23.15653	28/02/2014	66	18.19	53.15	-	-	-	72	20	0.28	0	90
SD2-10	-28.30932	23.13851	2013/10/13	71	12.3	59	4	-	20.3	24	15.0	9.8	0	40
SD2-11	-28.30498	23.12651	2013/09/23	34	10.6	29	4	-	30.4	48	30.1	1.3	0	1440
SD2-12	-28.30806	23.16122	2013/09/19	74	20.2	71	4	-	21.2	24	20.1	5.0	0	300
SD2-12(2)	-28.30806	23.16122	22/02/2014	74	20.38	70	-	-	-	72	20	4.8	0	1
SD2-13	-28.29871	23.16361	2013/10/21	52	19.8	47	4	28.4	30.0	48	20.0	16.6	1.43	2880
SD2-14	-28.29601	23.17271	2013/10/16	100	23.9	89	4	-	20.4	24	15.2	12.2	0	90
SD2-15	-28.29281	23.14875	2013/10/21	82	16.1	77	4	-	20.0	24	20.0	3.4	0	30
SD2-15(2)	-28.29281	23.14875	05/03/2014	82	16.4	59.15	-	-	-	72	20	3.58	0	720
SD2-16	-28.28816	23.16310	2013/10/31	97	19.2	89	4	-	20.2	48	20.0	5.8	0	3
SD2-17	-28.32063	23.12369	2013/10/18	60	13.2	58	4	-	16.2	24	15.0	9.4	0	960
SD2-19	-28.33002	23.09772	2014/01/21	62	17.7	56	2	0.16	0.7	-	-	-	18.21	120
SD2-21	-28.27099	23.16394	2013/11/06	94	19.4	83	4	18.4	20.0	48	13.0	24.2	0	2

Borehole Number	Borehole Coordinates		Borehole Information			Pump Testing Details								
	Latitude	Longitude	Completion Date	Borehole Depth (m)	Static Water level (mbgl)	Pump Installation Depth (m)	No of SDT's	PI Yield (l/s)	Final Yield of SDT	Duration of CDT (min)	Yield of CDT (l/s)	CDT Drawdown (m)	WL Recovery (m)	WL Recovery (min)
SD2-22	-28.21927	23.23948	2013/10/25	73	45.0	71	4	18.8	20.0	48	13.0	9.3	0	1200
SD2-23	-28.26321	23.16927	2013/11/02	71	21.1	58	4	-	20.0	24	15.0	6.7	0	3
SD2-24	-28.25125	23.21373	2013/11/15	119	47.4	95	4	-	20.2	48	15.0	8.5	0.22	2880
SD2-25	-28.21161	23.23614	2013/11/12	61	41.3	58	2	4.4	4.5	-	-	-	0.21	80
SD2-26	-28.27414	23.17470	2013/11/10	72	23.3	64	4	-	25.0	48	20.0	13.6	0	720
SD2-29	-28.23921	23.25444	2014/01/25	70	47.74	62	2	0.21	0.74	-	-	-	6.42	70
SD2-30	-28.23913	23.22551	2013/11/29	98	52.5	88	3.5	15.4	17.0	24	10.0	15.2	0	210
SD2-31	-28.21906	23.20117	2013/11/21	85	10.7	77	4	10.0	15.0	24	7	2.3	0	600
SD2-32	-28.22203	23.20685	2013/12/02	90	31.3	83	3	10.7	12.3	24	8	32.8	0	180
SD2-33	-28.23505	23.25757	2014/01/14	102	59.3	94	4	13.2	19.0	48	9	12.9	0	840
SD2-34	-28.22227	23.20102	2013/12/05	34	11.9	29	4	-	30.1	24	20.1	1.4	0.04	1440
SD2-34(2)	-28.22227	23.20102	27/02/2014	34	19.68	29	-	-	-	72	30	2.7	0	1560
SD2-35	-28.23638	23.22553	2013/12/11	100	50.4	76	6	-	30	24	25	0.3	0	15
SD2-35(2)	-28.23638	23.22553	23/02/2014	100	50.12	70.84	-	-	-	72	30	0.43	0	1200
SD2-36	-28.20202	23.13838	20-13/12/08	97	33.9	88	4	-	20	24	15	2.3	0	480
SD2-37	-28.23835	23.24119	20/02/2014	83.86	59.8	76.5	4	-	20.5	48	20	0.77	0	10
SD2-38	-28.22186	23.21807	05/03/2014	88.75	38.08	82.04	4	-	20.3	56	15	27.43	0	20
SD2-39	-28.23631	23.14913	10/03/2014	70	16.1	64.8	4	-	-	-	-	-	0	90
SD2-42	-28.23549	23.15964	12/03/2014	39	5.21	33.34	4	-	20.58	72	15	4.62	0	360

APPENDIX G

Sinkhole Risk Assessment of Exploration Boreholes

Area Investigated	BH ID	Topsoil	Sand & Gravel	Clay	Calcrete	Banded Ironstone	Breccia/Conglomerate/ Quartzite	Dolerite	Limestone	Weathered Chert/chert residuum	Dolomite residuum	Weathered Dolomite/Boulders	Chert	Dolomite Bedrock	Wad	Cavities	Water-Level (m)	Ingress Scenario Characterization	De-watering Scenario Characterization	Drawdown and Ingress Implications to sinkholes and subsidence
SD1	SD1_01			3-14 m	0-3 m					14-18 m			18-20 m	20-28.5 m, 31-82 m		28.5-31.0 m	11	3	4	Medium-high susceptibility to sinkholes and subsidence (to 5 m)
	SD1_02			3-17 m	0-3 m								17-32 m, 34-35 m	NE		33-34 m	10	3	4	Medium-high susceptibility to sinkholes and subsidence (to 5 m)
	SD1_03		0-2 m		2-5 m									5-80 m				3	4	Medium susceptibility to sinkholes and subsidence (to 5 m)
	SD1_04		0-1 m		1-5 m	5-8 m				16-18 m, 19-20 m				8-16 m, 22- 60 m	20-22 m	18-19 m	11.5	3	1	Medium susceptibility due to ingress and low susceptibility due to groundwater drawdown
	SD1_05	0-2 m								2-10 m, 15- 17 m				10-15 m, 17-20 m, 27-40 m		20-21 m, 23-24 m	17	3/4	4	Medium susceptibility to sinkholes and subsidence (to 5 m)
	SD1_06	0-2 m		7-11 m						2-7 m				11-70 m		16-17 m	12	3	4	Medium susceptibility to sinkholes and subsidence (to 5 m)
	SD1_07	0-1 m		4-17 m	1-4 m									18-50 m		17-18 m	13	2/4	4	Low-medium susceptibility to sinkholes and subsidence (to 5 m)
	SD1_08			4-22 m	0-4 m	24-25 m				25-31 m		31-34 m		34-40 m	22-24 m	33-34 m	15	2	4	Low-medium susceptibility to sinkholes and subsidence (to 5 m)
	SD1_09	0-1 m		14-19 m	1-4 m					31-35 m		4-12 m	35-37 m	18-31 m, 37-40 m		12-14 m	7	4	4	Medium susceptibility to sinkholes and subsidence (to 5 m)
	SD1_10			10-22 m	0-10 m	22-28 m								NE			13	1	4	Low susceptibility due to ingress and low- medium susceptibility due to groundwater drawdown
	SD1_11			7-37 m	0-7 m							37-49 m		49-67 m		67-70 m	14	1	4	Low susceptibility due to ingress and low- medium susceptibility due to groundwater drawdown
	SD1_12			6-24 m	0-6 m	24-48 m								48-110 m			3	3	4	Medium susceptibility to sinkholes and subsidence (to 5 m)
	SD1_13				0-11 m							11-13 m		13-60 m			19	1	1	Low susceptibility to sinkholes and subsidence
	SD1_14	0-2.5 m		20-53 m	2.5-20 m	53-66 m								NE			13	1	4	Low susceptibility due to ingress and low- medium susceptibility due to groundwater drawdown

Area Investigated	BH ID	Topsoil	Sand & Gravel	Clay	Calcrete	Banded Ironstone	Breccia/Conglomerate/ Quartzite	Dolerite	Limestone	Weathered Chert/chert residuum	Dolomite residuum	Weathered Dolomite/Boulders	Chert	Dolomite Bedrock	Wad	Cavities	Water-Level (m)	Ingress Scenario Characterization	De-watering Scenario Characterization	Drawdown and Ingress Implications to sinkholes and subsidence
	SD1_14S																13	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_15	0-18 m		36-41 m	0-36 m			41-64 m						NE			17.5	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_16S				0-16 m													1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_16			21-36 m	0-21 m	36-54 m						54-57 m		58			10	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_17			7-9 m	0-7 m					40-58 m		9-18 m		18-40 m			9.5	4	4	Medium susceptibility to sinkholes and subsidence (to 5 m)
	SD1_17M				0-9 m									9-24 m				3	4	Medium susceptibility to sinkholes and subsidence (to 5 m)
	SD1_18			29-57 m	0-29 m									57-71 m	49-57 m			1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_19			5-12 m	0-5 m								12-46 m					4	4	Medium susceptibility to sinkholes and subsidence (to 5 m)
	SD1_20			5-24 m	0-5 m	24-31 m								47-48 m	31-44 m	44-47 m		1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_21			0-23 m		23-45 m				45-73 m				73-99 m			3	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_22			4-20 m	0-4 m	20-38 m							38-48 m					1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_23				0-44 m	44-53 m								58			18	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown

Area Investigated	BH ID	Topsoil	Sand & Gravel	Clay	Calcrete	Banded Ironstone	Breccia/Conglomerate/ Quartzite	Dolerite	Limestone	Weathered Chert/chert residuum	Dolomite residuum	Weathered Dolomite/Boulders	Chert	Dolomite Bedrock	Wad	Cavities	Water-Level (m)	Ingress Scenario Characterization	De-watering Scenario Characterization	Drawdown and Ingress Implications to sinkholes and subsidence
	SD1_24				0-37 m									37-69 m			13	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_25			2-6 m	0-2 m						50-52 m			6-52		47-48 m	7	3	4	Medium susceptibility to sinkholes and subsidence (to 5 m)
	SD1_26			16-39 m	0-16 m	49-56 m	39-49 m						56-58 m	60-66 m				1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_27			34-43 m	0-34 m, 43-61 m					61-67 m								1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_27LOG			60-67 m	0-61 m									67-101 m				1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_27S			8-12 m	0-8 m, 12-18 m													1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_28				0-36 m			58-66 m						36-58 m				1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_29			5-24 m	0-5 m	24-60 m				60-70 m				NE			10	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_30				0-38 m									38-70 m				1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_31		58-69 m	52-58 m	0-46 m	46-52 m								69-120 m				1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_32			31-49 m	0-31 m							49-68 m		68-72 m			14	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown

Area Investigated	BH ID	Topsoil	Sand & Gravel	Clay	Calcrete	Banded Ironstone	Breccia/Conglomerate/Quartzite	Dolerite	Limestone	Weathered Chert/chert residuum	Dolomite residuum	Weathered Dolomite/Boulders	Chert	Dolomite Bedrock	Wad	Cavities	Water-Level (m)	Ingress Scenario Characterization	De-watering Scenario Characterization	Drawdown and Ingress Implications to sinkholes and subsidence
	SD1_32 M			36-54 m	0-36 m									54-71 m				1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_32S				0-16 m													1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_33	0-3 m		57-61 m		3-57 m				67-78 m								1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_34	0-4 m				4-22 m								22-138 m				2	1/4	Low-medium susceptibility due to ingress and medium susceptibility due to groundwater drawdown
	SD1_35				0-19 m									19-28 m				1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_35M				0-18 m									18-30 m				2/4	4	Low and medium susceptibility to sinkholes and subsidence (to 5 m)
	SD1_36			17-20 m	0-17 m	20-39 m	76-87 m							39-76 m				1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_37			27-37 m	0-27 m, 37-48 m, 49-67 m							67-80 m		NE		48-49 m	12	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_38			19-40 m	0-19 m			40-70 m						NE			67	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_39			5-24 m	0-5 m									24-70 m			22	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_40		80-96 m	22-80 m		0-22 m								NE			31	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown

Area Investigated	BH ID	Topsoil	Sand & Gravel	Clay	Calcrete	Banded Ironstone	Breccia/Conglomerate/ Quartzite	Dolerite	Limestone	Weathered Chert/chert residuum	Dolomite residuum	Weathered Dolomite/Boulders	Chert	Dolomite Bedrock	Wad	Cavities	Water-Level (m)	Ingress Scenario Characterization	De-watering Scenario Characterization	Drawdown and Ingress Implications to sinkholes and subsidence
	SD1_40M			28-52 m		0-28 m, 52-86 m				86-94 m								1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_41		91-96 m	20-64 m		0-20 m, 64-73 m				73-91 m				NE	-	-	44	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_42			49-73 m		0-49 m, 73-91 m						91-103 m		103	-	-	35	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_43			21-27 m, 32-38 m	0-21 m, 27-32 m							38-64 m		38	-	-	15	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD1_44	0-1 m								1-3 m				3-20 m, 22.5-24 m, 39-34 m		20-22.5 m, 24-29 m	18	5	1	High susceptibility due to ingress and low susceptibility due to groundwater drawdown
	SD1_45	0-1 m		3-10 m		1-3 m, 10-16 m				16-34 m				34-38 m, 42-44 m		38-42 m	13	4	6	Medium susceptibility due to ingress and high susceptibility due to groundwater drawdown
SD2	SD2_1	0-4 m		12.5-105 m	4-12.5 m													1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_2			29-54 m	0-14 m, 18.5-21.5 m, 26-29 m	14-18.5 m, 21.5-26 m		54-73 m									48	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_3		28-33 m, 37-69 m	21-28 m	0-21 m, 33-37 m									69-117 m			19	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_4				0-24 m									24-74 m			14	2	4	Low-medium susceptibility due to ingress and medium susceptibility due to groundwater drawdown (< 5 m sinkholes and subsidence)
	SD2_5		10-15 m, 20-39 m,	39-42 m, 49-52 m	0-10 m, 15-20 m					91-105 m							15	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown

Area Investigated	BH ID	Topsoil	Sand & Gravel	Clay	Calcrete	Banded Ironstone	Breccia/Conglomerate/ Quartzite	Dolerite	Limestone	Weathered Chert/chert residuum	Dolomite residuum	Weathered Dolomite/Boulders	Chert	Dolomite Bedrock	Wad	Cavities	Water-Level (m)	Ingress Scenario Characterization	De-watering Scenario Characterization	Drawdown and Ingress Implications to sinkholes and subsidence
			42-49 m, 52- 91 m																	
	SD2_6	0-2.5 m	27-29 m, 32- 35 m	29-32 m, 35- 38 m	5.0- 27.0 m	2.5-5.0 m, 38-87 m											20	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_7	0-2.0 m	18-37 m		4-18 m	2.0-4.0 m				37-52 m							21	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_8		35-58 m	28-35 m	0-28 m									58-120 m			21	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_9		28-40 m, 44- 53 m	40-44 m	0-28 m									53-65 m			18	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_10		15-18 m	22-34 m	0-15 m, 18-22 m							56-58 m		34-56 m, 58-70 m			12	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_11	0-1.0 m		20-22 m		8-11 m				1-6 m		22-26 m		6-8 m, 11- 20 m, 33-34 m	26-33 m	27-28 m	11	3	4	Medium susceptibility to sinkholes and subsidence (to 5 m)
	SD2_12		23-26 m, 28- 32 m	26-28 m, 32- 34 m	0-15 m	15-23 m						34-40 m		40-75 m			20	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_13	0-2.0 m		51-54 m	2-29 m	29-51 m											22	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_14	0-2.0 m	10-20 m, 35- 47 m	20-25 m, 27- 35 m	5-10 m, 25-27 m	2-5 m						47-60 m		60-100 m			24	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_15				0-17 m, 24-28 m	17-24 m, 43-67 m				79-82 m, 67-79 m							16	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown

Area Investigated	BH ID	Topsoil	Sand & Gravel	Clay	Calcrete	Banded Ironstone	Breccia/Conglomerate/Quartzite	Dolerite	Limestone	Weathered Chert/chert residuum	Dolomite residuum	Weathered Dolomite/Boulders	Chert	Dolomite Bedrock	Wad	Cavities	Water-Level (m)	Ingress Scenario Characterization	De-watering Scenario Characterization	Drawdown and Ingress Implications to sinkholes and subsidence
	SD2_16	0-3.0 m	3-6 m	73-79 m	6-34 m	34-73 m				79-95 m							20	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_16M	0.3.0 m			3-10 m	10-74 m											19	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_17	0-11 m	11-14 m		14-19 m							19-42 m		42-58 m			13	2/4	4	Low to medium susceptibility to sinkholes and subsidence (to 5 m)
	SD2_18				0-16 m							16-26 m, 26-34 m		34-74 m			12	4	4	Medium susceptibility to sinkholes and subsidence (to 5 m)
	SD2_19			12-15 m	0-12 m, 15-18 m		21-41 m					18-21 m		41-60 m			18	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_20			12-22 m, 31-35 m	0-12 m, 22-23 m	23-31 m, 51-60 m						35-43 m		43-51 m			13	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_21	0-6 m	25-29 m		6-25 m	29-35 m								35-95 m			20	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_22					0-35 m					35-56 m			56-74 m			46	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_23			10-23 m		0-10 m		23-27 m						27-74 m			22	2	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_24			41-51 m		0-41 m, 51-61 m								61-115 m			48	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_25	0-3 m				3-58 m								58-65 m			43	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown

Area Investigated	BH ID	Topsoil	Sand & Gravel	Clay	Calcrete	Banded Ironstone	Breccia/Conglomerate/Quartzite	Dolerite	Limestone	Weathered Chert/chert residuum	Dolomite residuum	Weathered Dolomite/Boulders	Chert	Dolomite Bedrock	Wad	Cavities	Water-Level (m)	Ingress Scenario Characterization	De-watering Scenario Characterization	Drawdown and Ingress Implications to sinkholes and subsidence
	SD2_26			18-64 m	6-18 m	0-06 m				64-75 m							50	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_27	0-2			2-9 m						22-30 m	9-22 m		30-60 m			17	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_27S			8-12 m	0-8 m, 12-18 m												13	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_28	0-5 m				5-85 m											50	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_29	0-2 m				2-80 m											48	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_30					0-53 m				80-84 m		73-80 m		33-73 m, 84-90 m			53	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_31	0-3 m		19-33 m	8-16 m	3-8 m, 16-19 m						8-12 m		12-85 m			12	3	4	Medium susceptibility to sinkholes and subsidence (to 5 m)
	SD2_32	0-3 m		20-33 m	7-16 m	3-7 m, 16-20 m								33-90 m			32	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_33	0-10 m				10-84 m									90-100 m	84-90 m	60	1	7	Low susceptibility due to ingress and high susceptibility due to groundwater drawdown (up to 15 m)
	SD2_34	0-1 m				1-12 m						12-16 m		16-29 m, 30-34 m		29-30 m	12	3	4	Medium susceptibility to sinkholes and subsidence (to 5 m)
	SD2_35	0-4 m			14-24 m	4-14 m, 24-47 m			47-67 m					67-100 m			51	1	1	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown

Area Investigated	BH ID	Topsoil	Sand & Gravel	Clay	Calcrete	Banded Ironstone	Breccia/Conglomerate/ Quartzite	Dolerite	Limestone	Weathered Chert/chert residuum	Dolomite residuum	Weathered Dolomite/Boulders	Chert	Dolomite Bedrock	Wad	Cavities	Water-Level (m)	Ingress Scenario Characterization	De-watering Scenario Characterization	Drawdown and Ingress Implications to sinkholes and subsidence
	SD2_36				14-35 m	0-14 m			92- 95 m			35-71 m		71-92 m			24	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_37			32-72 m		0-32 m						73-85 m				72-73 m	58	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_38	0-2 m		14-27 m	7-14 m	2-7 m				27-40 m				40-86 m			38	2	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_39	0-2 m								2-5 m,18- 30 m				5-18 m, 30- 70 m			16	5	4	Medium susceptibility to sinkholes and subsidence (to 5 m)
	SD2_40									0-17 m				17-60 m			53	4	4	Medium susceptibility to sinkholes and subsidence (to 5 m)
	SD2_41	0-3 m				3-30 m,42- 54 m				30-42 m				54-70 m				1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_42									0-34 m		34-38 m						4	4	Medium susceptibility to sinkholes and subsidence (to 5 m)
	SD2_43	0-5 m				5-30 m								30-120 m				1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_44									0-15 m				15-60 m				4	4	Medium susceptibility to sinkholes and subsidence (to 5 m)
	SD2_45	0-2 m				2-32 m					32-42 m	44-48 m		48-130 m		42-44 m	53	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown
	SD2_46	0-5 m				5-10 m,18- 32 m						10-18 m		32-125 m			40	1	4	Low susceptibility due to ingress and low-medium susceptibility due to groundwater drawdown

APPENDIX H

Document Limitations

DOCUMENT LIMITATIONS

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APPENDIX I

**SD1 Static groundwater levels
(2014 & 2019)**

BH Nr	Latitude	Longitude	SWL (2014) mbgl	SWL (2019) mbgl	Owner
SD1-04	- 28.2219	23.5884	13.14	11.99	Municipality
SD1-21	- 28.3043	23.58906	3.55	3.32	Petrus van Roi/Lena Kok
SD1-22	- 28.2974	23.58331	4.45	4.24	Petrus van Roi/Lena Kok
SD1-35	-28.345	23.58328	11.02	10.82	Lennox Cloete
SD1-16	- 28.3643	23.5978	11.2	10.28	Ansie Stander
SD1-26	- 28.3513	23.59879	11.28	10.9	Ansie Stander
SD1-10	- 28.3352	23.60812	13.18	12.9	Ansie Stander
SD1-32	- 28.4008	23.65853	16.33	12.6	Kokkie
SD1-24	- 28.3906	23.62879	16.64	14.15	Kokkie
SD1-27D	- 28.3787	23.6247	16.84	13.45	Kokkie
SD1-43	- 28.3688	23.62928	17.36	14.81	Ansie Stander
SD1-08	- 28.2579	23.58555	15.04	13.76	Lennox Cloete
SD1-40	- 28.3016	23.49494	33.59	31	Botha Markram
SD1-41	- 28.3043	23.49428	46		Botha Markram
SD1-42	- 28.2979	23.48335	55.68		Botha Markram
SD1-34	- 28.1745	23.53161	0	25.43	Municipality

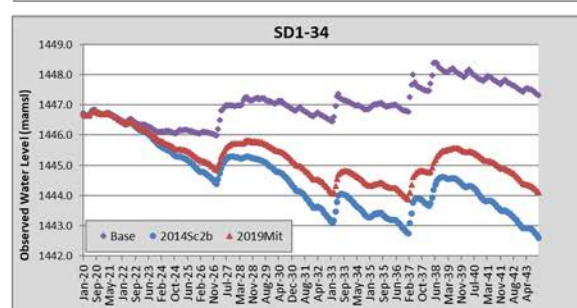
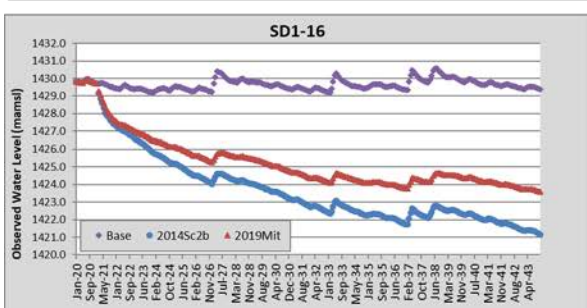
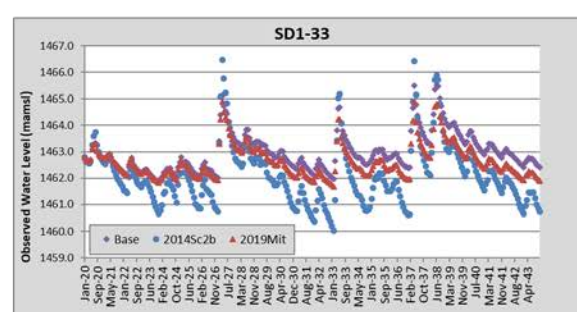
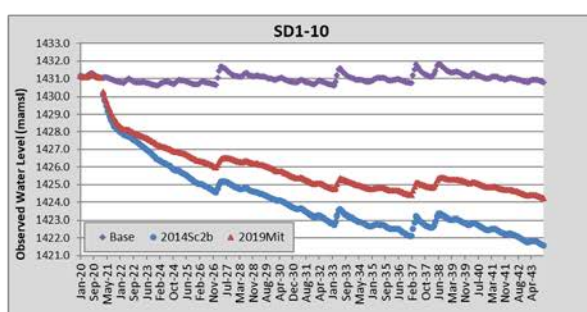
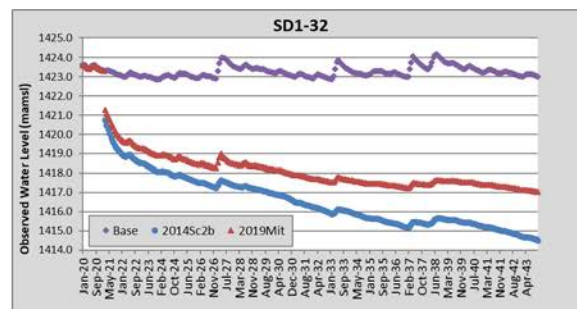
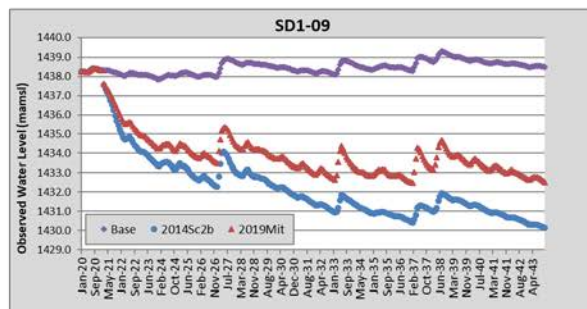
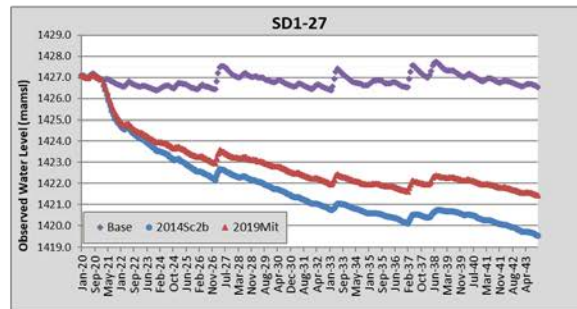
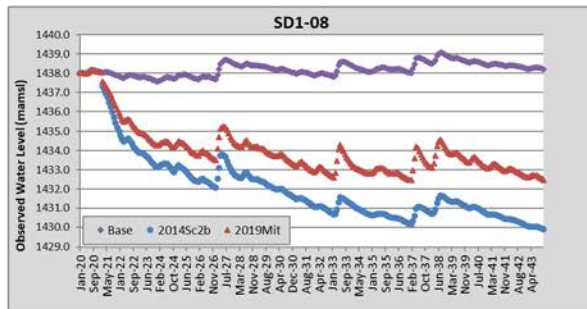
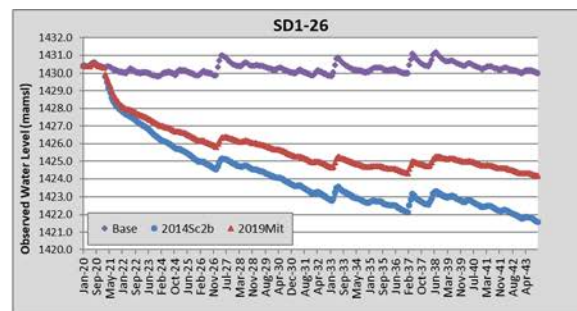
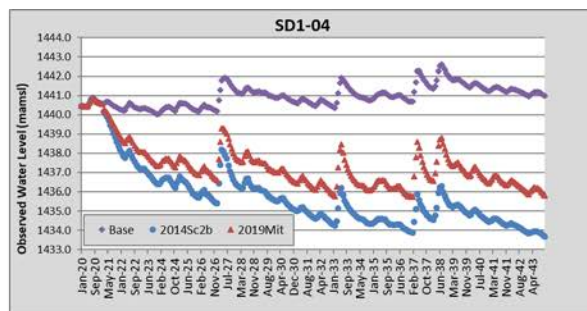
BH Nr	Latitude	Longitude	SWL (2014) mbgl	SWL (2019) mbgl	Owner
SD1-33	- 28.1731	23.5186	25.13	25.08	Municipality
SD1-45	- 28.1928	23.55202	0		Municipality
SD1-09	- 28.2553	23.59748	8.2	8.04	Lennox Cloete
SD1-25	- 28.2231	23.56914	6.91	8.2	Municipality
SD1-44	- 28.2113	23.59929	19.21	19.15	Municipality
SD1-11	- 28.2999	23.57918	14.97	14.61	Petrus van Roi/Lena Kok
SD1-17	- 28.3161	23.58026	3.81	3.53	Petrus van Roi/Lena Kok
SD1-19	-28.31	23.57928	3.49	3.24	Petrus van Roi/Lena Kok
SD1-20	- 28.3148	23.59588	3.71	4.26	Petrus van Roi/Lena Kok
SD1-28	- 28.3856	23.58745	15.52	15.45	Leon Venter
SD1-38	- 28.4025	23.53199	29.4		Hannes Meyer
SD1-39	- 28.4024	23.53262	28.94		Hannes Meyer
SD1-01	- 28.2279	23.5819	11.93	11.75	Municipality
SD1-02	- 28.2358	23.58102	11.13	10.8	Municipality
SD1-03	- 28.2345	23.57317	13.37	13.35	Municipality
SD1-05	- 28.2112	23.59939	19.02	18.61	Municipality

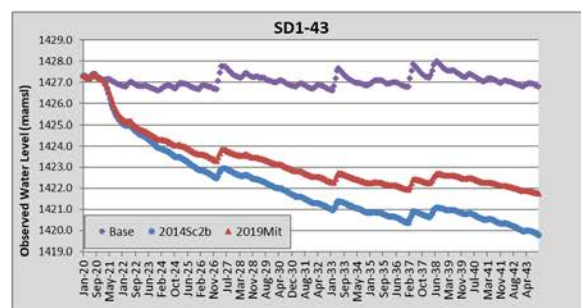
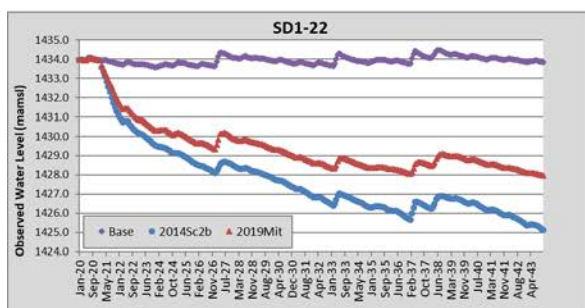
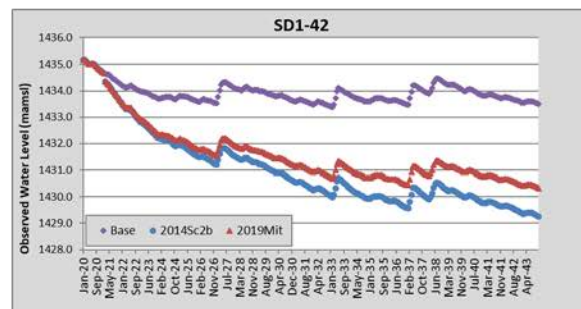
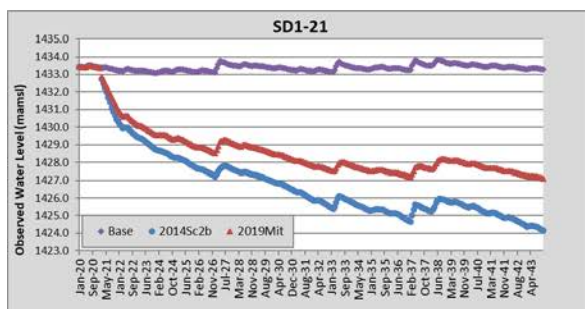
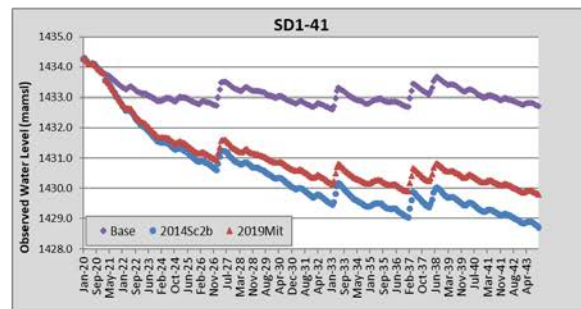
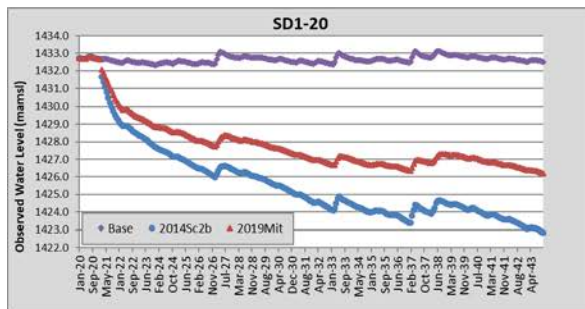
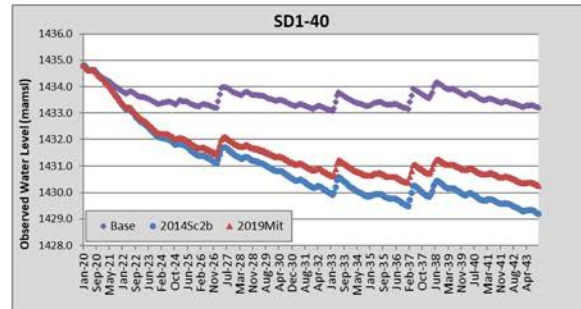
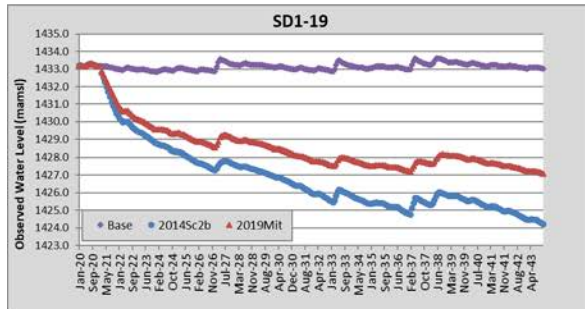
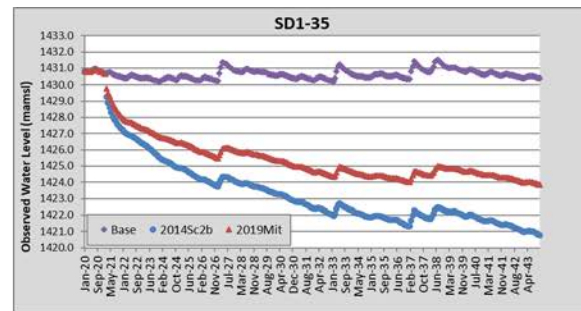
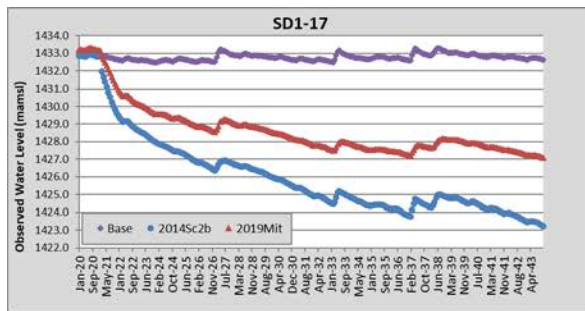
BH Nr	Latitude	Longitude	SWL (2014) mbgl	SWL (2019) mbgl	Owner
SD1-06	-28.209	23.58192	11.98		Municipality
SD1-07	-28.2186	23.57834	14.35		Municipality
SD1-12	-28.3246	23.59331	4.6		Petrus van Roi/Lena Kok
SD1-16(A)	-28.3644	23.59788	10.92		Ansie Stander
SD1-17(M)	-28.3161	23.58062	3.72	3.34	Petrus van Roi/Lena Kok
SD1-29	-28.2846	23.58589	11.31	11.07	Sibuse
SD1-31	-28.3752	23.59744	14.28	0	Leon Venter
SD1-35(M)	-28.3454	23.58276	11.1	0	Lennox Cloete
SD1-36	-28.3372	23.60471	13.19	0	Ansie Stander
SD1-13	-28.3938	23.54737	23.46	18.76	Leon Venter
SD1-14D	-28.3853	23.6448	17.18	14.53	Kokkie
SD1-14S (A)	-28.3854	23.64476	16.5		Kokkie
SD1-15	-28.3933	23.54794	23.73		Leon Venter
SD1-18	-28.3896	23.5837	20.74		Leon Venter
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SD1-27S	-28.3787	23.62472	16.86		Kokkie

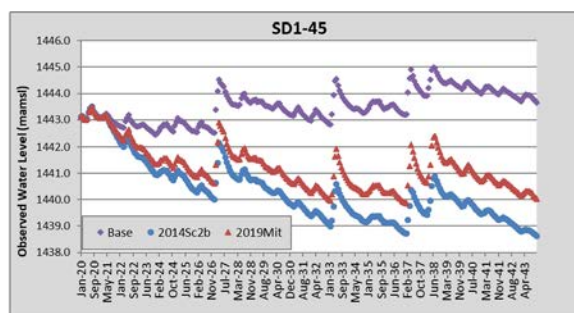
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SD1-32M	- 28.4004	23.65872	15.75		Kokkie
SD1-32S (A)	- 28.4008	23.65846	12.64	13.92	Kokkie
SD1-37	- 28.3877	23.62333	16.22	13.77	Kokkie
SD1- 40(M)	- 28.3013	23.495	33.28		Botha Markram

APPENDIX J

**SD1 Predicted production
borehole drawdown curves**

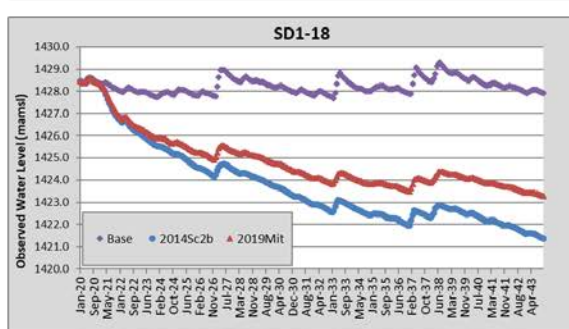
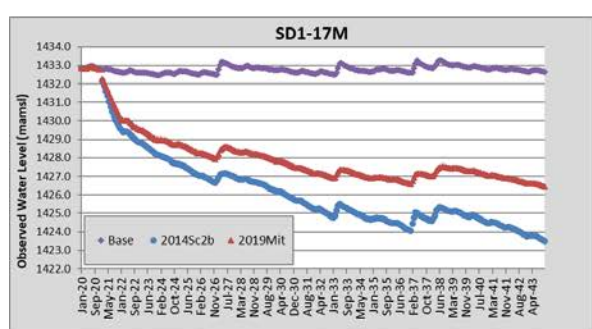
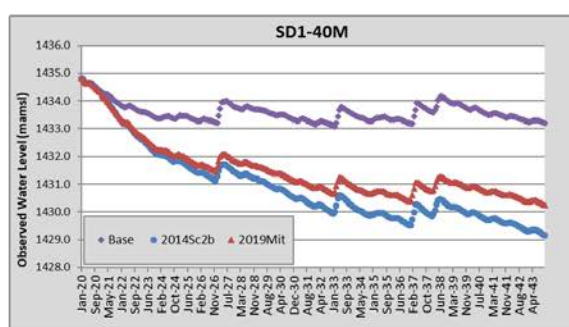
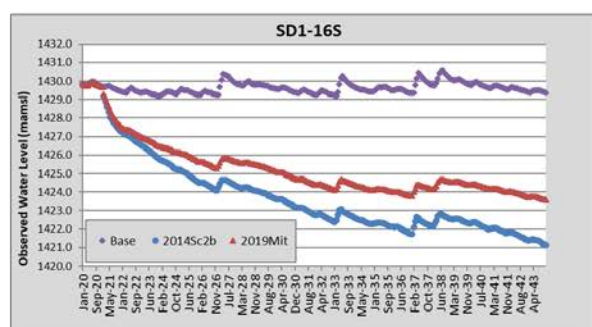
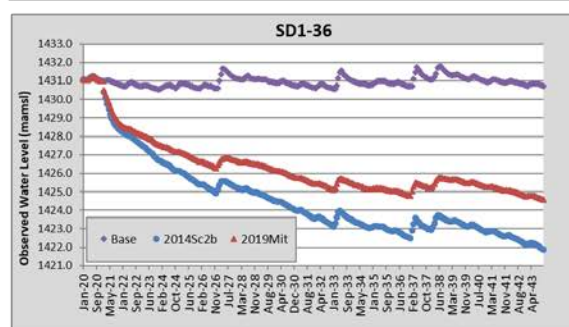
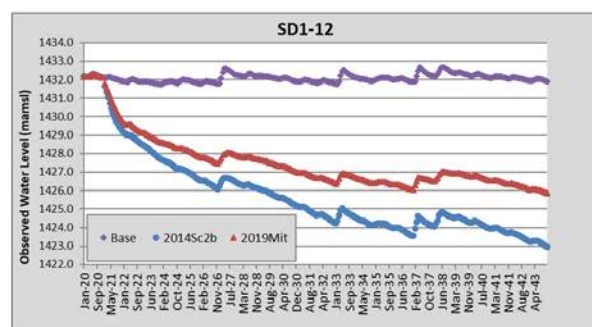
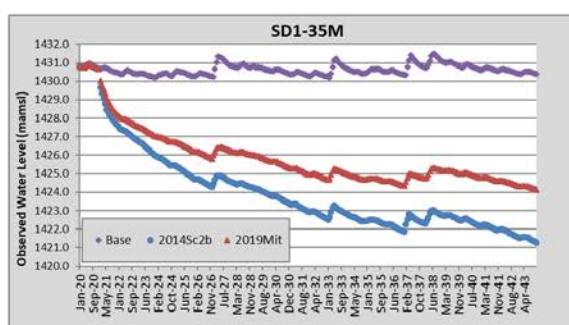
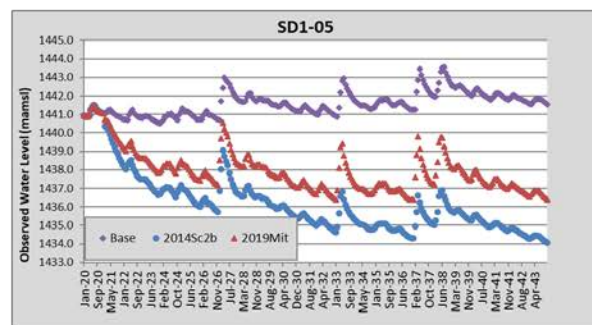
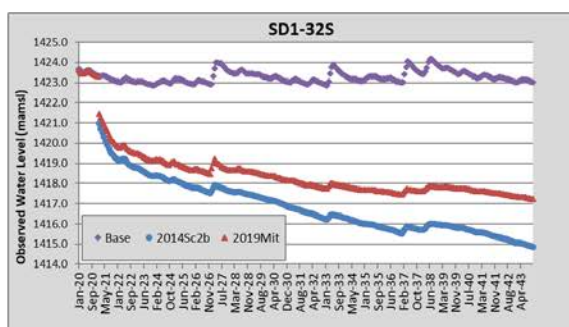
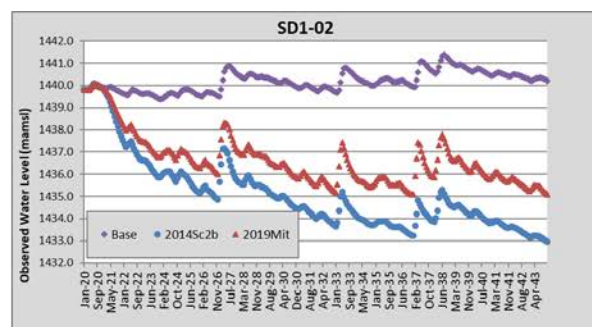






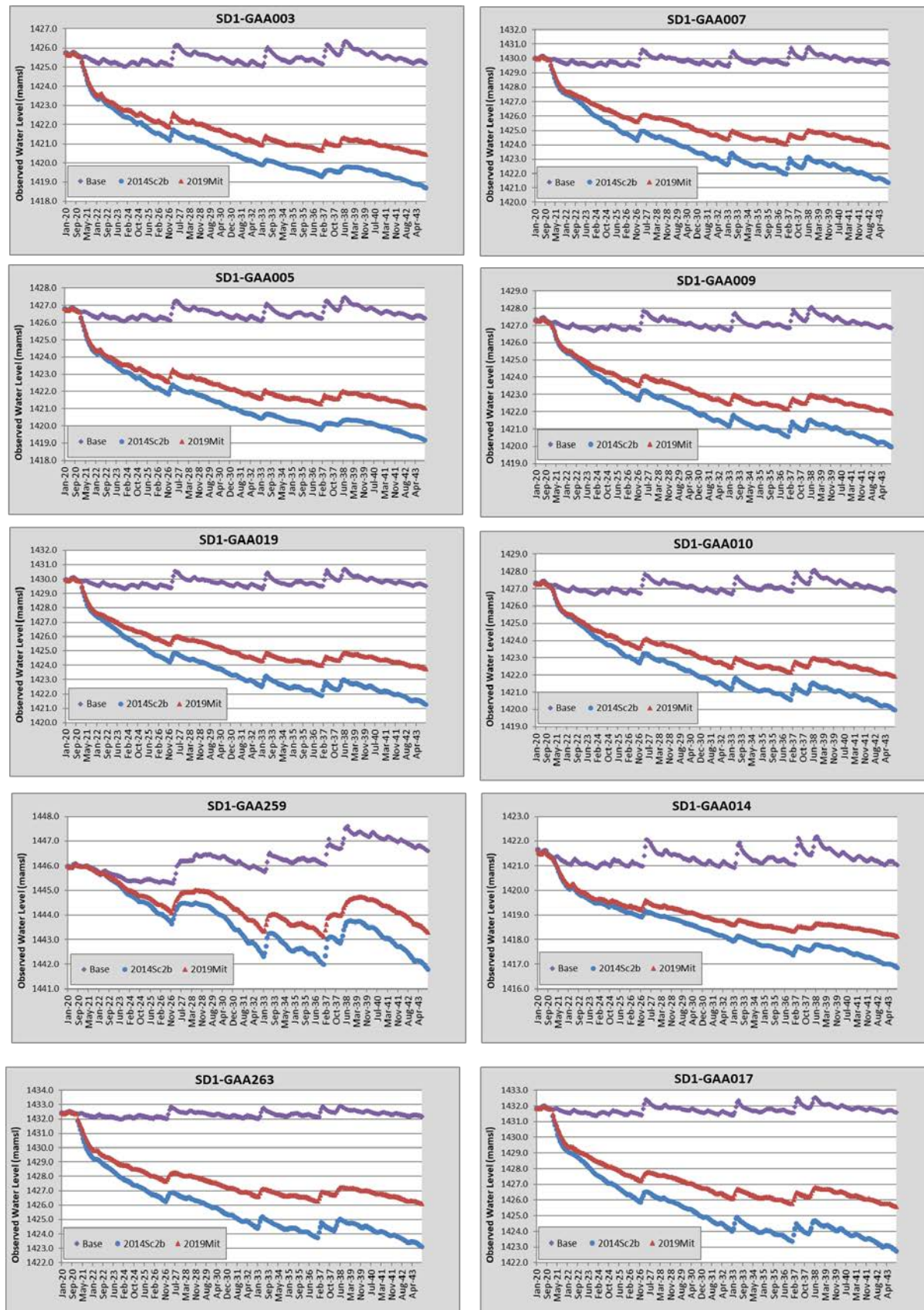
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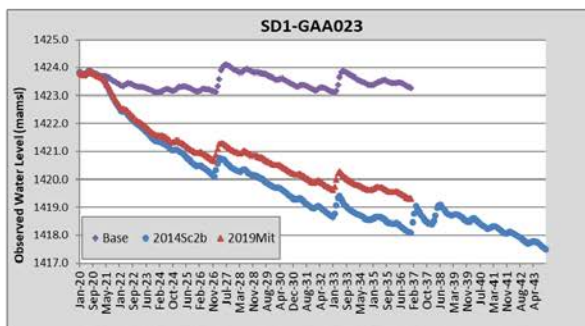
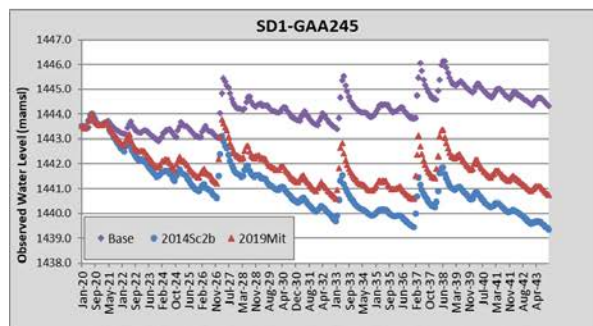
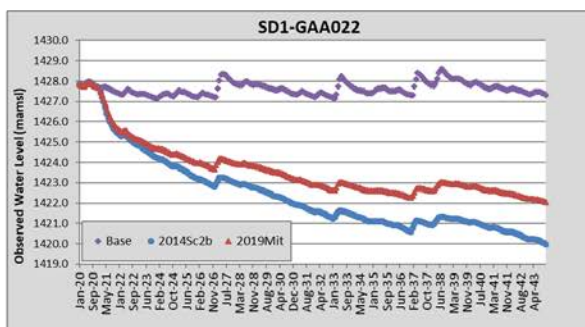
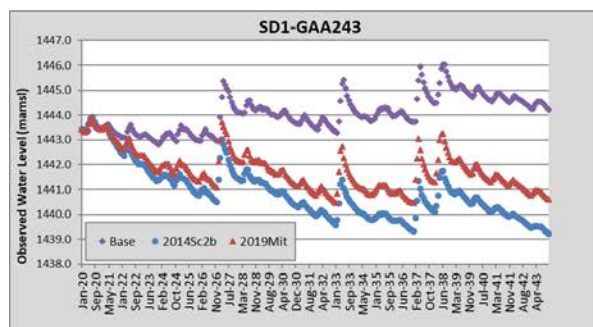
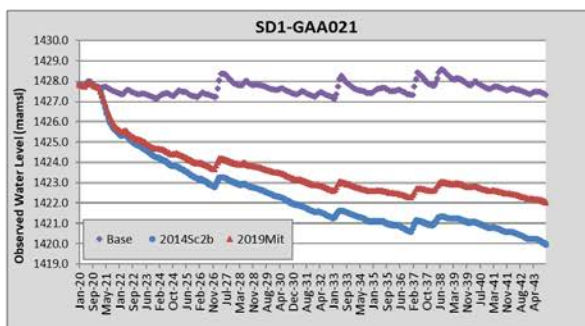
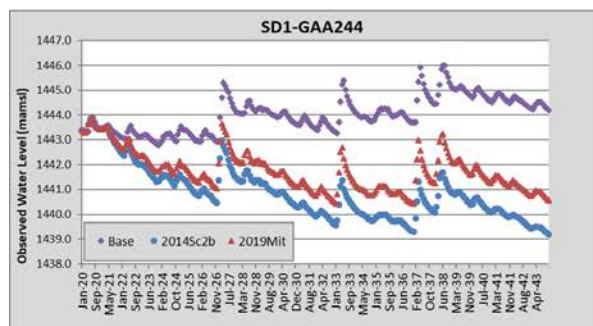
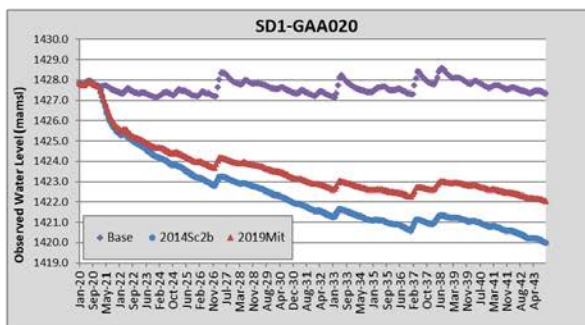
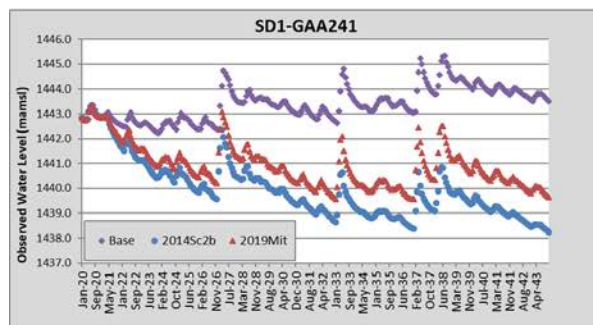
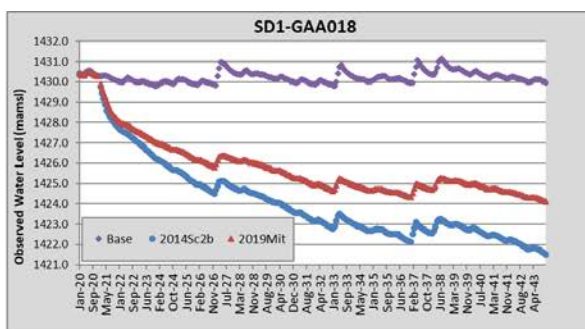
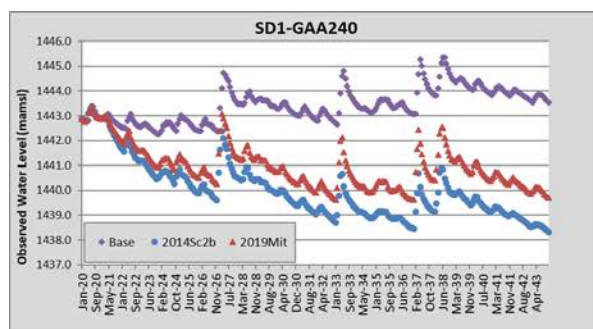
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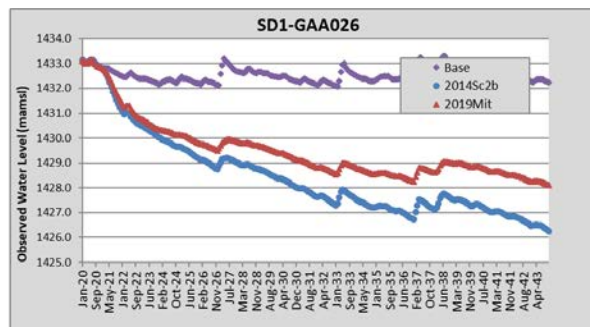


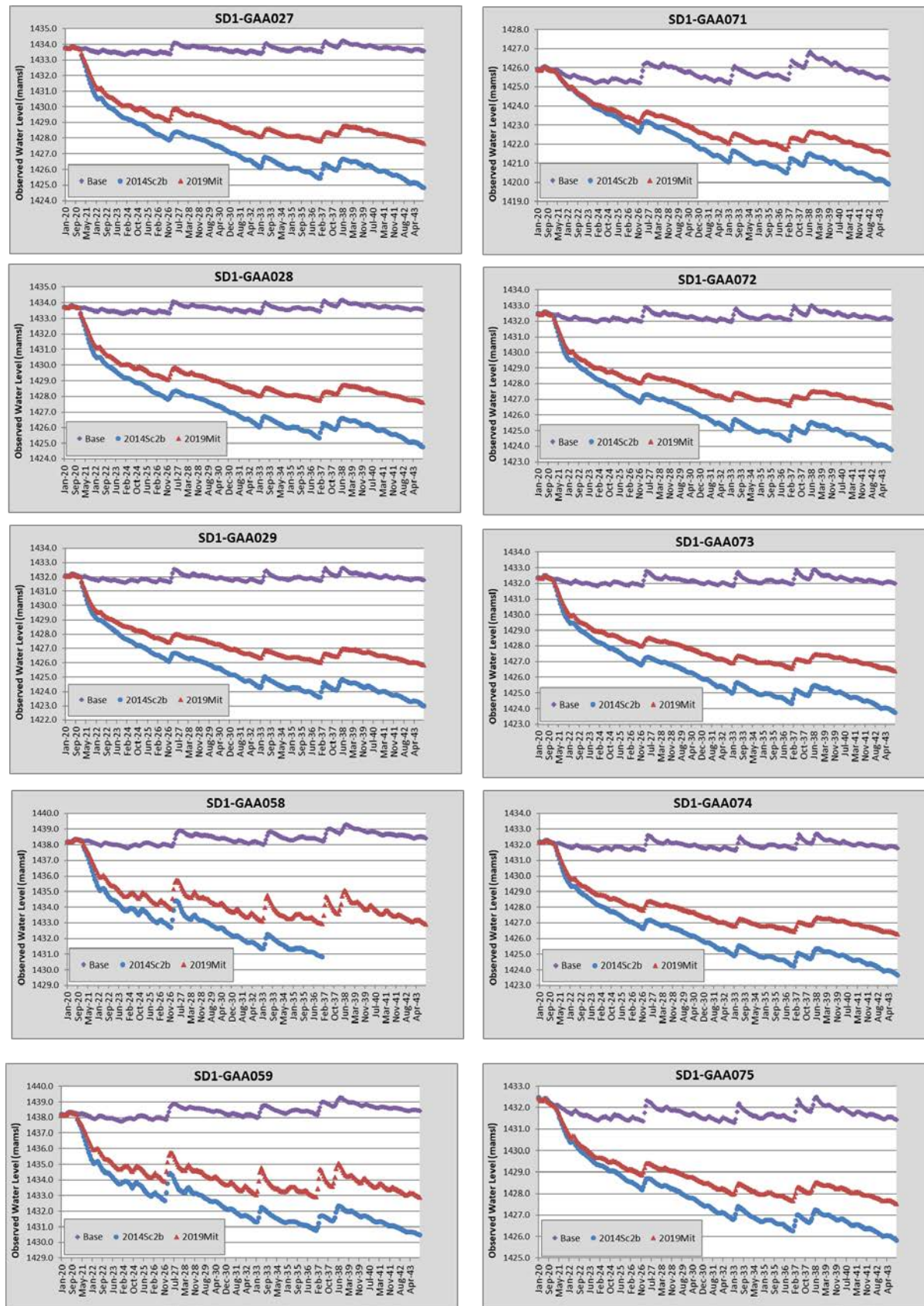
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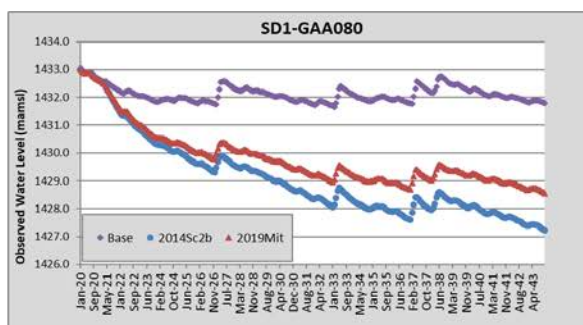
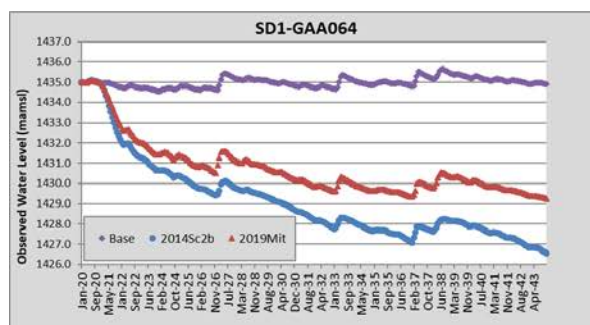
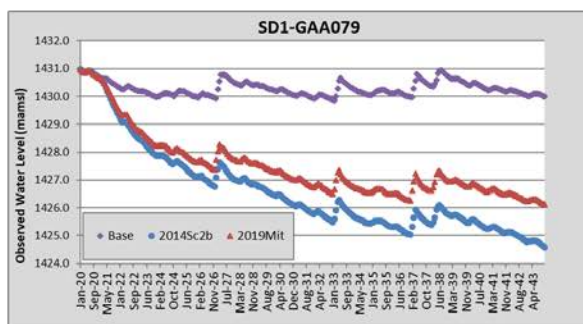
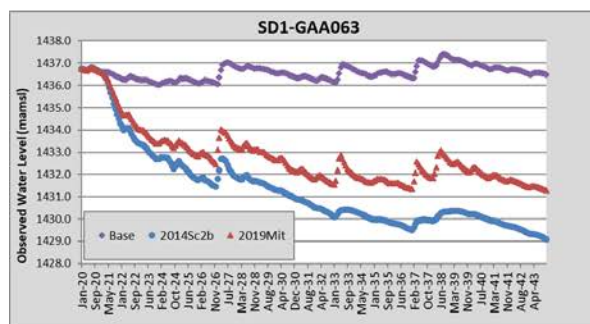
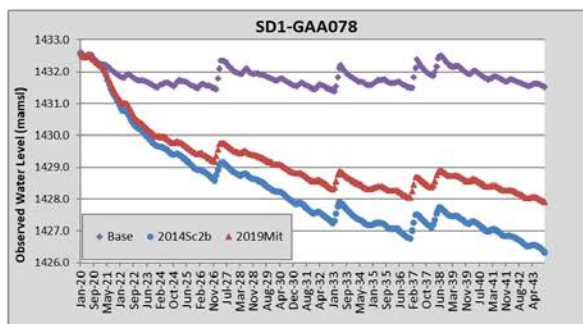
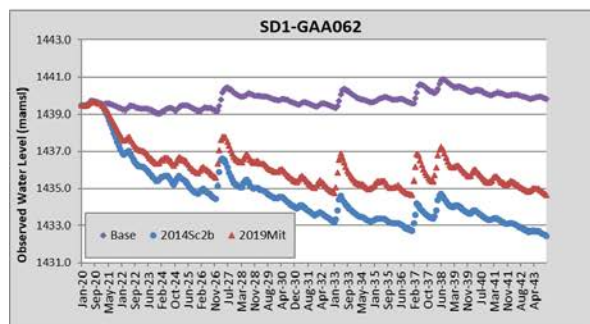
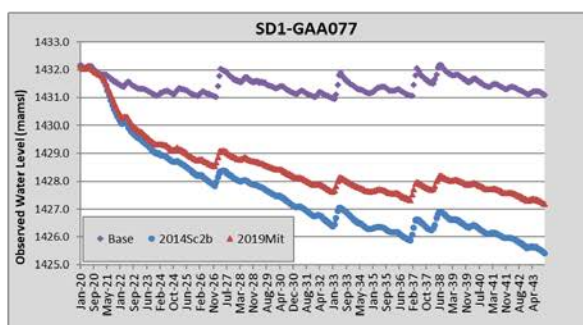
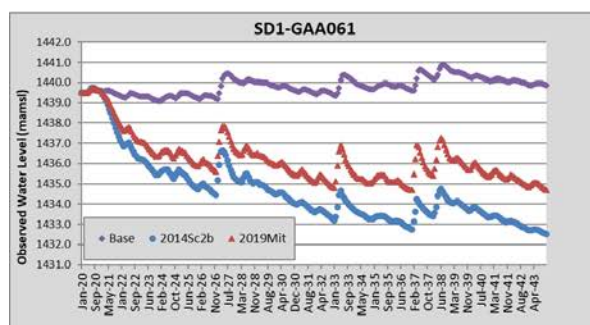
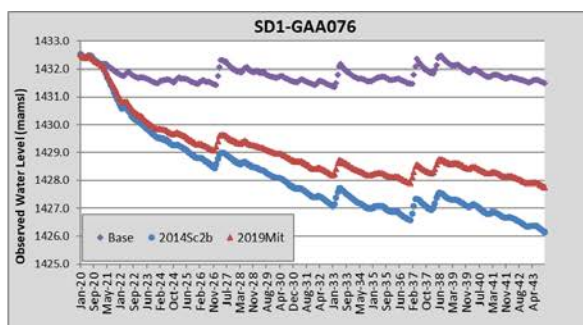
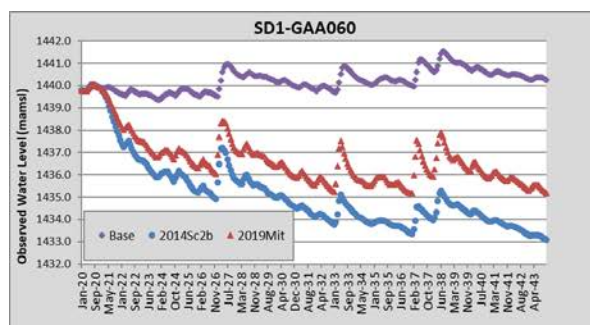
**SD1 - Predicted private borehole
user drawdown curve's**

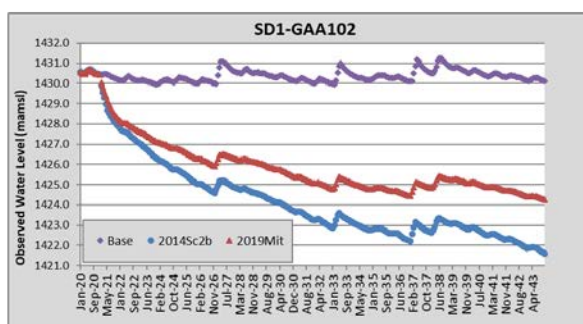
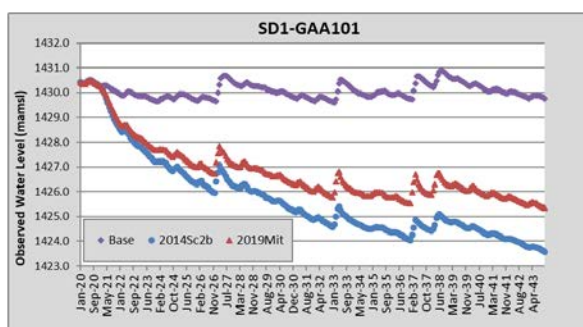
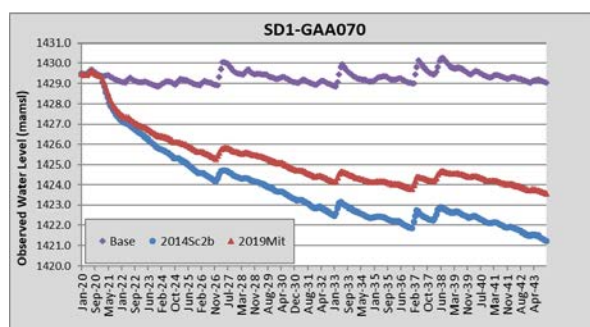
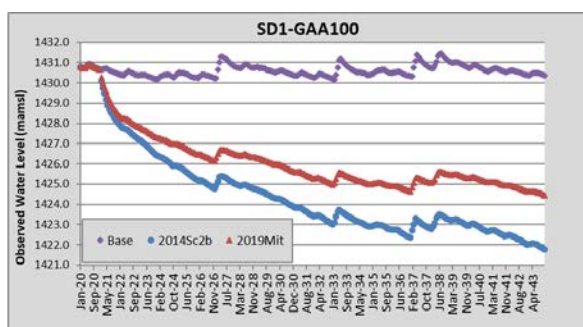
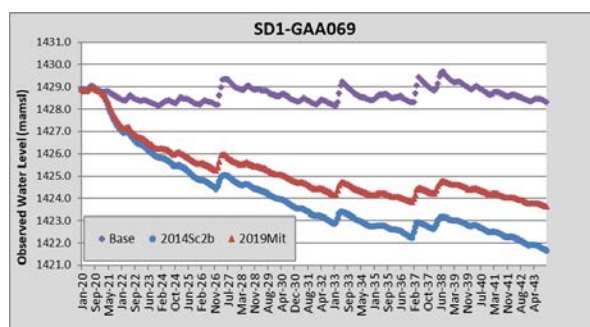


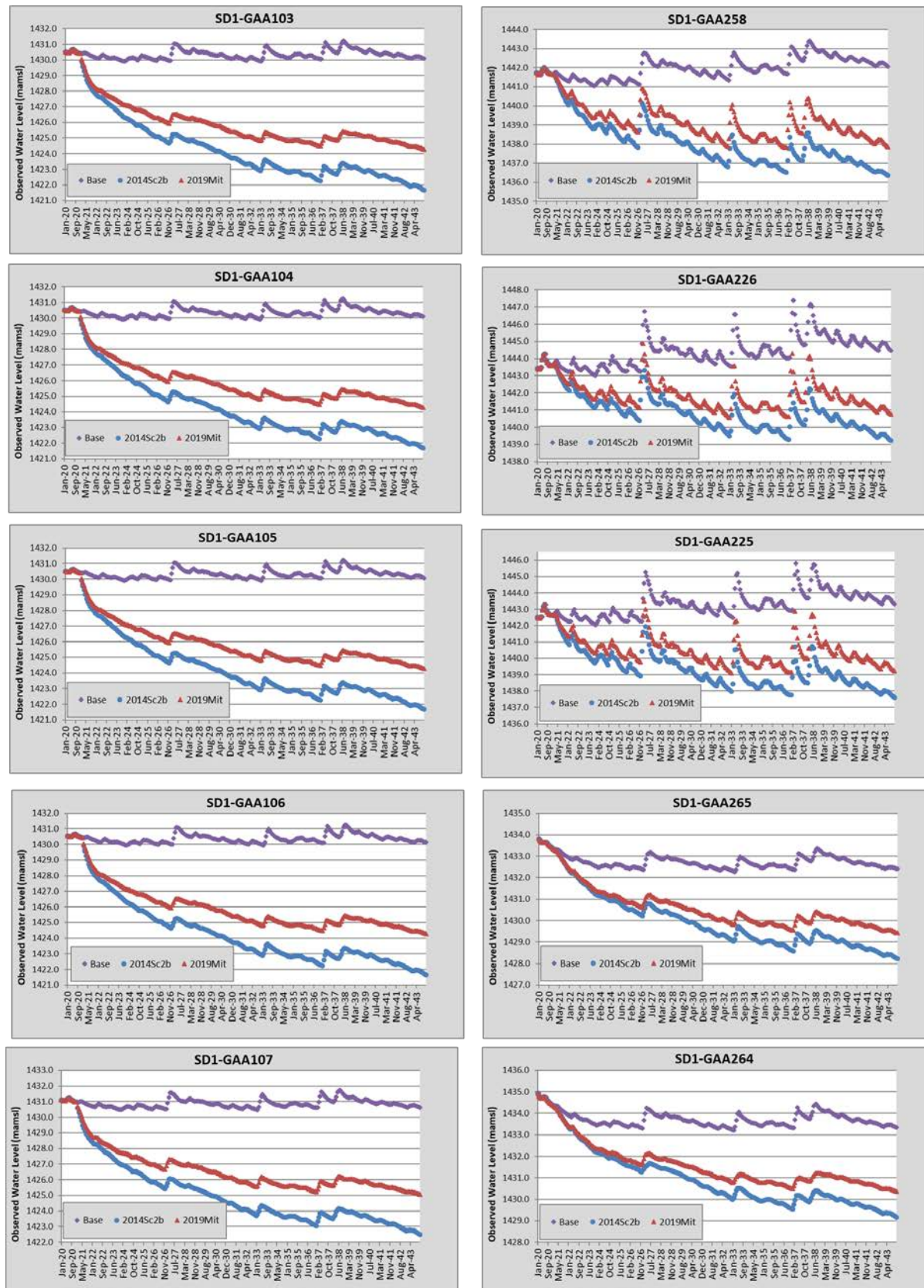


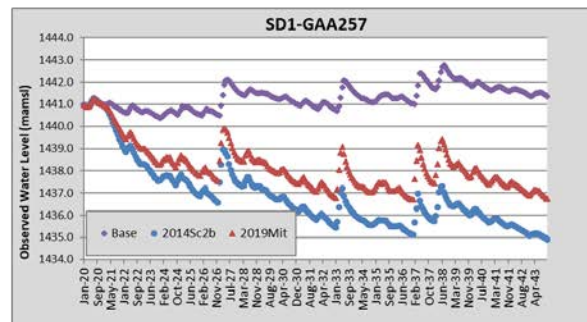
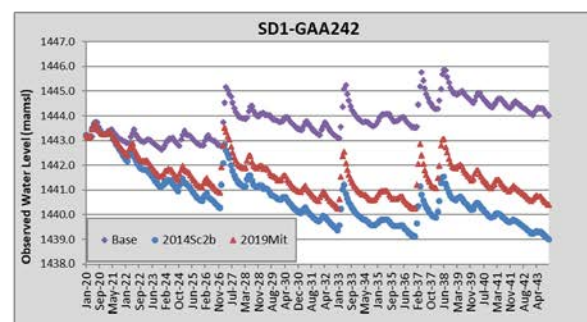
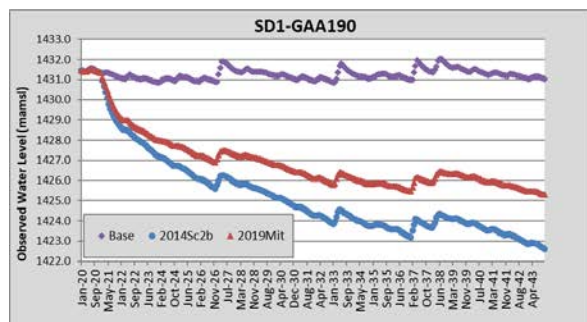
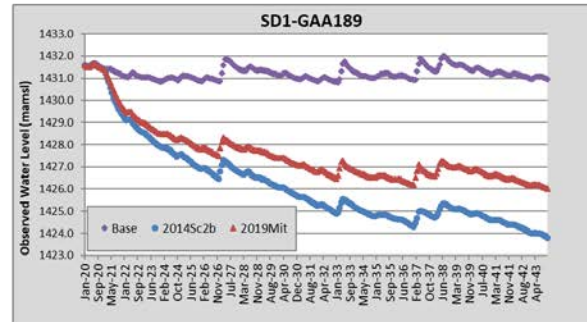
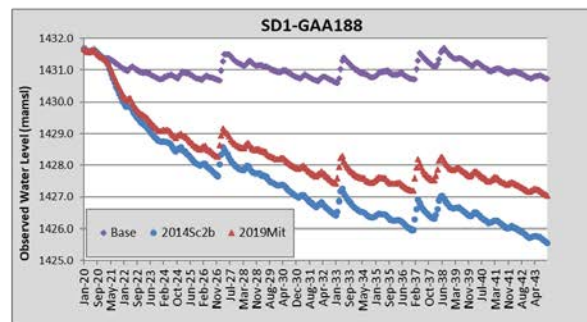
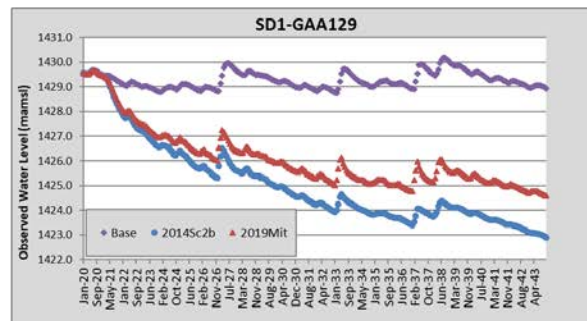
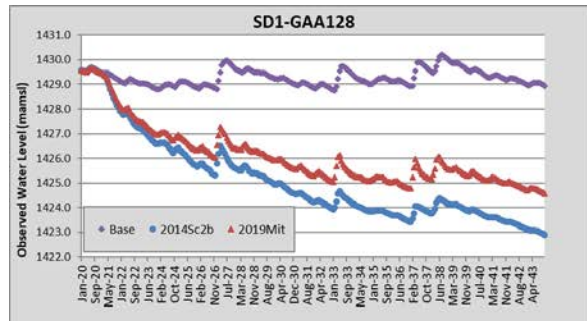












APPENDIX M

**SD2: Static groundwater levels
(2019)**

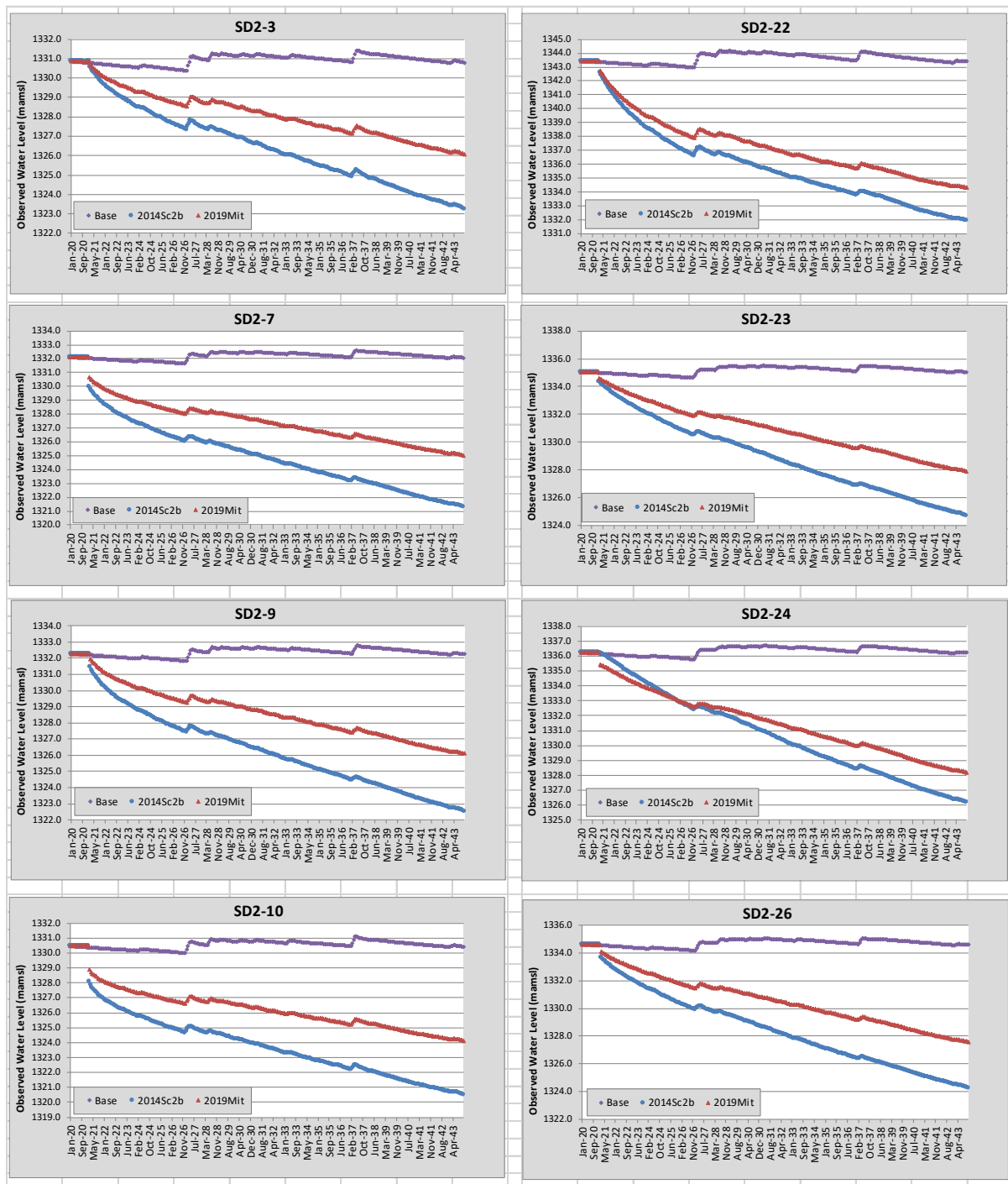
BH_Nr	Latitude	Longitude	Groundwater level (mbgl)	Date Measured	Owner
SD2-01	-28.3376	23.1409	-	2019/10/16	
SD2-02	-28.3178	23.11722	22.69	2019/10/16	Municipality
SD2-03	-28.3186	23.14214	-	2019/10/16	Municipality
SD2-04	-28.3298	23.09288	14.17	2019/10/16	Municipality
SD2-05	-28.327	23.13926	17.3	2019/10/16	Municipality
SD2-06	-28.325	23.15042	22.77	2019/10/16	Municipality
SD2-07	-28.3161	23.15721	23.41	2019/10/16	Municipality
SD2-08	-28.3135	23.15012	23.01	2019/10/16	Municipality
SD2-09	-28.3063	23.15653	20.82	2019/10/16	Municipality
SD2-10	-28.3093	23.13851	15.39	2019/10/16	Municipality
SD2-11	-28.305	23.12651	11.67	2019/10/16	Municipality
SD2-12	-28.3081	23.16122	22.8	2019/10/16	Municipality
SD2-13	-28.2987	23.16361	22.68	2019/10/16	Municipality
SD2-14	-28.296	23.17271	26.69	2019/10/16	Municipality
SD2-15	-28.2928	23.14875	18.5	2019/10/16	Municipality
SD2-16	-28.2882	23.1631	22.12	2019/10/16	Municipality

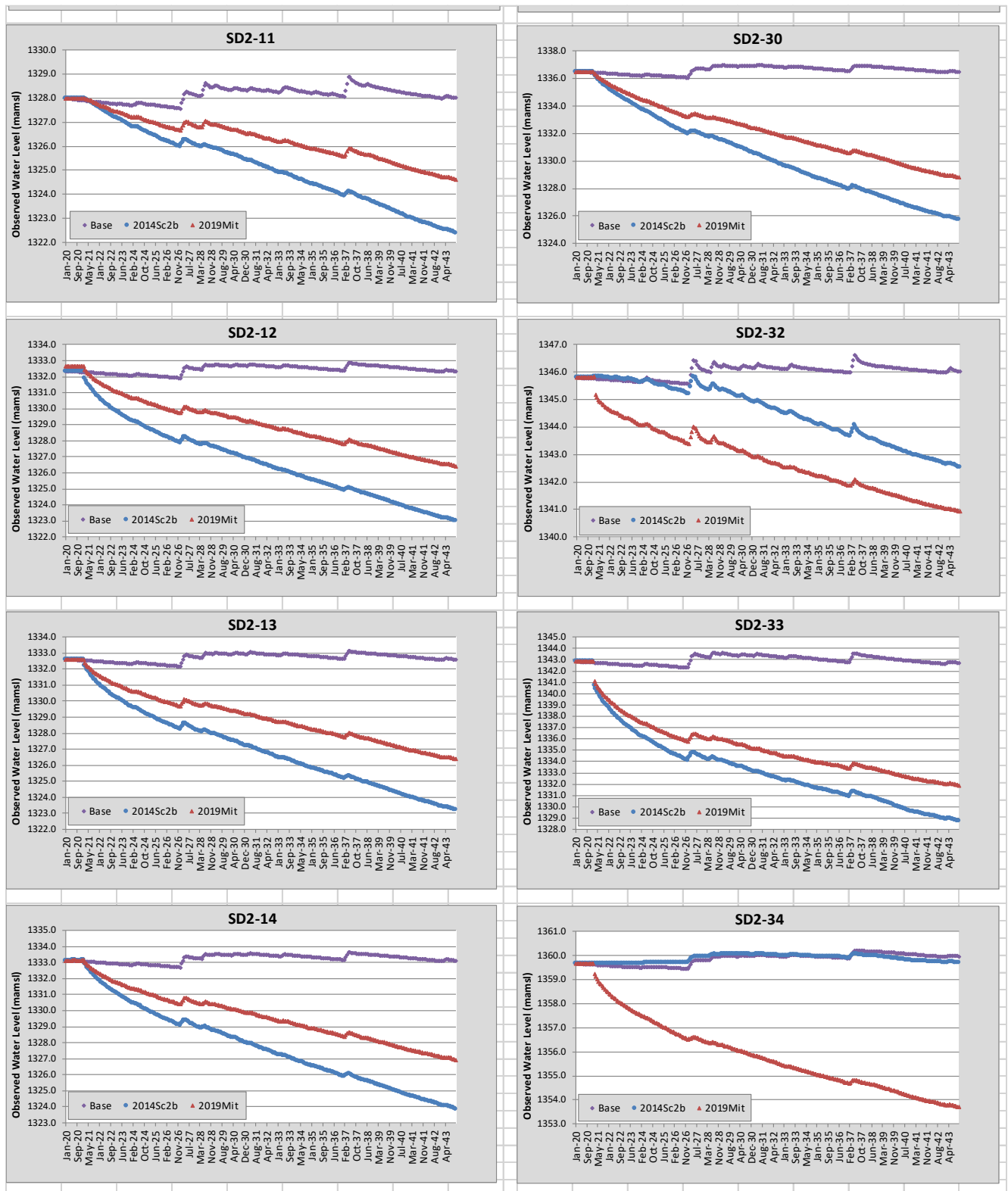
BH_Nr	Latitude	Longitude	Groundwater level (mbgl)	Date Measured	Owner
SD2-16(M)	-28.2883	23.16337	21.88	2019/10/16	Municipality
SD2-17	-28.3206	23.12369	14.14	2019/10/16	Municipality
SD2-18	-28.2872	23.14779	14.78	2019/10/16	Municipality
SD2-19	-28.33	23.09772	18.66	2019/10/16	Municipality
SD2-20	-28.33	23.09581	13.5	2019/10/16	Municipality
SD2-21	-28.271	23.16394	22.16	2019/10/16	Loekie van de Merwe
SD2-22	-28.2193	23.23948	46.25	2019/10/17	Jen Haven
SD2-23	-28.2632	23.16927	24.13	2019/10/16	Loekie van de Merwe
SD2-24	-28.2512	23.21373	50.38	2019/10/16	Jen Haven
SD2-25	-28.2116	23.23614	42.64	2019/10/17	Jen Haven
SD2-26	-28.2741	23.1747	25.52	2019/10/16	Loekie van de Merwe
SD2-27	-28.1832	23.23123	18.41	2019/10/17	Jen Haven
SD2-28	-28.2439	23.23268	-	2019/10/17	Jen Haven
SD2-29	-28.2392	23.25444	52.8	2019/10/17	Jen Haven
SD2-30	-28.2391	23.22551	55.11	2019/10/17	Jen Haven
SD2-31	-28.2191	23.20117	11.58	2019/10/17	Jen Haven

BH_Nr	Latitude	Longitude	Groundwater level (mbgl)	Date Measured	Owner
SD2-32	-28.222	23.20686	32.09	2019/10/17	Jen Haven
SD2-33	-28.2351	23.25757	60.47	2019/10/17	Jen Haven
SD2-34	-28.2223	23.20102	12.63	2019/10/17	Jen Haven
SD2-35	-28.2364	23.22553	52.93	2019/10/17	Jen Haven
SD2-36	-28.2558	23.18989	36.13	2019/10/16	Jen Haven
SD2-37	-28.2383	23.24114	62.38	2019/10/17	Jen Haven
SD2-38	-28.222	23.21828	38.9	2019/10/17	Jen Haven
SD2-39	-28.2364	23.14901	-	<Null>	Lucas Cloete
SD2-40	-28.2302	23.14522	-	<Null>	Lucas Cloete
SD2-41	-28.2332	23.24583	51.99	2019/10/17	Jen Haven
SD2-42	-28.2355	23.15964	-	<Null>	Lucas Cloete
SD2-43	-28.2202	23.22136	39.56	2019/10/17	Jen Haven
SD2-44	-28.2145	23.17077	-	<Null>	Lucas Cloete
SD2-45	-28.2363	23.24567	53.12	2019/10/17	Jen Haven
SD2-46	-28.2045	23.22878	40.2	2019/10/17	Jen Haven

APPENDIX N

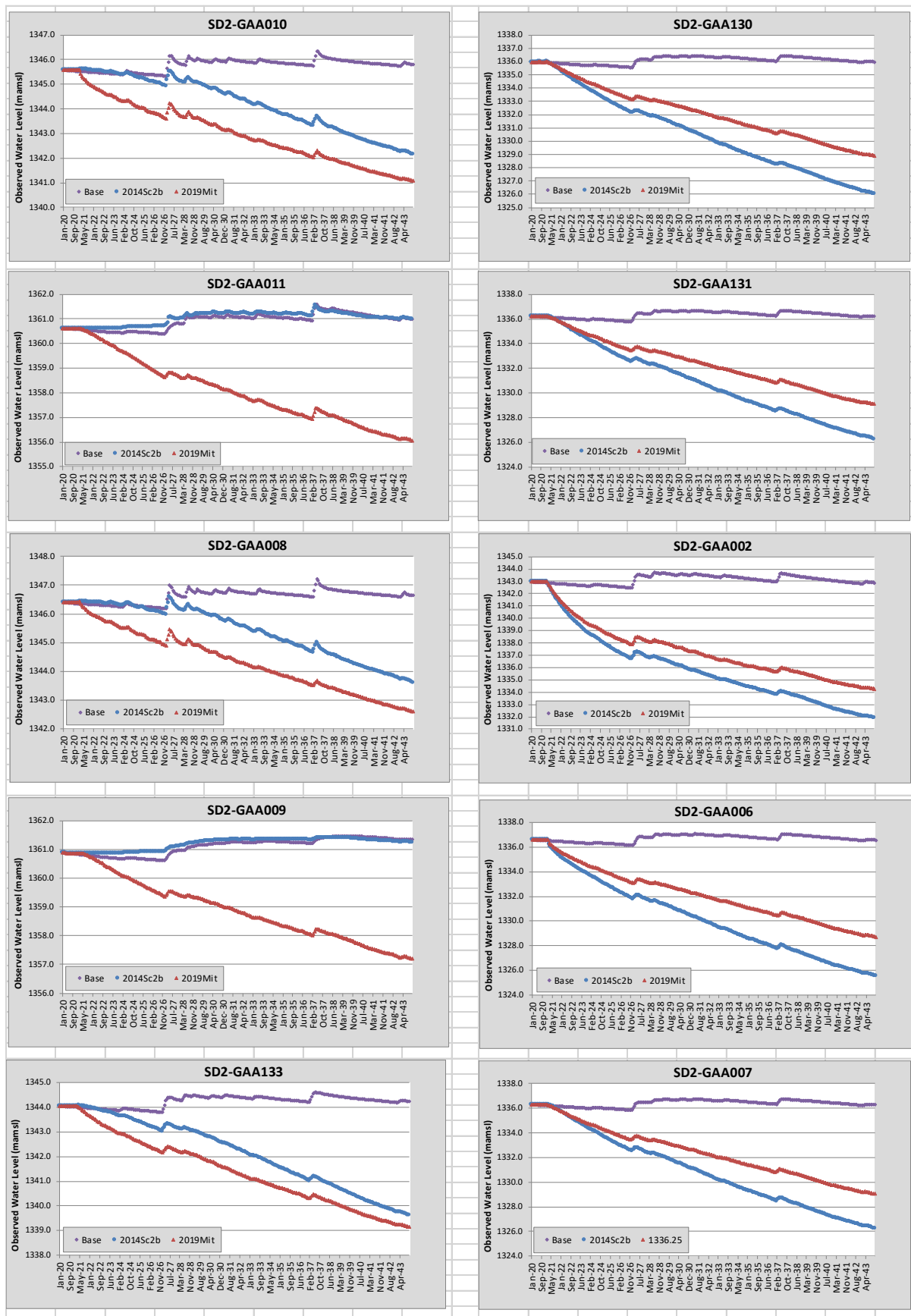
**SD2: Predicted Wellfield borehole
drawdown curve's**

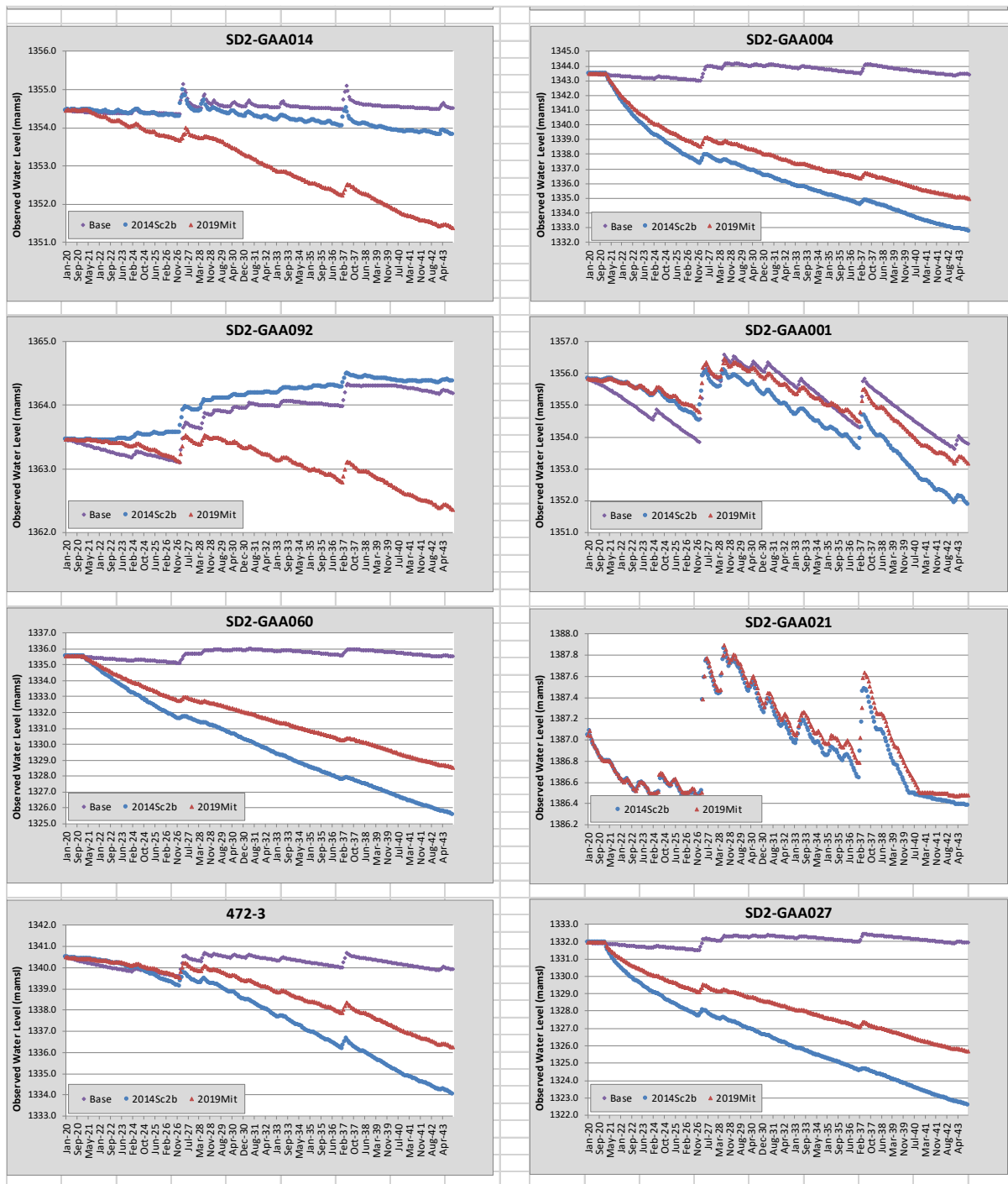


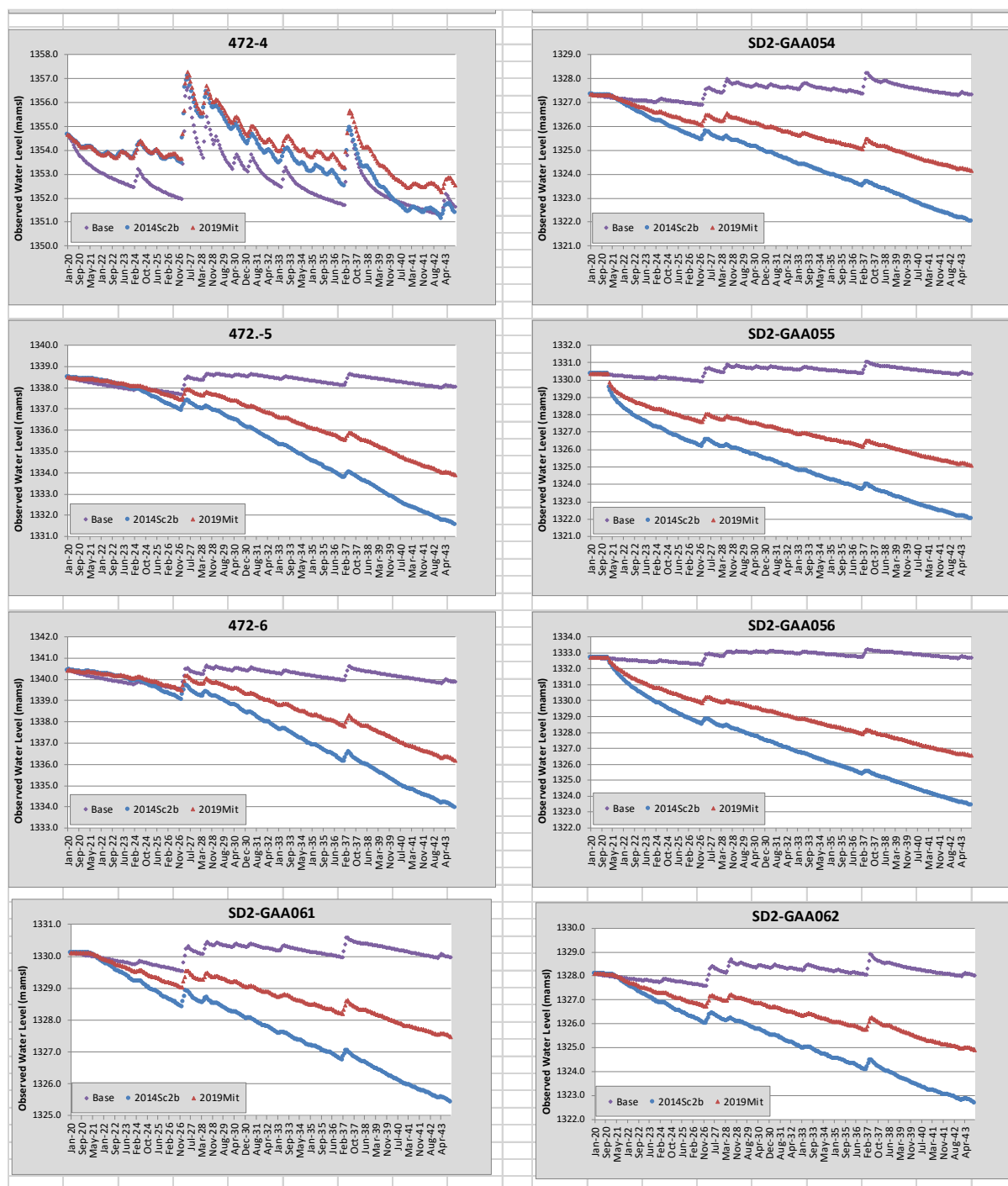


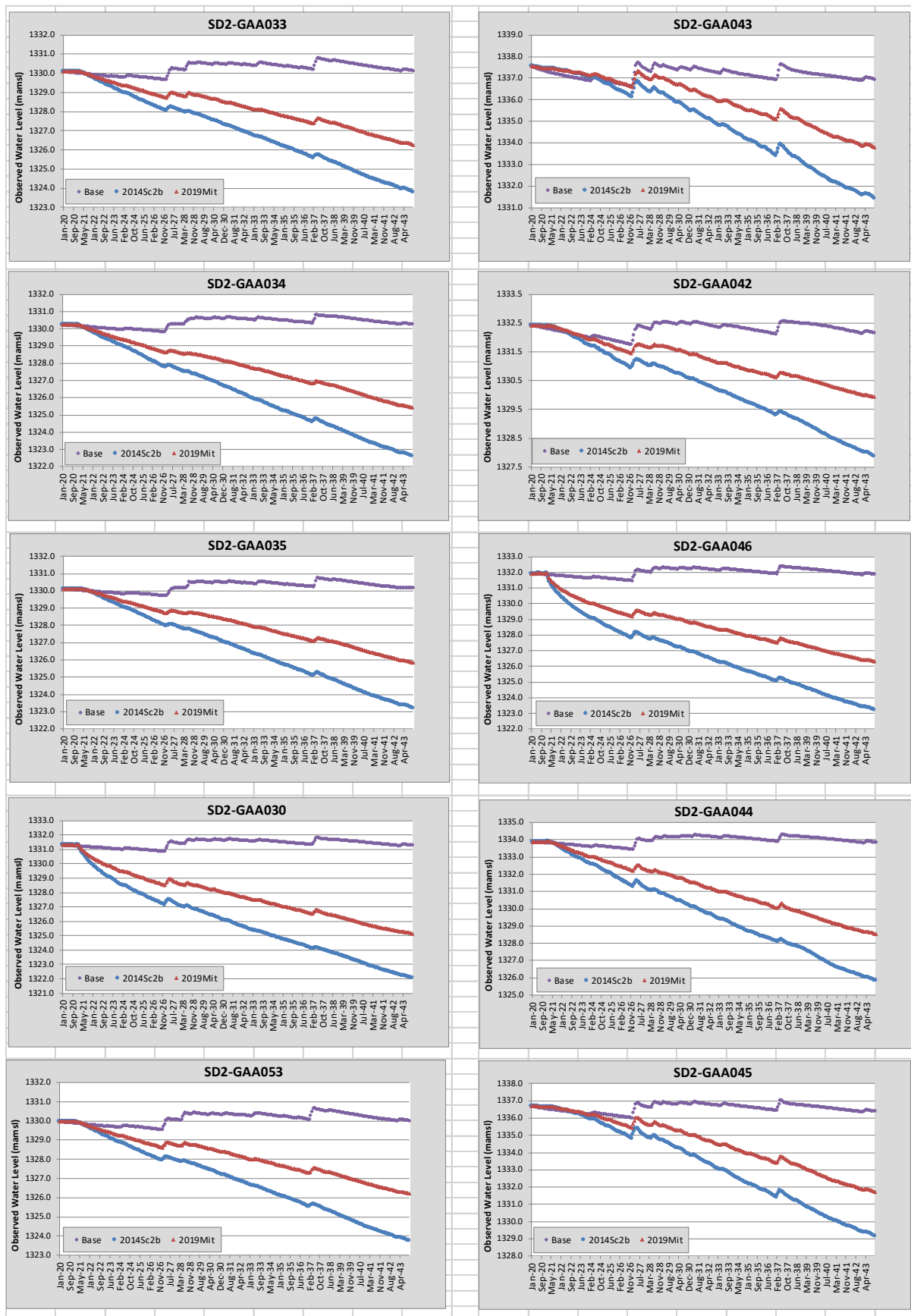
APPENDIX O

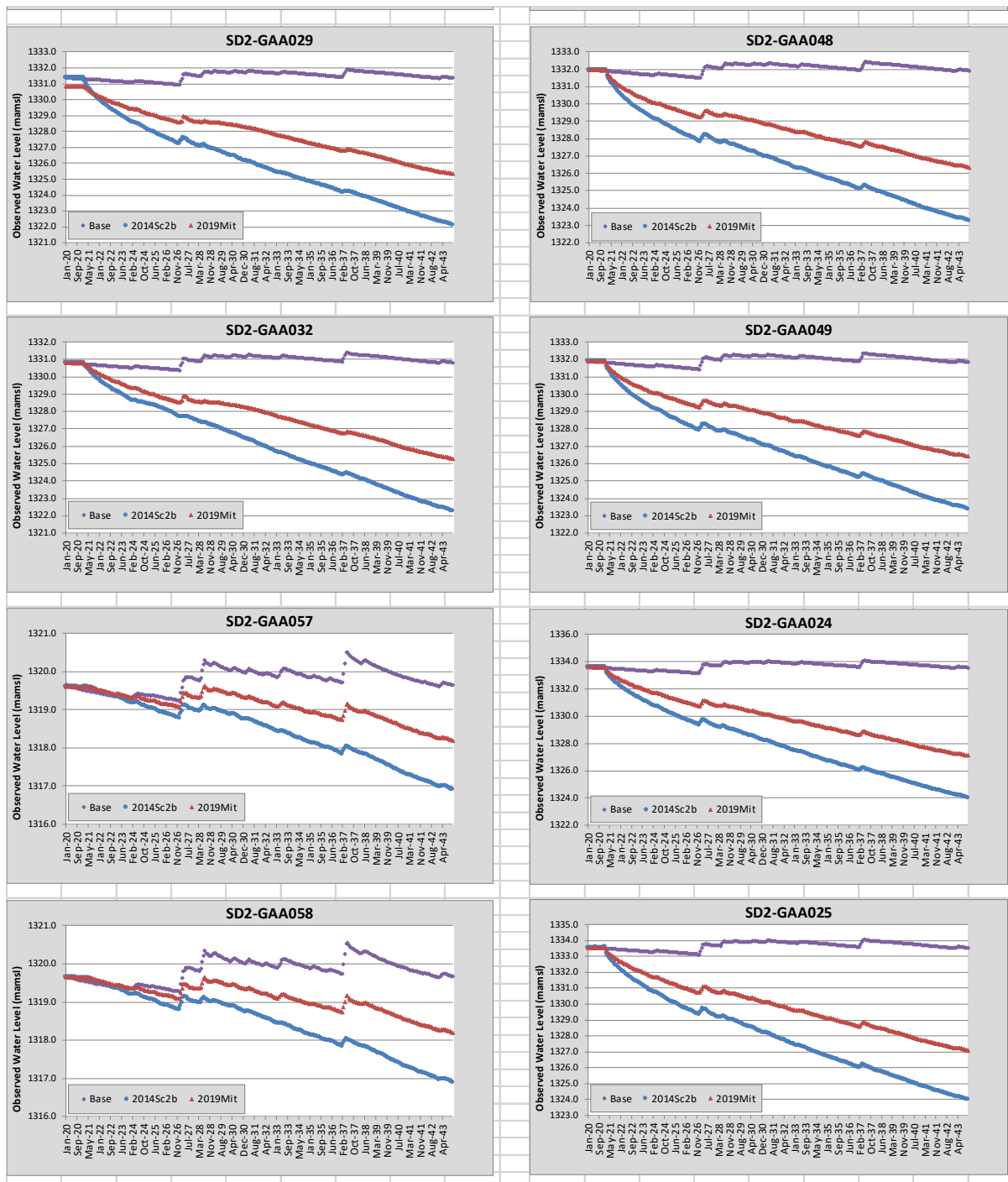
**SD2: Private groundwater user
drawdown curve's**

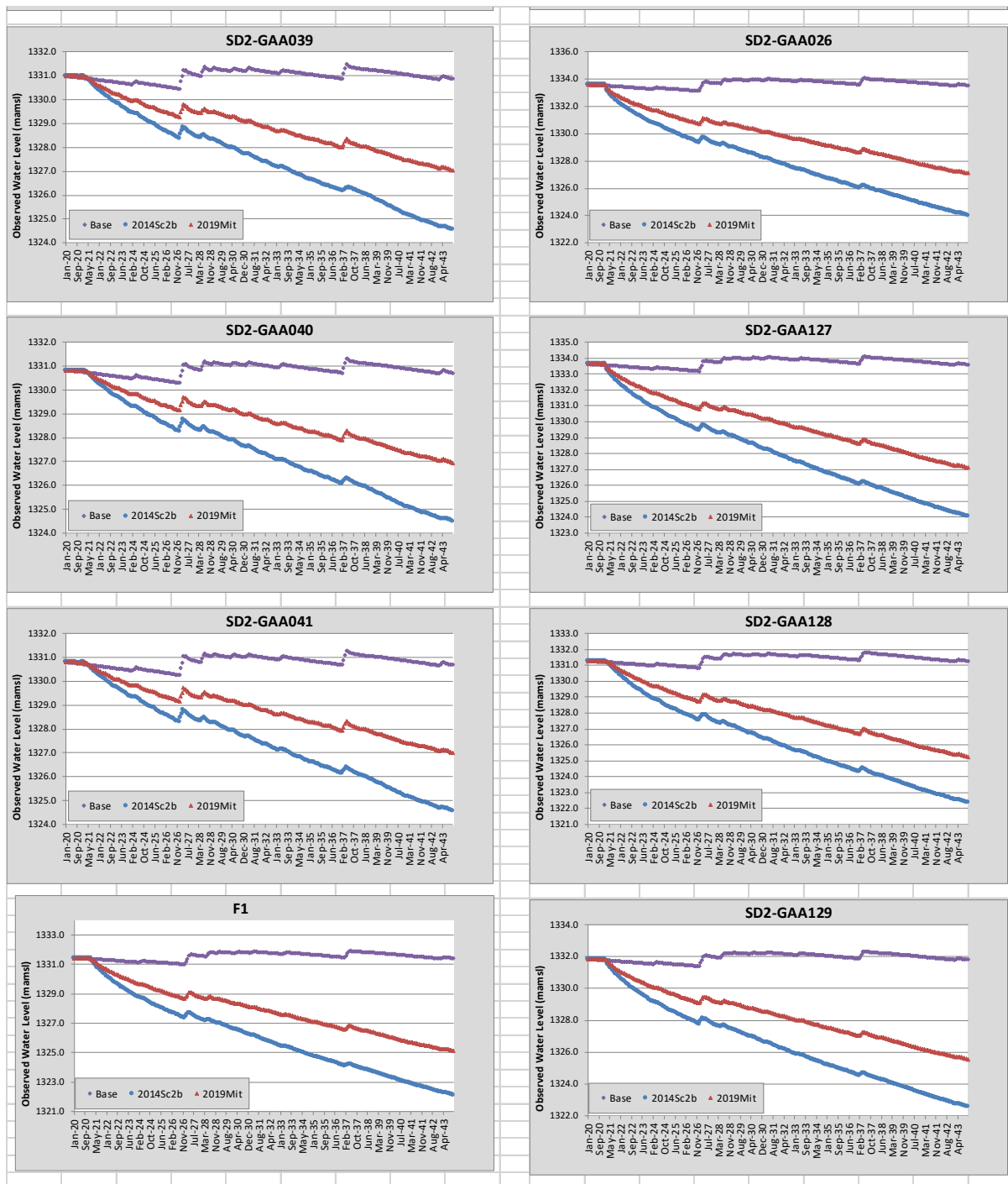


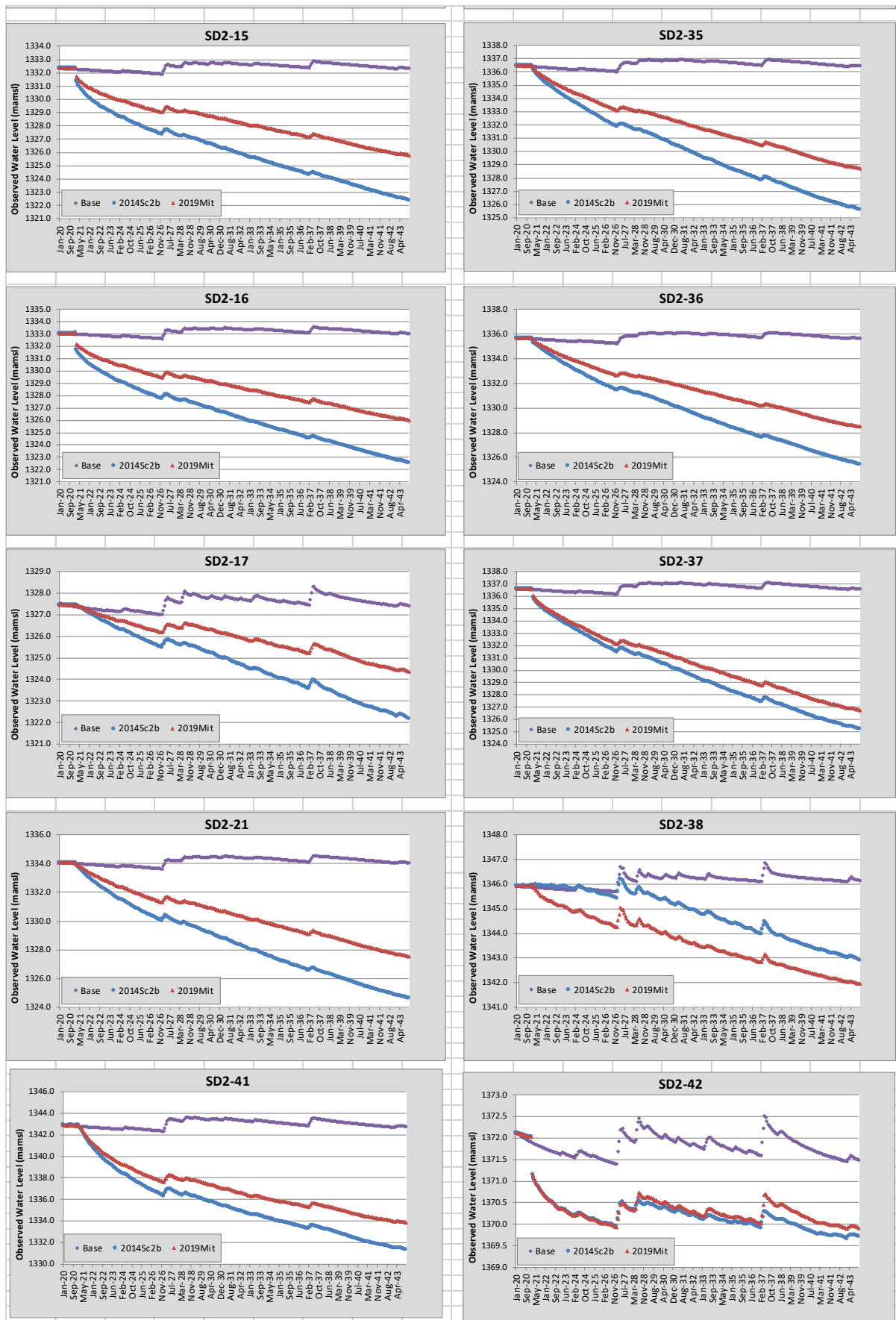














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