Reconceptualization of the Extended Groundwater Regime of the Vaalputs Radioactive waste Site

Mbuthokazi Mandaba

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Mbuthokazi Mandaba

05/08/2015

Abstract

Vaalputs Radioactive Waste Site is the only nuclear waste facility in South Africa that stores Low- and Intermediate Level Radioactive Waste. Disposal of waste is carried out under the authorization granted by the National Nuclear Regulator (NNR) under the Act (Act 47 of 1999). The disposal Site is managed and owned by a state company called South African Nuclear Energy Corporations (Necsa). The NNR reviews its license periodically to update information required by the NNR regulation.

The method of disposal at Vaalputs can be described as both engineer and natural barrier concept. The metal drums are for LLW and concrete drums for ILW, these drums are buried in trenches 8m deep. These trenches consist of mixtures of clay, e.g. smectite, Kaolinite and illite. These clays act as a secondary barrier in the prevention of nuclear migration.

Environmental isotopes can be used as tracers for natural groundwater movement. At the Vaalputs Site and surrounding farms, analysis of ^{3}H, ^{14}C, ^{2}H and ^{18}O were performed on two occasions which yielded significant results concerning groundwater recharge. The initial standard for this study was established by studying dataset for year 1988 and 2000. Not enough radioisotope data is available on the western side of Vaalputs Site where the granite gneiss is weathered. This study aims to address that inadequate. Recharge plays a crucial role in updating the safety case assessment and potentially identifying the preferential groundwater pathways.

The second standard for the base of this study was established by studying the analytical chemistry results collected over 27 years. Systems of monitoring boreholes were drilled to a level below the water table on the perimeter security fence around the disposal Site. In total there are 19 boreholes situated on or just outside the security fence, evenly distributed around the trench. A total of 54 monitoring and extraction boreholes exist within the 20-km radius of the Site. Some of these boreholes will be used in this study. Bi annual sampling and monitoring results at the Vaalputs Site has been studied. Cations and anions behavior was assessed to determine any detectable contaminants on the groundwater system.

Pump test results for the study area revealed a great decrease in hydraulic conductivity in the matric with depth. Four boreholes (GWB1, GWB3, GWB5 and PBH16) adjacent to the repository were subjected to aquifer tests. Fracture zones in these boreholes yielded from 0.75 ℓ/s to 3.6 ℓ/s. this indicated the fracture zone of the study area has different variable conductivity. These aquifer tests were conducted on the eastern side of the Vaalputs Site.

The conceptual model for the study area revealed the Vaalputs aquifer is bounded in the west by Kamiebees shear zone and in the south by a Platbakkies shear zone. In the east a physical boundary is formed by the Koa River valley drainage system. The regional fault zone the Garing fault influences the piezometric head elevation, groundwater chemistry and flow. The purpose of this report is to re-conceptualise the groundwater regime using recent updated data.

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List of Acronyms and Abbreviations

1. A: Amperes
2. AEB: Atomic Energy Board
3. AEC: Atomic Energy Corporation
4. Necsa: South African Nuclear Energy Corporation
5. CGSSA: Council for Geoscience South Africa
6. CMB: Chloride Mass Balance
7. CPN: Campbell Pacific Nuclear
8. EC: Electrical conductivity
9. EPA: Environmental Protection Agency
10. ESRI: Environmental System Research Institute
11. GIS: Geographic Information System
12. GWh: Gigawatt per hour
13. IGS: Institute for Groundwater Studies
14. IAEA: International Atomic Energy Agency
15. ILW: Intermediate Level Radioactive Waste
16. KNPS: Koeberg Nuclear Power Station
17. ℓ: litres
18. ℓ/s: litres per second
19. LILW: Low and Intermediate Level Radioactive Waste
20. LLW: Low Level Radioactive Waste
21. LSC: Liquid Scintillation Counting
22. mamsl metres above mean sea level
23. MAP: Mean Annual Precipitation
24. mmHg: millimetres mercury
25. NNR: National Nuclear Regulator
26. PCRSA: Post-Closure Radiological Safety Assessment
27. pmc: Percent Mode Carbon
28. WRC: Water Research Counsel
29. NRC: Nuclear Regulatory Commission
30. SANS South African National Standard
31. SHEQ: Safety, health, environment and Quality
32. SMOW: Standard Mean Ocean Water
33. V: Volt
34. VRWS: Vaalputs Radioactive Waste Site
35. WISH: Windows Interpretation System for Hydrogeologists

1. INTRODUCTION

1.1. BACKGROUND

In 1978 a programme was launched to select a suitable Site for the disposal of nuclear waste in South Africa. This study entailed an examination of a variety of socio-economic and the geosphere related parameters. Three potential Sites were selected: the central portion of the Richtersveld, the Kalahari, roughly north of Upington, and an area in Namaqualand/ Bushmanland (Levin, 1988). Based on the geosphere study and the distance from international boundaries and from Koeberg, the Vaalputs Site in Namaqualand/Bushmanland was selected. Some of the factors that contributed to Vaalputs being regarded as a suitable Site were (Levin 1988, Ainslie, 2003):

- Low population density (in initial Vaalputs stages, only 102 people lived within a 20 km radius of Vaalputs);
- Sparse agricultural activities - the main agricultural activity around Vaalputs is sheep farming;
- Low potential for economic mineral exploitation;
- The disposal area in the Vaalputs Site is locally elevated above the surrounding area, reducing flooding potential;
- Low seismic activities in and around the Vaalputs area (Andreoli 1986, Andreoli
- 2009, Viole 2005).
- Long-term geological and geomorphological stability (Andreoli, 1986).

After the selection of a suitable Site, the state acquired three farms on behalf of Necsa, the corporation responsible for the management of the radioactive waste facility. The VRWS is the only nuclear disposal Site in South Africa. It was essential, because any nuclear power station produces a certain amount of Low and Intermediate Level Radioactive Waste during normal operations, which cannot be disposed of by ordinary waste disposal methods. Disposals are carried out in terms of an authorisation granted by the National Nuclear Regulator (NNR) Act (Act 47 of 1999). The NNR reviews the authorisation periodically to take account of new information and to implement any revisions to regulatory requirements (Van Blerk, 2008). Waste disposed of is classified according to radiological levels: Intermediate Level Radioactive Waste consists of ventilation filters and evaporates; Low Level Radioactive Waste is composed of garbage such as tissues, gloves, glassware, plastic containers and clothing (Levin, 1988). The main radioactive isotopes found in the waste include ^{60}Co, ^{90}Sr and ^{134}Cs with half-lives ranging from six to thirty years.

The VRWS has been licensed as the only disposal Site for radioactive material since it first received waste from the Koeberg Nuclear Power station (KNPS) in 1986. KNPS is the only nuclear power station in South Africa and is located 30 km north of Cape Town near Melkbosstrand on the west coast of South Africa. KNPS is owned and operated by the countries only mandated, commercial electricity supplier, Eskom. Koeberg's average annual power production is 13,668 GWh (Eskom, 2007). Necsa started generating waste since the commissioning of the Safari 1 reactor at the Pelindaba Site in 1965. The bulk of the nuclear waste at Necsa was generated between 1970 and 1998 by the nuclear fuel production facility, specifically by the conversion, enrichment, and fuel fabrication plants (Van Blerk, 2007). Starting in May 2008, Long-Lived Low Intermediate Level Radioactive Waste (containing small amounts of uranium) from Necsa have been disposed of at the Vaalputs Site (Figure 1).

Figure 1: Aerial photo of the Vaalputs Radioactive Waste Site (Adapted after Van Blerk 2007)

Near-surface trenches are used as a disposal concept for LILW. The LILW is disposed of in shallow trenches about 8 m deep, 20 m wide and 100 m long. This method of disposal is accepted internationally as a safe and reliable way to dispose of radioactive waste and has been practiced by several countries (Figure 2).

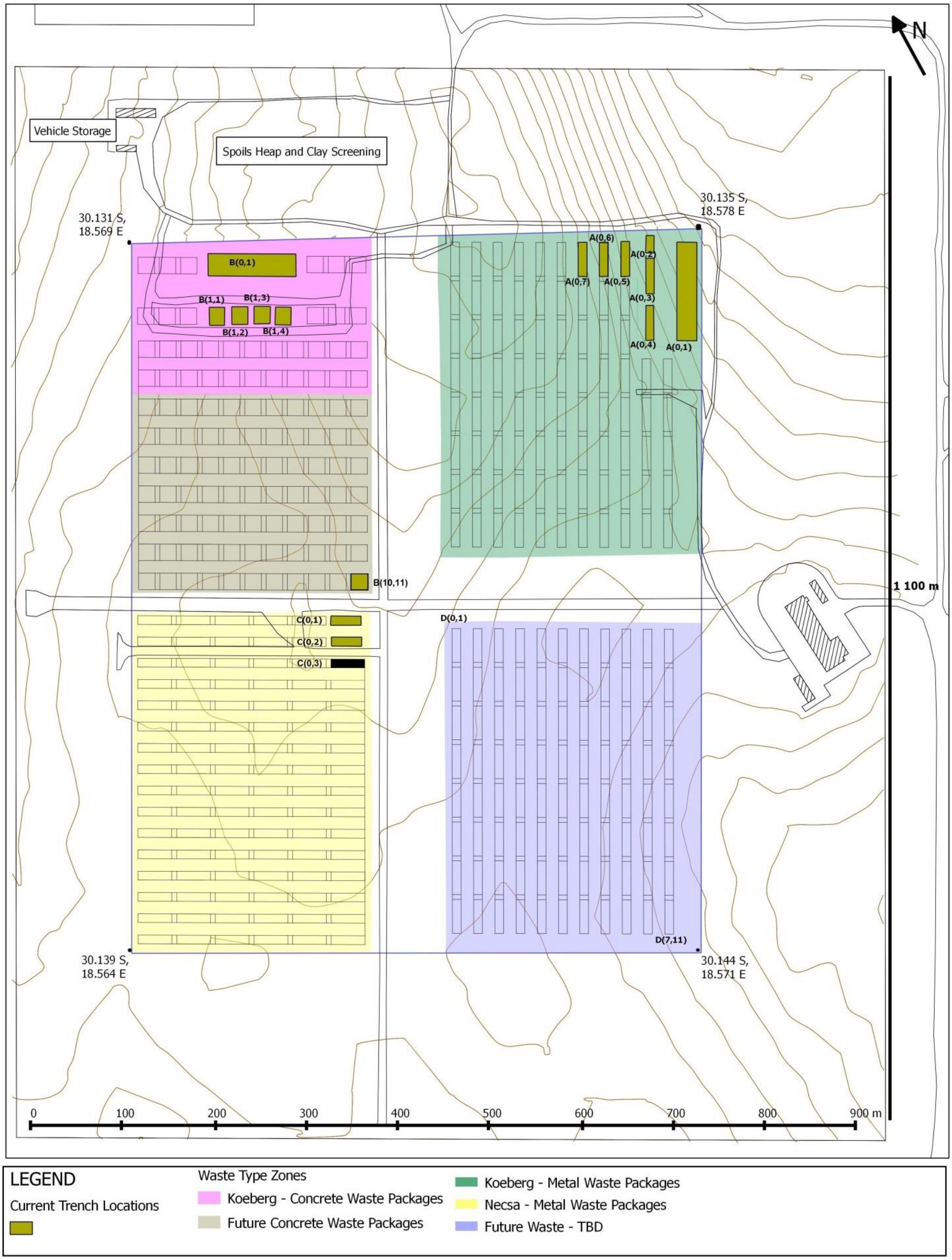

Figure 2: Layout plan of future trenches for LILW at the Vaalputs Facility

Figure 2 shows the trench layout plan of the Vaalputs facility, as well as the elevation of the disposal Site and its coordinates. shows the steel drums being lowered into a trench; the steel drums contain LLW, i.e. solid waste consisting of previously mentioned radioactive garbage, such as clothes, tissues, gloves, glassware etc.

Figure 3: Metal drums with low level waste being lowered into a trench

Figure 4 shows how concrete drums containing Intermediate Level Waste are stored in trenches at the Vaalputs Site. The ILW, as mentioned before, is solid waste consisting of ventilation filters and evaporates. Steel drums of about 210ℓ from Necsa in Pelindaba, containing similar radioactive waste to that of Koeberg, have been disposed at the Vaalput Site trenches. According to Truter (2008), an average of 201 concrete containers (Figure 4and 600 steel drums (Figure 3) are delivered at the Vaalputs Site from Koeberg Nuclear Power Station (KNPS) every year. Necsa is planning to ship about 6,000 210ℓ drums and a further 3,000 100ℓ steel drums to the Vaalputs Site annually (Truter, 2008).

Figure 4: Stocking of concrete containers of Intermediate Level Waste in the Vaalputs Site trench

Table 1: Year 2015 Vaalputs Waste inventory for trenches A, B and C

TRENCH No.	STATUS	WASTE CLASS	INVENTORY (waste packages)	REMARKS
A01	Closed	Low Level Waste	11740	100% full. Currently in after care.
A02	Closed	Low Level Waste	840	100% full. Currently in after care.
A03	Closed	Low Level Waste	1639	100% full. Currently in after care.
A04	Closed	Low Level Waste	1079	100% filled. Capping completed.
A05	Full	Low Level Waste	1560	100% filled. To be capped.
A06	Full	Low Level Waste	1829	100% filled. To be capped.
A07	Open	Low Level Waste	569	Koeberg metal drums.
C01	Closed	Low Level Waste	2873	100% full. Currently in after care.
C02	Open	Low Level Waste	2666	92% full (Necsa metal waste packages for MAC waste).
C03	Empty	Low Level Waste	0	Ready for Necsa waste.
B01	Closed	Intermediate Level Waste	3177	100% full. Currently in after care.
B02	Full	Intermediate Level Waste	400	100% full. Ready for capping
B03	Open	Intermediate Level Waste	391	Currently in use, 97% filled
B04	Open	Intermediate Level Waste	23	5% filled
B05	Open		0	Empty. Crack in separation wall being monitored.
B (10,11)	Open	Low Level Waste	192	48% full, NTP high density concrete waste packages
TOTAL			**28 978**	

Table 1 shows the waste inventory for the VRWS. The table records the current status of the different trenches. Once trenches are filled with containers of LILW, capping is done by means of covering the full trenches with material that has been excavated and stored for this purpose. Clay-rich materials excavated are used at lower levels, while red sand layers fill shallower depths. This ordering is repeated when trenches are refilled with excavated material.

1.2. SAFETY CASE ASSESSMENT

When VRWS started operating in 1986, a safety report was approved by the Atomic Energy Corporation of South Africa (moore et al., 1987). The safety report only emphased on operational issues and not long term post closure safety for the Vaalputs Site. Some of post closure safety assessment reports for the VRWS are documented in the following reports;

- JJ Van Blerk and JJP Vivier (GEA-1476/NWS-RPT-01/001)
- JF Beyleveld (VLP-SAC-003)
- M W Kozak (VLP-SAC-005)
- A Wiethoff and JJP Vivier (VLP-SAC-006)
- JJ Van Blerk (VLP-SAC-008)

According to Van Blerk, 2006, the role of a Post Closure Radiological Safety Assessment is to focus on these fundamental issues;

- Why is the assessment being undertaken
- Against what criteria will the results of the calculations for the assessment be compared?
- What are the characteristics of the site under evaluation?
- What are the primary features of the disposal system?
- Over what timescales will the endpoints are considered?
- What is the basis of the assessment methodology

Implementation of Post Closure Radiological Safety Assessment depends on a number of components. Site characterization information represents the main input to the assessment. Key site characterization components are hydrological, geological, groundwater data which forms the basis of a Post Closure Radiological Safety Assessment. These components can at times pose as uncertainties due to the nature of data collected, integrity of the data analysis and interpretation. When compiling a safety assessment the aim is not to completely eliminate uncertainties but to understand their impact on the safety of the site.

A crucial tool in managing and understanding uncertainties is compiling a conceptual model. A conceptual model describes the state of behavior of a disposal system and its environment; this includes groundwater recharge, groundwater quality, aquifer parameters and boundary conditions. Conceptual model uncertainties can also be associated with unavailability of data, which would require studies to be done. The aim of this study is to address some of the uncertainties mentioned to update the Post Closure Radiological Safety Assessment.

1.3. RATIONALE OF THE STUDY

A radioactive waste disposal Site is designed with the primary aim of containing and isolating waste. Containment means to confine the radionuclides within a waste matrix, i.e. the packaging and disposal facility itself. Isolation means keeping the waste and its associated hazards isolated from both the biosphere and the geosphere (EC, 2011). Since complete containment cannot be guaranteed for entire duration that the waste presents a potential hazard, a further aim of a repository is to ensure that any potential release does not present an unacceptable risk. Safety after closure of a radioactive waste disposal Site is provided by the durable passive safety functions of the geological environment and by the engineered barriers placed around the waste, as well as by the stability of the waste form itself (NEA/RWM/R, 2013). The components of the Safety Case should include the following: the assessment context, the safety strategy, the facility description, safety assessment, limits, controls and conditions, iteration and design optimisation, uncertainty management and integration of safety arguments (IAEA, 2012). A Safety Case Assessment should be developed from the very conceptualisation of the facility and should be maintained throughout its lifetime up to closure and license termination. Figure 5 shows the components of the Safety Case Assessment.

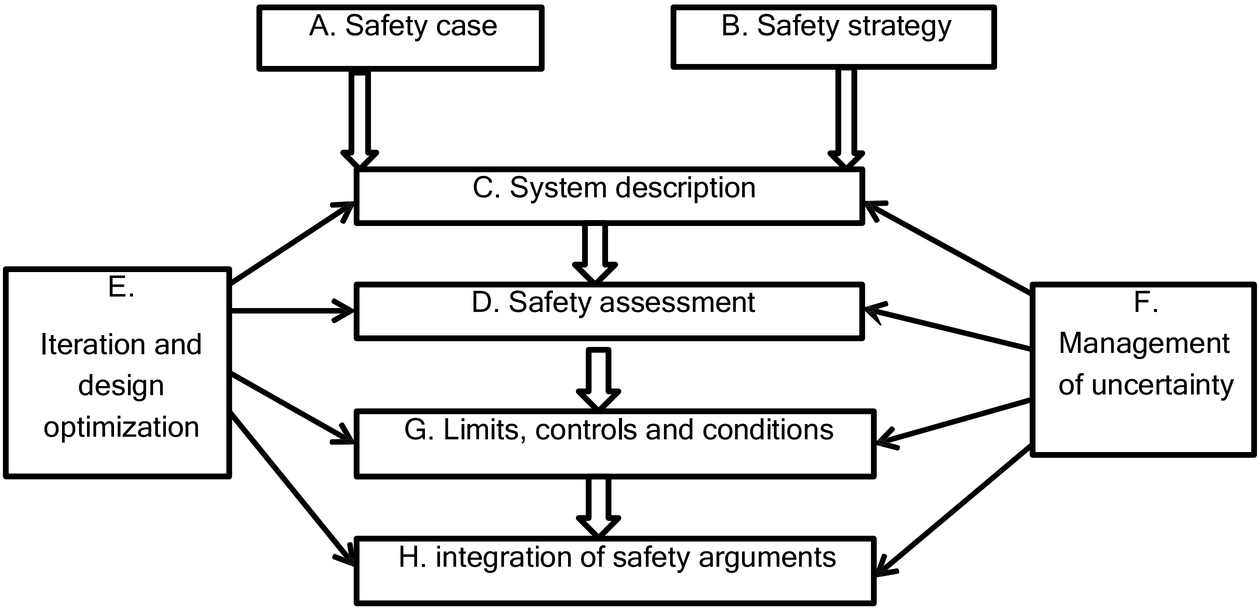

Figure 5: Components of the Safety Case Assessment (IAEA, SSR5)

In the field of radioactive waste disposal, difficulties face those who seek to assess safety and to achieve confidence in the findings of the Safety Assessment. This is mainly because of the uncertainties associated with the extensive timescales over which safety must be evaluated and the limited possibilities for monitoring and intervention over time (NEA, 1999). According to Van Blerk (2013), building confidence for a radioactive waste disposal Site must be considered as a process, both internal and external to the Safety Assessment. “Internal” refers to confidence of and trust in the professionals performing the Safety Assessment, i.e. provided that the analysis and results are accurate and reliable and that the uncertainties are clearly identified and minimised where possible. “External confidence” refers to establishing, building and maintaining public confidence and trust in all aspects of the mechanism.

The first post-closure Radiological Safety Assessment prepared for the VRWS is documented in Van Blerk (2001). Van Blerk (2013) explains that the inventory of that safety report was limited to Low Intermediate Level Waste (LILW) generated at the Koeberg Nuclear Power Station. This was followed in 2005 with an assessment to derive reference levels for the disposal of LILW at the Vaalputs Site (Van Blerk, 2005). The Van Blerk (2005) Safety Assessment was followed by a more comprehensive 2006 assessment aimed at the disposal of the national inventory of radioactive waste. The last assessment for the Vaalputs Post-Closure Safety Assessment includes the Necsa assessment (Van Blerk, 2007) which is ongoing.

Uncertainties are a common phenomenon in any long term assessment of a waste disposal system. Efforts were made in the 2007 Vaalputs Post-Closure Radiological Safety Assessment to understand the significance of uncertainties and to reduce them through qualitative and quantitative analysis. One of the aims of the 2007 Vaalputs PCRSA, according to Van Blerk (2007), is that it should be based on a physical understanding of scientific and technical knowledge, including Site-specific information, using realistic assumptions. More realistic assumptions require a broader knowledge of the geosphere for the repository and should include:

- A continual geological evaluation at the VRWS Site, which may influence the Safety
- Assessment;
- Recording climatological, seismological and vegetation changes at the VRWS Site; and
- Recording changes in hydrological and geohydrological trends, e.g. groundwater quality, groundwater levels, drainage patterns, recharge, run-off, etc.

1.4. AIMS AND OBJECTIVES OF THE STUDY

The aims of this study are 1) to establish the geohydrological status quo and 2) to focus on recharge estimations on a broader, regional scale. This will yield an independent data set against which historical and current data may be verified and should highlight possible data gaps in the existing monitoring programme.

An updated conceptual model is to be created that will assist with building and updating a Safety Case Assessment, which is an important requirement for maintaining an operating license for the VRWS Site. A current numerical groundwater flow model exists (Van Blerk, 2008) which is used to assist in groundwater management decisions. Van Blerk indicated that, due to a limited data set on isotopic information, the recharge parameter that was applied in his model should be investigated more comprehensively to increase the confidence in model output data.

In order to achieve the above mentioned aims, the following objectives were decided upon after communication between Necsa and the IGS on the campus of the UFS:

- Conduct both a winter and a summer monitoring programme, which will deliver an independent data set that can be used to assess historical and recent monitoring data;
- Perform a regional hydrocensus within a 20 km radius of the VRWS;
- Perform a more in-depth study of recharge estimation for the VRWS to address uncertainties and to improve on the Safety Case Assessment;
- Initialise a groundwater database by making use of software developed by the Institute for Groundwater Studies (IGS), which is called the Windows Interpretation System for Hydrogeologists (WISH);
- Incorporate the 2010 Geological Map data from the Council of Geoscience to improve and update the geohydrological knowledge pertaining to the VRWS; and
- To update the conceptual model with more recent geological and recharge information.

1.5. THESIS LAYOUT

A brief layout of this document is given below.

Chapter 2: A Site description as well as a literature review will be discussed with regards to location and physiography, geomorphology, climate, vegetation, topography, geology, geohydrology and recharge;

Chapter 3: A description of the methodology whereby data was collected, sampling conducted, laboratory analysis performed, calculations done and conversions made;

Chapter 4: A hydrogeochemical description of how and why groundwater chemistry is analysed by means of the WISH software package, which includes tools such as chemical diagrams and time graphs. This chapter also discusses radioisotope results in details;

Chapter 5: A general geohydrological description of groundwater levels, including aquifer parameters, e.g. transmissivity, storativity, porosity and recharge;

Chapter 6: A more in-depth analysis of recharge on a regional scale that includes appropriate groundwater quality information, such as isotopic;

Chapter 7: An update of the conceptual model with respect to recharge estimates, with a higher accuracy determined by applicable analytical methodology. Some comments will be included regarding appropriateness of aquifer parameters in the western part that were used for the numerical groundwater model;

Chapter 8: Conclusions will be summarised for each chapter and recommendations will be made on how to increase confidence in the VRWS groundwater management decisions and the way forward;

References: An alphabetical list of all references included during research for this project; And

Appendices: Raw field data and laboratory certificates will be included in this section.

2. SITE DESCRIPTION AND LITERATURE REVIEW

2.1. SITE DESCRIPTION

The Vaalputs Radioactive Waste Facility (VRWS) is located in the Northern Cape province of South Africa, as shown in Figure 6 ; the facility is situated in the Namaqua District Municipality, ±100km SSE of Springbok. The latitude and longitude coordinates of the facility are: 30°08’ South, 18°35’ East (Figure 7). On the 1:250 000 Geological Map by Council for Geoscience, the VRWS lies on the 3018 Loeriesfontein sheet. The facility has been established on three adjoining farms: Geelpan portion 1, Garing portion 2, Bokseputs portion 1 and Stofkloof. The facility is approximately 10, 000 ha in extent (Levin, 1988).

2.2. GEOMORPHOLOGY

The study area is divided by the North-South watershed escarpment into two broad regions (Figure 7). The watershed is defined approximately by the Springbok-Kliprand road to the west of this divide; the topography is rugged granitic terrain with gently sloping, sandy pediments as the valley floor and is known as the Namaqualand Plateau. To the East is the Bushmanland Plateau with an elevation of about 1,000 m above mean sea level that is quite featureless (Brandt, 1998; Levin, 1988). The main watershed in the study area that divides the Namaqualand and Bushmanland separates the drainage basins of the Olifants, Buffels and Koa rivers (Brandt, 1998). The drainage basin of the Buffels River occupies the West, the Olifants River basin the South to South-West and the Koa River basin the North-East. Vaalputs is situated within the Koa River basin which constitutes a fossil drainage system and no active drainage therefore occurs on the plateau in the vicinity of the disposal Site (Levin, 1988). Small pans occur in the interdune areas, and - in some cases - in depressions on the dunes themselves. Two of these pans are: Bosluis Pan, located in the Koa River, and Santab se Vloer Pan, located South-East of the VRWS.

Figure 6: Map of Sout Africa, showing the locality of VRWS, Pelindaba and the Koeberg Nuclear Power Station (adopted after Adreoli and Van Blerk)

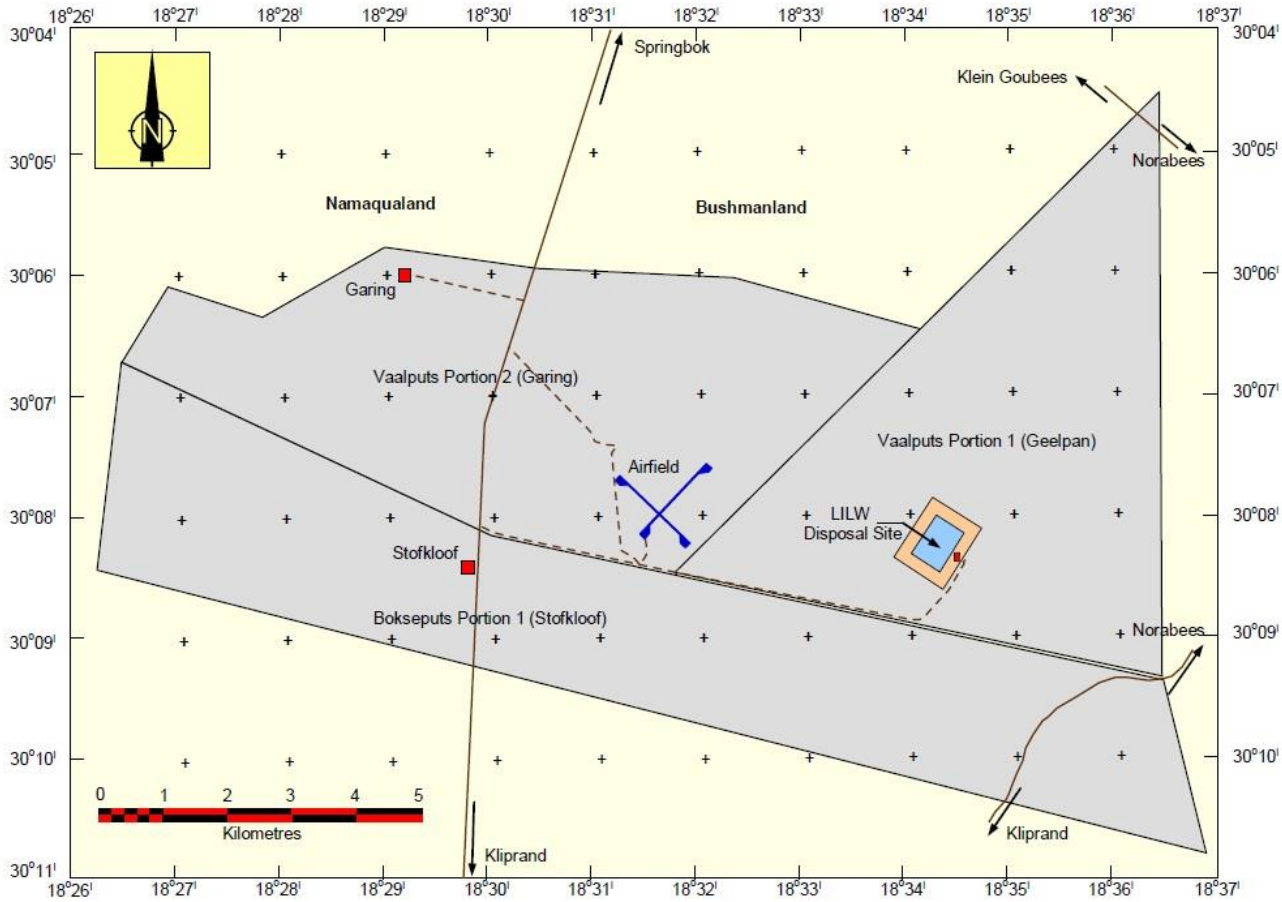

Figure 7: Vaalputs Site showing farm portions

2.2.1. General

According to Levin (1988), climate conditions in the study area are characterised by anticyclonic conditions throughout the year. The dominant wind direction is from the South to South-West. Rainfall of the study area shows a bi-modal distribution, with thunderstorms occurring during the months of September to April, whilst rainfall is during the months of May to August and is associated with frontal weather systems. The facility falls within winter/summer rainfall transition zones (Table 2), but it is located on the Bushmanland Plateau where summer rainfall appears to be predominant. The mean rainfall for the period of 1986 to 2015 was 130.7 mm, with winter rainfall (April to September) averaging 10.7 mm and summer rainfall (October to March) average is 11.5 mm.

2.2.2. Precipitation

Long term precipitation average was recorded as 74 mm per annum for the Vaalputs Site (Redding & Hutson 1983), while - in 1986 - Verhagen and Levin reported the mean annual precipitation (MAP) in the semi-desert area to be 78 mm. According to Pretorius (2012) the Vaalputs weather station data showed the mean annual precipitation (MAP) to be at 130 mm for the period of 1986 to 2005. The full rainfall and evaporation data can be viewed in Table 16, APPENDIX A.

Table 2: Mean monthly rainfall, evaporation and temperatures recorded at the VRWS Weather Station (dataset_EMG_S&LD_NECSA)

Month	Mean Rainfall(mm) (1986-2015)	Average Temp	Mean Evaporation (MM) (1990-2014)
January	8.4	22.4	333
February	12.2	23.3	269
march	15.4	20.95	240
April	12.9	18.28	163
May	11.6	13.57	124
June	12.8	9.86	89
July	11.9	9.53	100
August	10.4	10.62	122
September	4.6	14	164
October	13.3	16.74	225
November	11.1	18.62	257
December	8.5	21.08	312
Annual Average	130.7	16.58	199.83

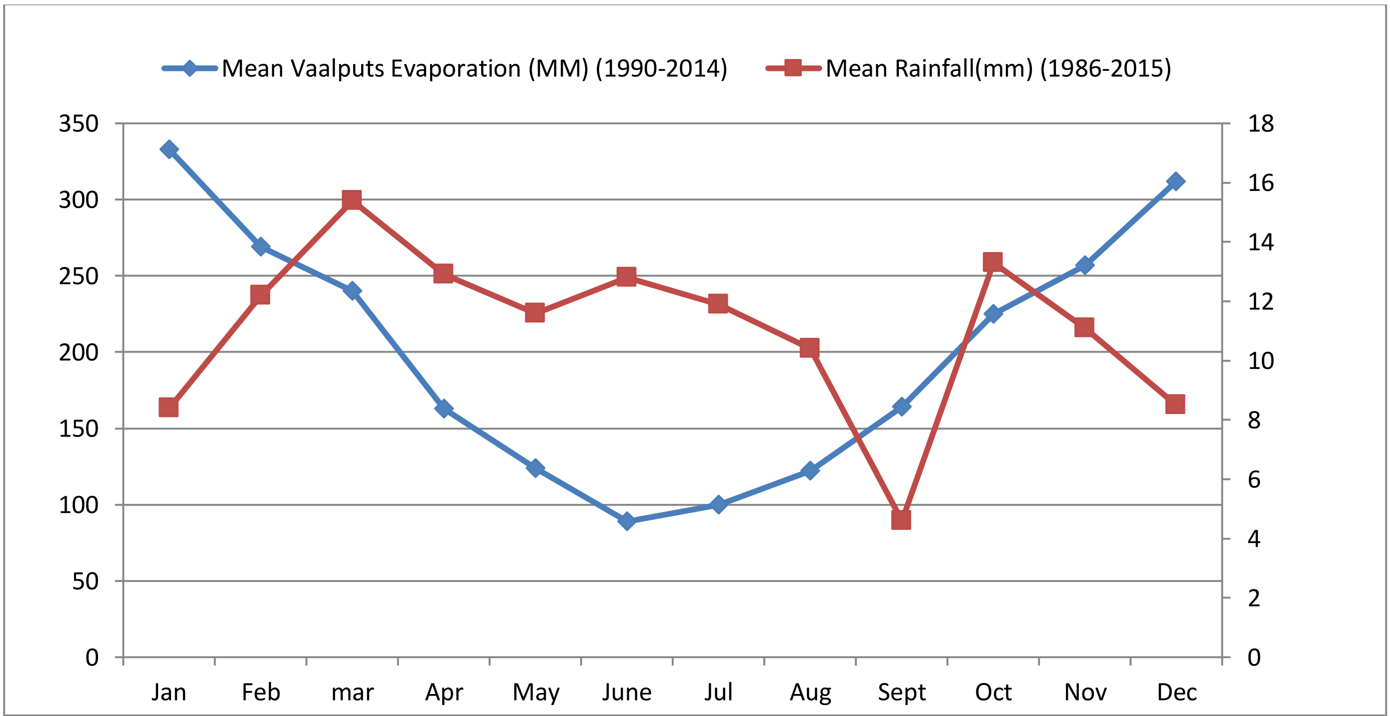

Figure 8: Mean monthly temperature and mean monthly rainfall (mm)

2.2.3. Evaporation

Table 2 and Figure 9 show the mean annual evaporation values recorded at the Vaalputs weather station for period 1990 to 2014. The pattern shows a seasonal trend, between the month of April to Aug and winter season evaporation lows with an average of 119.6 mm. The mean annual evaporation at the Vaalputs Site is 199.83 mm.

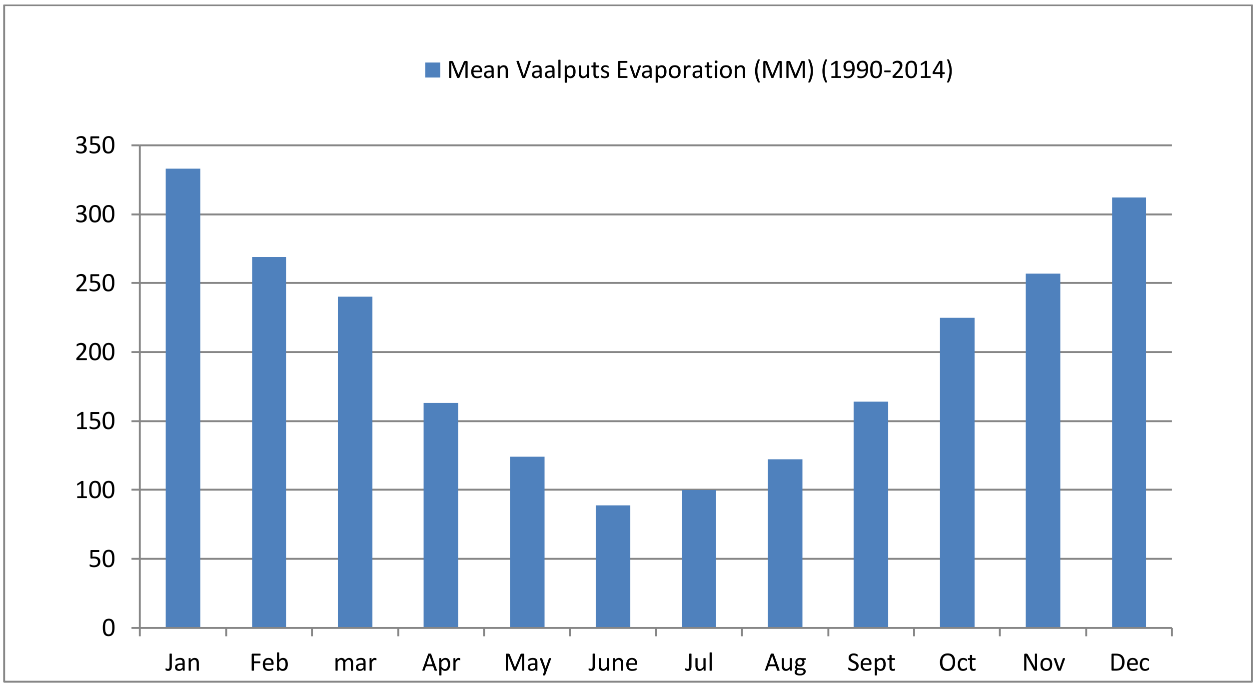

Figure 9: Monthly mean evaporation pan measurements - 1990 to 2013 (dataset EMG S&LD NECSA)

2.3. VEGETATION

The VRWS is located on the transition zone between succulent Karoo in the West and the Nama-Karoo in the East (Rutherford and Westfall, 1986) and more specifically on the boundary of the Namaqualand Hardeveld Bioregion in the West and the Bushmanland Bioregion to the East (Mucina and Rutherford, 2006). Vegetation is dominated by dwarf succulent shrubs and grasses are rare, except in some sandy areas. Annual flower displays occur in spring, following good rains. The Karoo Biome is found on the central plateau of the western half of South Africa and is the second largest biome in South Africa (Van Rooyen, Van der Merwe and Van Rooyen, 2011) (Figure 10)

The eastern side of Vaalputs is classified as Dwarf Karoo Shrubland, false Succulent Karroo and Bushmanland (White, 1983, Acocks 1953, Low & Rebelo 1996). The three vegetation types in the study area are described by (Mucina & Rutherford 2006) on the vegetation map of South Africa:

- Namaqualand Klipkoppe Shrubland on the western rocky section,
- Bushmanland Arid Grassland on the eastern plains ; and
- Platbakkies Succulent Shrubland on the transitional area on both sides of the watershed.

The Namaqualand Klipkoppe Shrubland is prominent with trees such as Aloe dichotoma, Ficus ilicina and Pappea capensis. The Bushmanland Arid Grassland is classified with grass species such as Stipagrostis Uniplumis, Stipagrostis Obtusa, Stipagrostis Ciliata, Aristida Congesta, Enneapogon Desvauxii and Schmidtia Kalahariensis which is common in study study areas after summer rains (Figure 11 - Van Rooyen, Van der Merwe and Van Rooyen, 2011).

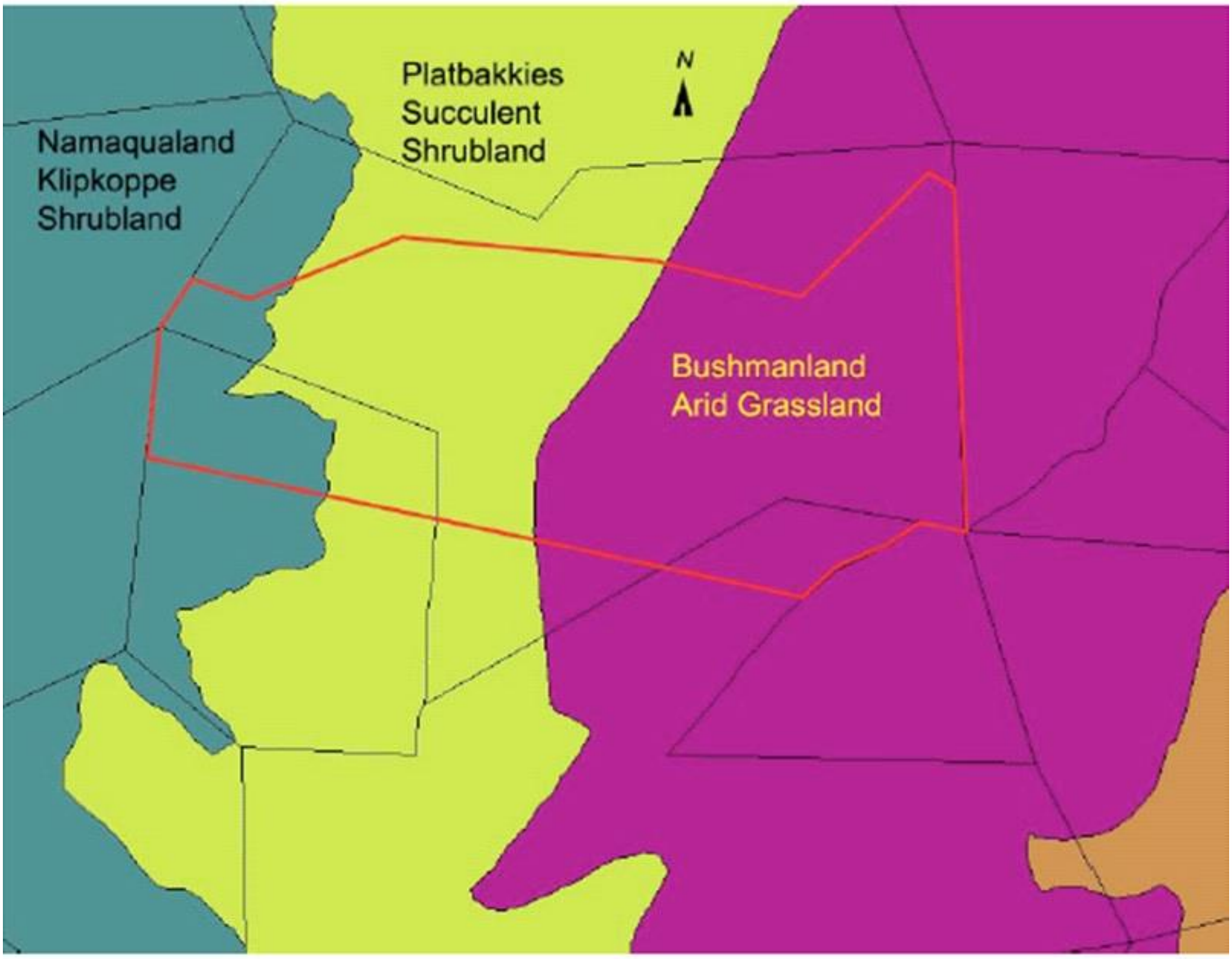

Figure 10: Vegetation types in the VRWS and surroundings (adapted after Mucina & Rutherford 2006)

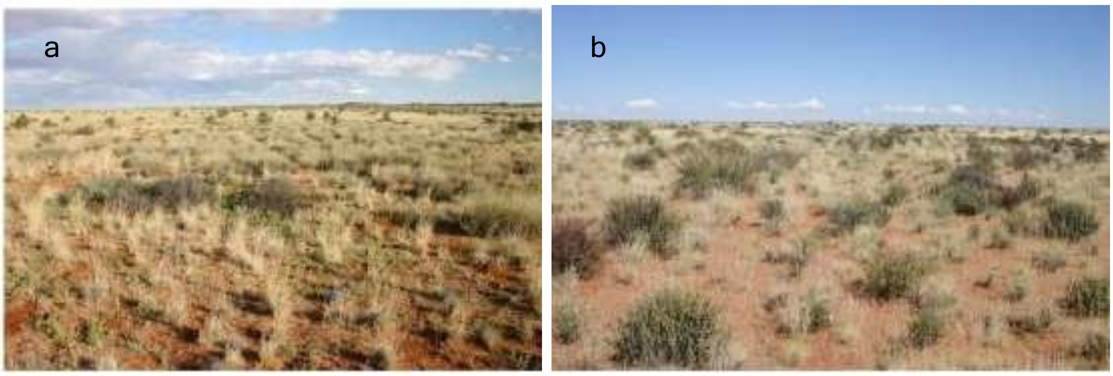

Figure 11: a)Stipagrostis brevifolia-, lycium cinereum-, stipagrostis obtusa grassland, b) Stipagrostis brevifolia-euphorbia decussate grassland grass classification of the Bushmanland arid grassland (adapted after Van Rooyen, Van der Merwe and Van Rooyen, 2011

2.4. SOIL MOISTURE CONTENT

Soil moisture monitoring was conducted between periods 2009 to 2015. A total of 20 sensors in two trenches were installed at different depth from 125 to 3 000 mm. These sensors were used for soil temperature and moisture content on Trench A and Trench B at the VRWS. According to Van Blerk (2015), soil moisture at shallow layers is low. It increases with depth with possible maximum values of 3 to 3.5 m from surface. This confirms results from Maphoto (2009) soil moisture due to impact of rain could be detected 3+below the surface at the Vaalputs Site. Figure 12 is a profile showing moisture up to 3.0 + m

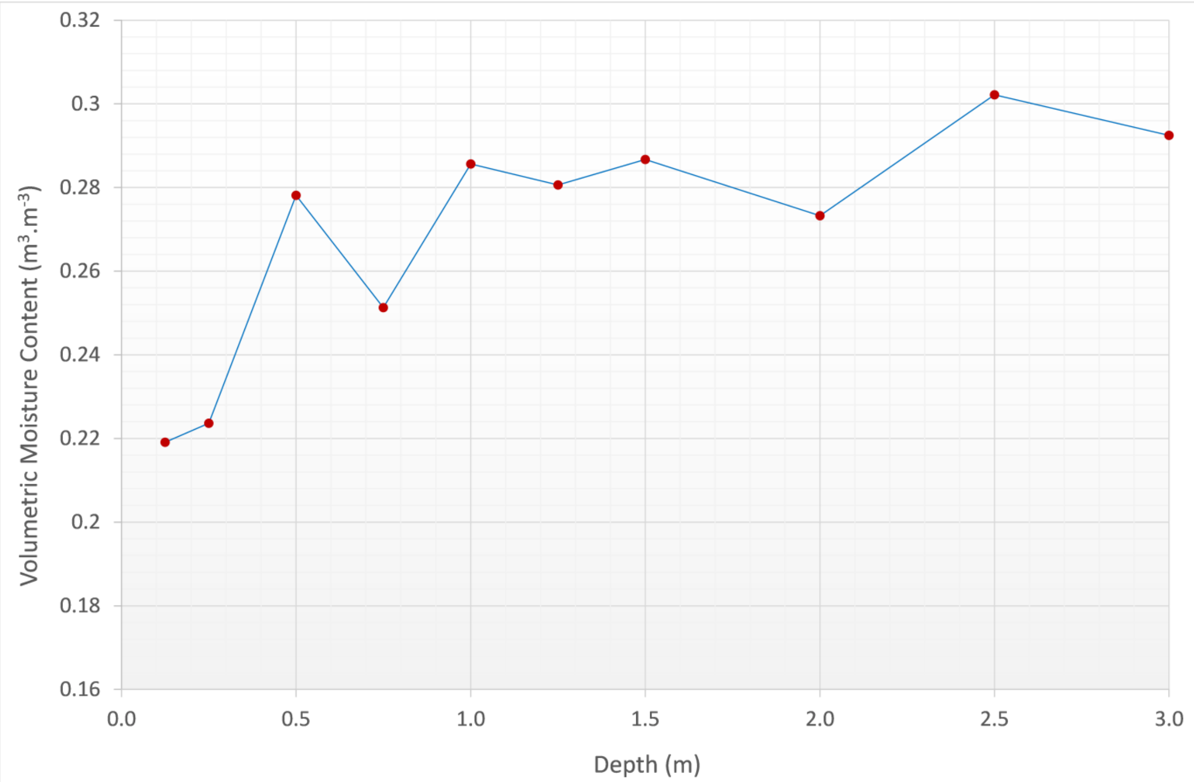

Figure 12: Soil moisture content observed in trench B over the period of 2009 to 2015 at the VRWS. (Adapted after Van Blerk, 2015)

2.5. TOPOGRAPHY

The topography in the VRWS varies from low to high altitude escarpment zone, as shown in Figure 13. The VRWS is dominated by rugged mountain landscape of granitic rocks on the western side. On the eastern side of the Vaalputs Site is a sandy pediment with minor gentle slopes. The Vaalputs disposal area is located on the East side of the study area, which is mainly a featureless, rolling Bushmanland Plateau at an elevation of 1000 m above mean sea level. The topographical variance at the Vaalputs disposal Site is less than a metre. The disposal Site has higher elevation than the surrounding area, which plays a big role in water draining away from the disposal Site.

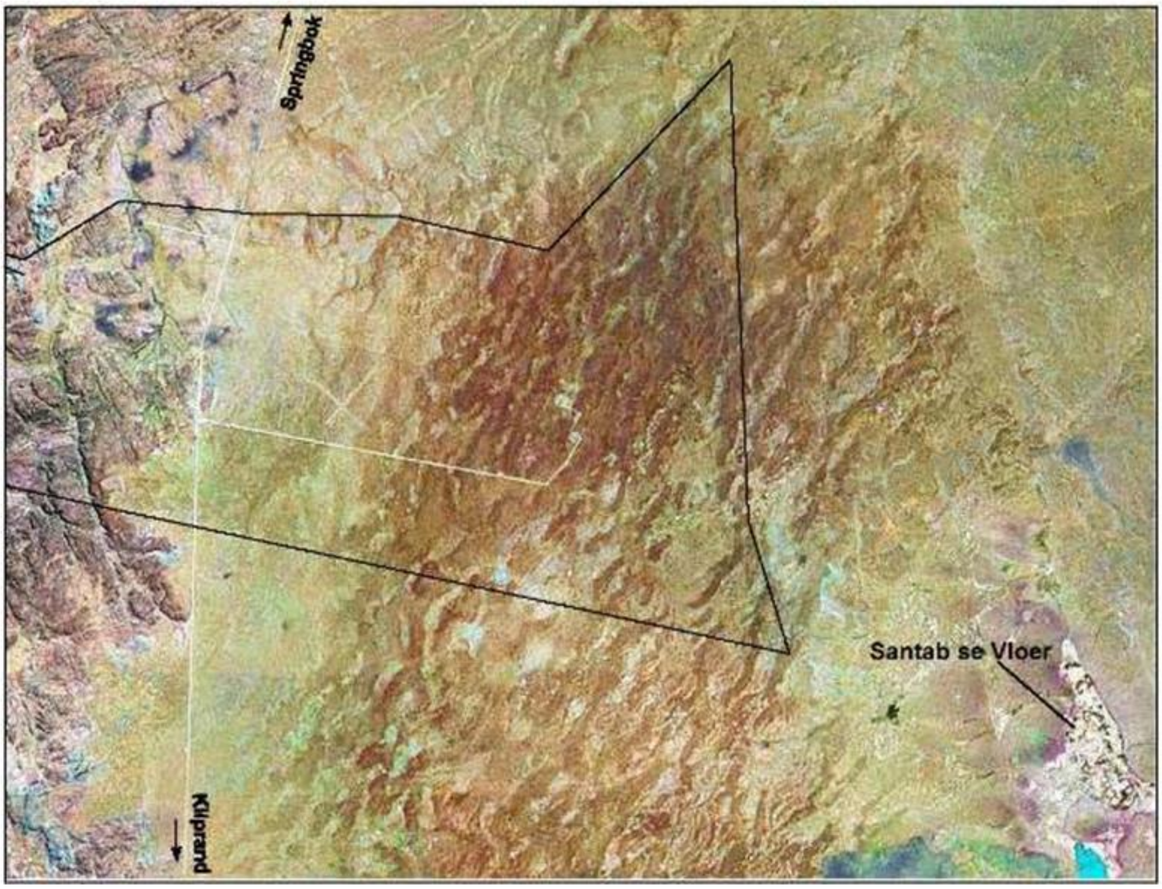

Figure 13: VRWS overlain on SPOT imagery, showing the location of Santab se Vloer Pan

2.6. GEOLOGY

The regional geology of the VRWS and surrounding area ranges in age between the Mesoproterozoic Era and very recent superficial deposits and alluvium (Figure 14). Table 3 represents the simplified stratigraphic subdivisions of the rocks. On a regional scale, the area to the West of the VRWS is dominated by the rocks of the Namaqua Metamorphic Province (NMP) consisting of a sequence of intensely deformed high-grade ortho- and paragneisses and mafic granulites intruded by large volumes of late-tectonic granitoids and minor post-tectonic noritoids. In the south-western parts of the area, NMP basement rocks are unconformably overlain by low-grade Cambrian meta-sedimentary rocks of the Vanrhynsdorp Group, which crop out in the form of three parallel, N-S-trending half-grabens.

The eastern parts of the region are mostly underlain by the flat-lying sedimentary rocks of the Permian-Carboniferous Dwyka and Ecca Groups. Large volumes of Jurassic dolerite sills and dykes intrude the sedimentary rocks representing the basal units of the Karoo Supergroup.

The Dasdap and Vaalputs formations formed post-Karoo and represent late Cretaceous and Tertiary alluvial deposits. Swarms of olivine melilitite pipes of the Gamoep Suite, concentrated in the central northern parts of the region, also date from the aforementioned period. Much of the central parts of the area are covered by unconsolidated aeolian, colluvial and alluvial deposits.

Table 3: Simplified stratigraphic subdivision of the rocks in the 3018 Loeriesfontein mapped area (Macey et al., 2011)

AGE	SUPRACRUSTAL SUCCESSIONS		INTRUSIVE AND METAMORPHIC ROCKS
Tertiary to Quaternary		Surface deposits Vaalputs Formation	Gamoep Suite
Cretaceous		Dasdap Formation	Koegelfontein Complex
Jurassic			Karoo Dolerite Suite
Permian to Carboniferous	KAROO SUPERGROUP	Ecca Group Dwyka Group	
Namibian	VANRHYNSDORP GROUP	Knersvlakte Subgroup Kwanous Subgroup Flaminkberg Formation	
Mokolian	KAMIESBERG GROUP		Koperberg Suite
			Spektakel Suite
			Oorkraal Suite
			Little Namaqualand Suite
			Lekkerdrink Gneiss

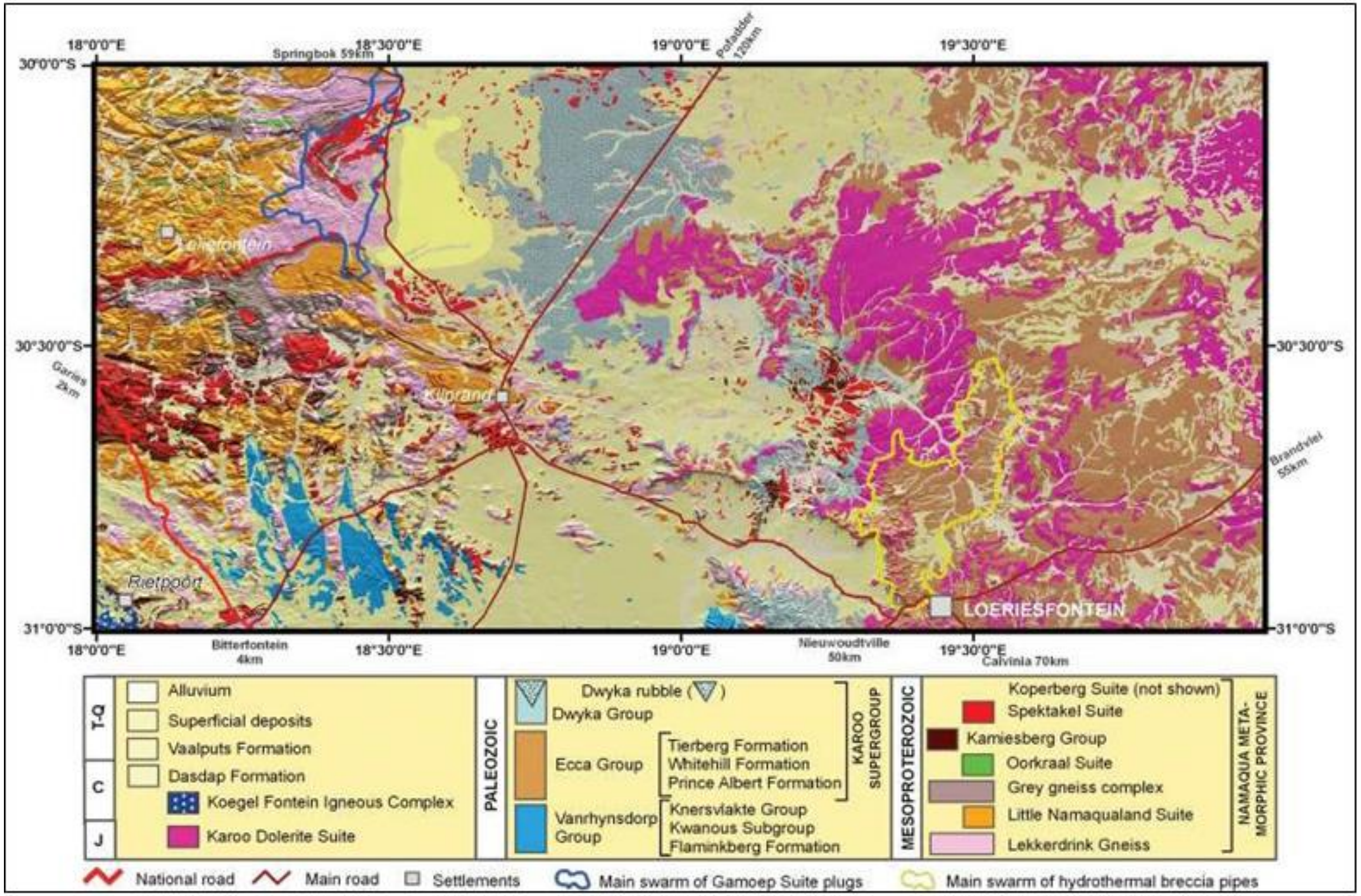

Figure 14: Simplified geology of the 3018 Loeriesfontein mapped area (Macey et al., 2011)

2.7. HYDROGEOLOGY

The hydrogeology of any region or sub-region can always be related to two basic components:

- The geological environment in which groundwater occurs; and
- The reigning hydrological pressure gradients within the aforementioned environment.

Groundwater systems can be sub-divided into:

- Unconfined systems;
- Semi-confined systems; and
- Confined systems.

All the above will influence the mechanisms through which precipitation will result as recharge in a specific groundwater system. The time it takes recharge to reach a specific system or aquifer will determine whether the resource is to be classified as either a renewable or a non-renewable resource. Recharge will be influenced by the following:

- **Precipitation** - The amount, type, duration, areal extent and intensity of rainfall events will be the most important variables influencing the amount of water that will be available to recharge aquifer systems;
- **Evapotranspiration** - The combined effect of evaporation on surface and transpiration of local vegetation will intercept a large percentage of any rainfall, especially in this arid area;
- **Climate** - Seasonal changes in the two aforementioned parameters will influence their respective rates, which in turn will influence the amount of recharge that will end up as groundwater;
- **Topography/Surface** - The slope, vegetation cover and near surface soil type will influence run-off and therefore have an impact on retention time of water particles;
- **Unsaturated zone** - The thickness of the sub-surface environment that any water particle needs to traverse before it ends up as groundwater has a direct effect on recharge. The longer the pathway, the more time there is for soil and rock to retard water particles on their journey due to gravity; and
- **Recharge pathways** - Recharge can occur through two basic pathways. Dense subsurface materials will allow for diffusive flow, which will take much longer than preferential flow through fractures or pathways with a high permeability.

Local groundwater users primarily make use of windmills and submersible pumps powered by solar energy. Abstraction rates are low and only a few higher yielding boreholes are sparsely distributed across the region.

All the above-mentioned processes and environments should be considered from a holistic point of view. Changes in one of them will influence all the others and recharge that will finally end up as groundwater will be a function of the combined influences of each of them.

At the VRWS the depth to the piezometric surface indicates a minimum unsaturated zone of between 50 m and 70 m (Van Blerk, 2006). The primary aquifer at the VRWS can be classified as semi-confined to confined (Levin, 1988) and confining layers together with permeable and impermeable fault zones structurally control movement of water within this aquifer. Compartmentalisation of the aquifer system(s) is therefore a reality.

3. METHODOLOGY

3.1. INTRODUCTION

As indicated in section 1, this research project has two primary aims:

- To establish an independent data set against which historical and current monitoring data can be evaluated and compared; and
- To conduct a more comprehensive and spatially expanded investigation to verify recharge estimates determined during numerical groundwater flow model calibration.

Objectives were decided upon, which include:

- To conduct both a winter and a summer monitoring programme, which will deliver an independent data set that can be used to assess historical and recent monitoring data;
- To carry out a regional hydrocensus within a 20 km radius of the VRWS;
- To perform a more in-depth study of recharge estimation for the VRWS so as to address uncertainties and to improve on the Safety Case Assessment;
- To incorporate the 2010 geological map from the Council of Geoscience to broaden and update geohydrological knowledge of the VRWS; and
- To update the current conceptual model with more recent geological and recharge information.

3.2. GEOLOGICAL REASSESSMENT

The need to update the existing geological information that was used during previous investigations at the VRWS was expressed by Dr J. van Blerk. The following recommendations are quoted from his saturated groundwater model report:

- "The measured groundwater levels need to be confirmed through a regional hydrocensus. This include (sic) the general characteristics of the sampling point (e.g. windmill, borehole) and to what extend (sic) the sampling point is being used (e.g. for water supply).
- Incorporate the existing geological logs into a database to facilitate the construction of a three dimensional geological block model. This will help to improve the conceptual model of the area.
- Incorporate the improved geological map of the area into the conceptual model.
- Perform aquifer tests in various locations with the purpose to get a distribution of aquifer parameter values in different geological media.
- Update the groundwater flow model with the improved data, and perform a transient simulation of contaminant transport."

During initialisation of the WISH database, the more recent 1:250 000 geological map 3018 - Loeriesfontein, released by the South African Council for Geoscience (SACGS) in 2010, was incorporated.

3.3. HYDROCENSUS

3.3.1. Introduction

A hydrocensus was conducted across the area to generate an independent dataset with which historical data could be compared. General information was recorded that includes:

- Borehole ID;
- Co-ordinates;
- Surface conditions;
- Equipment installed;
- Borehole depth; and
- Groundwater levels.

Various samples for specific analysis were collected at previously determined locations, as explained more comprehensively in section 3.3.2.

3.3.2. Borehole Selection

A total of 69 boreholes were selected for this study. These boreholes are located on the VRWS and 12 farms within a 20 km radius of the Site. Some of these boreholes have more than one purpose and several different field work activities were performed on them. Criteria for establishing the locations of the 69 boreholes selected for the study (Figure 15) are summarised as follows:

- 36 boreholes were selected for analysis of their natural chemistry. Of these, 22 boreholes form part of the current monitoring program;
- 23 boreholes were selected for the radioisotope study;
- 58 boreholes were selected for the water level measurements; and
- 30 boreholes were selected for electrical conductivity (EC) profiling and 2 boreholes for aquifer testing.

3.3.3. Groundwater levels

Groundwater level measurements were made to determine any seasonal trends exhibited during the summer and winter monitoring excursions. Data will be compared to information from the existing data base to identify any discrepancies between the two datasets that could require additional measurements. The numerical flow model report (Van Blerk, 2008) indicates a correlation between surface topography and groundwater levels, which validates the assumption that groundwater flow directions will mimic topography gradients. Groundwater levels from this project will be used to evaluate this observation.

During both the construction and operational stages of the VRWS radioactive waste facility, groundwater levels were monitored as part of an environmental monitoring and sampling program. The environmental monitoring and sampling program began in 1985 where water levels were measured on a quarterly interval during a year.

During this investigation, a Solinst 107 TLC meter with tape guide and protective carry case as well as a Solinst Model 102 Water Level Meter, specially designed to measure groundwater levels in small diameter tubes and piezometers, were used to take groundwater level measurements. TLC indicates that Temperature, Level and Concentration (EC) can be measured with this specific apparatus.

Measuring was performed on two borehole types. Open boreholes mostly located on Site and boreholes fitted with windmills in the surrounding farming area. For this study, 58 boreholes were selected: 39 boreholes which are open and 19 boreholes which are fitted with windmills. Figure 16 shows groundwater levels being recorded by a student during field work excursions. Access holes had to be drilled through base plates of boreholes fitted with windmills (Figure 17).

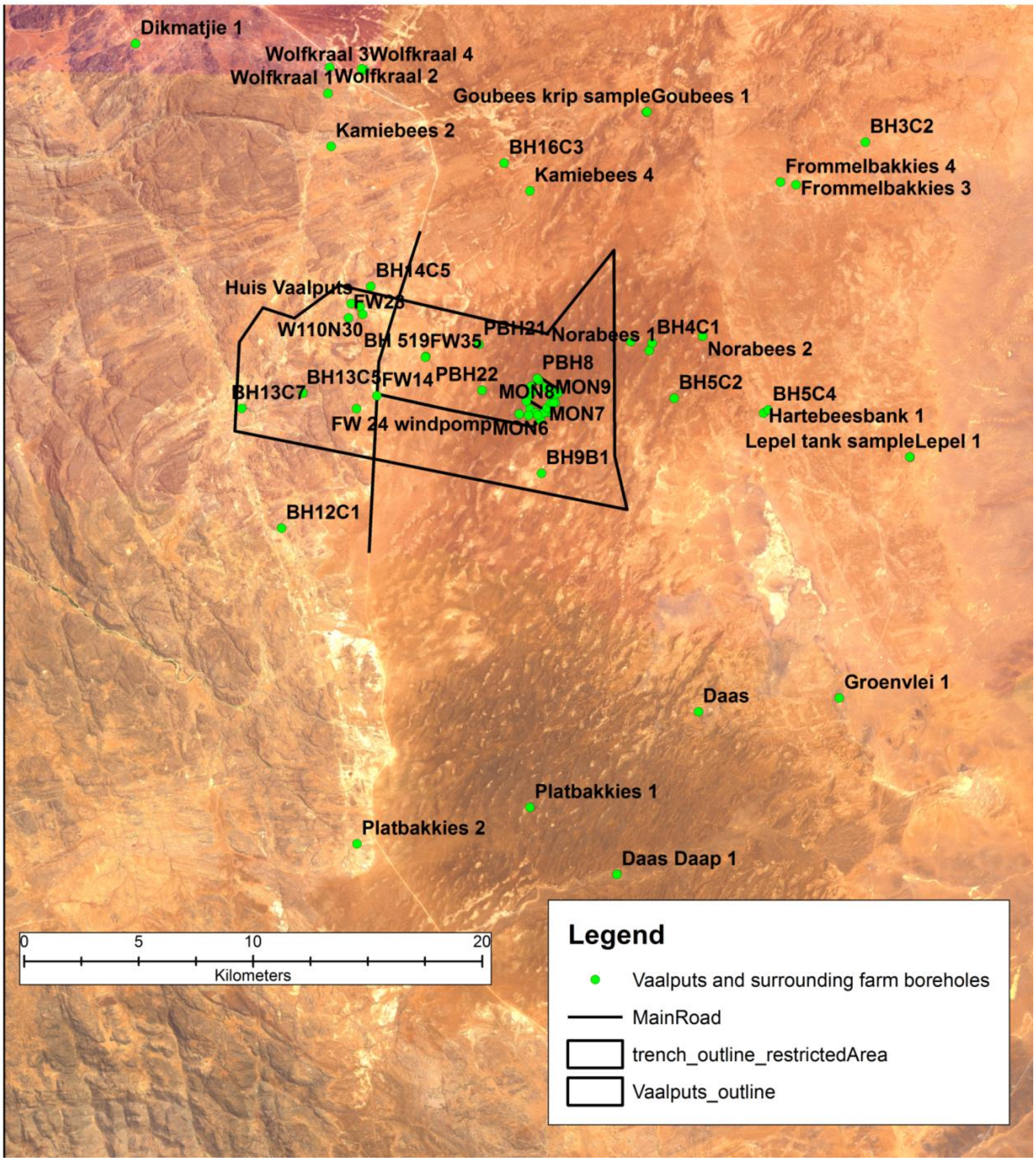

Figure 15: SPOT imagery overlain with the VRWS radioactive waste facility and borehole location.

Figure 16: Left, Student recording groundwater information using a TLC meter and right monitoring borehole in VRWS

Figure 17: Left, Drilling through a windmill base plate for access and right, Solinst Water Level Meter inserted through access hole to take measurements

3.3.4. EC profiling

Electrical conductivity (EC) profiling is a technique that is applied to identify zones of higher permeability within a borehole. By measuring EC concentrations over the depth of the borehole, a vertical profile can be constructed and compared to water strike recordings and aquifer test data. The reasoning behind EC profiling is that when a zone of higher permeability is intersected, e.g. a bedding plane fracture or a contact zone between sedimentary and intrusive rocks, the EC concentration will be lower due to the dilution effect caused by clean water entering and exiting the borehole at this location. Although this technique has been successfully applied at numerous locations, there are instances where dilution effects at the aforementioned zones of higher permeability could be masked by in-situ conditions.

Approximately 30 boreholes from the environmental monitoring and sampling program were used for profiling. Profiling was only conducted on open boreholes, using a YSI 600 XLM logger, which profiles and collects information up to 100 m depth (Figure 18). The logger records EC, pH and temperature at different depths below the static groundwater level. Recording of data is initialised once the logger is submerged and run down to depth and back to surface.

Figure 18: Left, Borehole FW1 at the VRWS Site being profiled using YSL 600 XLM logger which profiles up to 100 m depth and right, The YSI 600 XLM (logger) used for borehole profiling.

3.4. GROUNDWATER QUALITY

3.4.1. Sampling Procedures

Two sampling procedures were used for groundwater. By the first method, a disposable bailer (Figure 19) was inserted down an open borehole until it reached 5-10 m below the water table. The bailer was then pulled and its contents poured into a litre sample container. The sample was then labeled, and stored in a dry cool place. The bailer was rinsed with both soap water and clean water to avoid cross contamination. According to natural sampling instructions, a 1-litre sample must be bubble-free and filled to the brim to avoid any air interacting with the sample. The second form of sampling was performed using a bailer to sample groundwater at 80-100 m depths (Figure 19).

19 boreholes on the surrounding farms were sampled in this method. Boreholes with wind pumps were sampled by first turning the windmill blade manually and, once the electrical conductivity stabilises, the sample is then collected in a 1 litre container through an attached tap or pipe.

Figure 19: Left, Disposable plastic bailer used to sample groundwater 5-10m below the water table; right, Bailer used to sample groundwater 80 to 100 m deep.

Samples on open boreholes were collected by inserting a submersible pump into a borehole, then - at about 80-100 meters deep - a 25ℓ sample is collected. Additional 1ℓ samples were also collected for tritium, oxygen 18 and deuterium. Sampling of boreholes with windmills was done by manually turning the borehole blades and collecting a 25ℓ sample once the electrical conductivity is stabilised.

3.4.2. Natural chemistry

Groundwater natural chemistry is monitored to establish any change in chemical pattern. Reviewing of natural chemistry at the VRWS and selected surrounding farms has taken place during the construction and operational phases of the radioactive disposal waste facility in support of its environmental monitoring program. During early stages of sampling, according to the Necsa's database, the only measurements taken were of temperature, pH and EC. It is only from 1992 onwards that a more comprehensive analysis was done on groundwater in the study area.
Currently, at the VRWS and selected surrounding farms, a program monitoring and sampling is done biennially and includes:

- Cations - Ca^{2+}, Mg^{2+}, Na^{+} and K^{+};
- Anions - Cl^{-}, F^{-}, SO_4^{2-}, Si^{-} and NO_3^{-};

- Trace elements - Fe, Mn, U, Al; and
- Physical determinants - pH, EC and temperature.

3.4.2.1. Chemical Diagrams, Graphics and Maps

Geochemistry interpretation tools like Piper, Stiff, expanded Durov diagrams and timeline graphs were produced, using WISH. All maps were developed using ArcGIS software from ESRI. Borehole logs and construction logs were stored and obtained from the Necsa database, displayed and updated using WISH software. All historical groundwater levels and natural chemistry data were obtained from the existing Necsa database under stewardship of Necsa's SHEQ department.

3.4.2.1.1. Piper Diagrams

Piper diagrams allow for both anion as well as cation compositions to be represented on a single graph. In a Piper diagram, ion concentrations are plotted as percentages with each point representing a chemical analysis. The Piper diagram, therefore, has the potential to represent a large number of analyses and is convenient for showing the mixing of two waters from different sources. Piper diagrams are an example of water quality diagrams that are probably the most frequently used today. These diagrams are also useful for visually describing the differences in major ion chemistry in groundwater flow systems. Piper diagrams also conveniently reveal similarities and differences among groundwater samples. Those samples with similar qualities will tend to plot together as groups.

3.4.2.1.2. Expanded Durov diagrams

An Expanded Durov Diagram is similar to a Piper Diagram in that relative percentages of anions and cations are plotted, namely three for the anions and three for the cations. An Expanded Durov Diagram consists of nine plots for anions and cations.

3.4.2.1.3. Stiff diagrams

Stiff diagrams are plotted for individual samples as a method of graphically comparing the concentrations of selected anions and cations for several individual samples. The shape formed by the Stiff diagrams will quickly identify samples that have similar compositions and are particularly useful when used as map symbols to show the geographic location of different water facies. In a Stiff diagram, data is plotted as a polygon, with cations to the left and anions to the right. Stiff diagrams are good for examining spatial relationships, because they can be readily plotted on a map.

3.4.2.1.4. Timeline Graphs

Timeline graphs are valuable visual representations of long term data and trends or inconsistencies can be readily identified. Decisions can then be made on whether to collect fresh samples for analysis or the laboratory can be asked to analyse the same sample again.

Different parameters that can influence groundwater levels and/or quality can be plotted on the same graph and interdependencies can be identified. In the case of recharge, it is also very helpful if the lag-time between rainfall events and groundwater response can be identified.

3.4.3. Isotopes

According to the IAEA, stable and radioactive isotope techniques are cost effective tools in groundwater investigation and assessment. Stable isotopes have been used for decades in hydrological systems to understand the groundwater systems. Most frequently used environmental isotopes include heavy elements of water molecules, hydrogen (^2H, and ^3H), oxygen (^{18}O) and the element carbon (^{14}C) occurring in groundwater as constituents of dissolved inorganic and organic compounds. Radioisotopes are commonly used to investigate the sources and mechanisms of groundwater recharge, groundwater age and dynamic interconnections between aquifers, interaction between surface water and groundwater and groundwater salinisation. In a semi-arid environment like the VRWS Site and surrounding farms, according to the IAEA, isotope techniques are the only tools which can be used to identify and evaluate present day groundwater recharge. Two radioisotope studies have been performed in the study area, which yielded questionable results. The current radioisotope together with recharge studies will address some of the uncertainties raised about the recharge of the study area. Four stable isotopes will be used: ^{14}C, ^{-2}H, ^{-3}H, and ^{18}O.

3.4.3.1. Radio isotopes

3.4.3.1.1. Tritium

3.4.3.1.1.1. Preparation and Analysis

The preparations of the samples for tritium analysis were carried out according to the method described by Verhagen, Butler and Mabitsela, (2004). There are three phases for the tritium analysis:

- A distillation process,
- An electrolysis process and
- A counting stage.

Distillation process

A distillation flask is first rinsed with sample water to be discarded before pouring the 500ml sample (Figure 20). Samples should be below atmospheric pressure during the distillation process and the temperature should be set lower than the room temperature. For the second distillation step (vacuum distillation), the same measures and precautions apply as with the first step. A good vacuum within the distillation unit is required and the vacuum distillation flasks are heated with gas-flames. Immediately after completion of distillation, the volumetric flask is rinsed with a small amount of distilled sample water, which is discarded.

Figure 20: Tritium first distillation process; Tritium electrolysis phase

Electrolysis process

After the distillation process, a volume of the 500 ml of sample water is mixed with 4 g sodium peroxide (Na_2O_2 is used as a catalyst) and introduced into the electrolytic cell (Figure 20). A direct current of 10-15 Amperes (A) at 12 Volts (V) is passed through the cell, which is continuously cooled as the process generates heat. After 5-6 days, the electrolyte volume is reduced to around 20ml. The volume reduction of about 25 times produces a corresponding tritium enrichment factor of about 20. Samples of standard, known tritium concentration (spikes) are run in one cell of each batch to determine the enrichment attained. During the electrolysis phase, light-hydrogen and oxygen are released and the heavy tritium isotope remains.

Counting stage

For liquid scintillation counting, the enriched water sample is directly distilled from the now highly concentrated solution. 10 ml of the distilled water is mixed with an 11 ml Ultima Gold LLT LSC cocktail in a counting vial. The sample is then placed in a Packard Tri-Carb 2,770 TR/SL Low-Level Liquid Scintillation Analyser and counted for 2 to 3 cycles of 4 hours each. The detection limit is 0.2 TU for enriched samples (Figure 21).

Figure 21: Distilled samples mixed with 10ml of Ultima Gold and inserted in a Liquid Scintillation Analyser

3.4.3.1.2. ^{14}C

3.4.3.1.2.1. ^{14}C Precipitation process and analysis

As mentioned before, radioisotope samples were collected at the VRWS and surrounding farms. 23 boreholes were selected for radioisotope studies; 9 are located on the VRWS and 14 on the surrounding farms. These samples were taken using 25ℓ containers for 14C and 1ℓ containers for tritium, oxygen 18 and deuterium. The following summary explains the custody and handling of the 14C samples:

- All 25ℓ containers were transported to iThemba Laboratories in Johannesburg for the carbon precipitation and analysis process;
- The preparation process for Carbon 14 was performed on each 25ℓ drum sample according to K.Froehlich procedure, IAEA;
    - A dash of phenolphthalein solution was poured into the sample after which about 200 ml of cleaned NaOH solution and about 200 g of BaCl2 solution was added to the sample;
    - A 1½ hour precipitation process occurs. The precipitate settles at the bottom of the drum and excess water is decanted;
    - The precipitate and remaining water are then bottled, reduced to approximately 1ℓ for analysis. Figure 24, shows the water samples in 25ℓblue plastic drum containers; the second stage are samples mixed with solution for the precipitation phase and the third stage are the precipitants in 1 litre bottles.



Figure 22: 22 of total 25ℓ containers with groundwater samples; precipitation phase; and completed precipitate solution in 1ℓ bottles

Preparation of samples for carbon 14 analysis was carried out according to the method described by Verhagen, Butler and Mabitsela, (2004):

- Carbon is extracted as carbon dioxide (CO2), which is released from the sample by adding orthophosphoric acid (H3PO4) under vacuum conditions;
- Carbon dioxide is directed through three dry-ice traps and then held in a liquid nitrogen trap (Figure 22). The liquid nitrogen trap is then isolated from the dry ice traps and depressurised to 2-3 mmHg pressure. A 1ℓ round-bottomed flask is also brought down to this vacuum pressure;
- The litre of CO2 is poured from the flask into a 10 ml ampoule. Once the mercury level reaches the original position on the manometer (between 62.0 and 62.7cm), the flask is closed. The glass vial containing Carbo-Sorb is placed in water to cool during the absorption of CO2, as this is an exothermic reaction;
- The 10ml ampoule is removed from the liquid nitrogen, releasing the CO2 into the Carbo-Sorb. The vial containing the Carbo-Sorb must be vigorously shaken in order for the CO2 to be absorbed;
- The glass vial is removed from the vacuum system and 10 ml Permafluor is added (Figure 22). The vial is closed and shaken and left in the LSC for 2-3 weeks before counting to allow for any generated radon to decay completely.

Figure 23:(a) adding (H_3PO_4) to sample, (b) carbon dioxide is directed through three dry-ice traps then held in a liquid nitrogen trap; (c) Vial removed from the vacuum system and 10ml Permafluor is added.

3.4.3.1.2.2. Carbon 14 conversion from Percent Mode Carbon (pmc) to Groundwater Age

For the Carbon 14 conversion from pmc to groundwater age in years, the equation used was postulated by K.Froehlich:

$$t = (5730/ln2)\ ln(C_{nd}/C) \qquad \text{(Equation 1)}$$

Where t= age in years

C is the measured ^{14}C concentration in (pmc)

Cnd is the ^{14}C concentration which should be expected as a result of all processes except radioactive decay.

$$C_{nd} = qC_0 \qquad \text{(Equation 2)}$$

Where C0 is the ^{14}C concentration at atmospheric (soil or rock) CO_2 and q is the adjustment factor, often called dilution factor. Cnd or q can only be determined if the reaction details for the evolution of a groundwater sample are known.

At the VRWS and surrounding farms within the 20 km radius, q values for this calculation are both of a crystalline rock (0.90 - 1.00) and sediments with fine grained carbonate (0.75 - 0.90). Results will be discussed in later chapters.

3.4.3.2. Stable isotopes

3.4.3.2.1. ^{18}O and Deuterium Preparation and Analysis

The preparation of samples for the deuterium and oxygen 18 analyses was carried out according to the method described by Verhagen, Butler and Mabitsela M (2004):

- From the 1litre groundwater sample taken for ^{18}O, deuterium and tritium, 200 µl are poured into vials using a micro-calibrated pipette;
- A platinum-stick catalyst is inserted into the vial (Figure 24);
- A calibration standard against which samples are compared is inserted at the beginning, middle and end of the process line. Any temperature changes on the machine due to drift are monitored during the calibration stage. Temperature must be kept constant to ensure accuracy. Calibration is against Standard Mean Ocean Water (SMOW). Samples are inserted into the feed tray of the Delta V Advantage Isotope Ratio MS;
- Equilibration is done at 27°C (~5°C above room temperature) and the room

temperature should be kept at 22°C due to hydrogen measurements, which are temperature dependent; and

- The sample is flushed with 2% hydrogen in a helium (He) mixture.

Figure 24: ^{18}O and deuterium preparation: vial with 200 µl sample and platinum stick. Delta V Advantage Isotope Ratio MS used for calibration, equilibrium and flashing of samples.

3.5. RECHARGE

When one considers groundwater, recharge is the single most important parameter that needs to be determined. Just by making use of a very basic water balance, it must be evident that abstraction from a resource cannot exceed recharge to it. Depending on the information available, different methods are available to determine recharge in a specific region. Unfortunately infrastructure for climatic information measurements has been declining over the past 3 decades. These were the 3 methods used in this study to determine recharge:

- Chloride Mass Balance method and,
- Radioisotopes (^{14}C, ^{3}H, ^{2}H and ^{18}O)

The abovementioned methods will be compared to groundwater ages calculated after ^{14}C analysis as well as with Tritium concentrations in order to identify definite trends or information gaps.

3.6. AQUIFER PARAMETER ESTIMATION

3.6.1. Slug tests

At the VRWS, four boreholes were slug tested. Due to restrictions specified by Necsa concerning pump tests, it was decided to conduct slug tests to establish a first estimate of localised parameters. Slug tests are a commonly used field technique for obtaining preliminary estimates of possible aquifer parameters (James and Butler, 2002). It is most commonly used to determine whether it would be useful to conduct further aquifer tests on a borehole if no information regarding blow yield or historical capacity is available. Information from slug tests must be regarded as being representative of aquifer reaction for a very small radius surrounding the borehole.

3.6.2. Aquifer tests

Two pump tests were then conducted on selected boreholes West of the VRWS. These boreholes were pump tested at 0.5 ℓ/s for approximately 14 minutes. A constant rate test is performed by pumping a borehole at a constant rate and measuring the drawdown at different time intervals in order to estimate aquifer storativity and transmissivity.

Although the data set is limited, it will be analysed and interpreted in chapter 5, using an appropriate method. The focus will primarily be on interpreting the recovery data.

Figure 25: A. The submersible pump used for the constant rate test; B. The pump test in progress at borehole FW 28

3.7. CONCEPTUAL MODEL

As previously mentioned, recommendations were made regarding the inclusion of more recent geological information. Some concerns about the accuracy of recharge estimates used during previous studies were also highlighted.

An attempt will be made to update the previous conceptual model of the groundwater regime at the VRWS with regard to the aforementioned inadequacies. This can be considered as important, as management decisions are based upon the outcome of this model.

4. GEOLOGICAL REASSESSMENT

4.1. INTRODUCTION

From a geological perspective, the geological assessment can be sub-divided by means of scale:

- A regional scale, which will assist in understanding hydrogeological concepts across larger temporal and spatial intervals; and
- A Site-specific scale, which will assist in assessing more immediate risks, associated with management of the VRWS trenches.

On a regional scale level, the area of interest surrounding the VRWS includes the NMP, Karoo Supergroup and the Nama and Vanrhynsdorp Groups mentioned earlier in section 2.6. It is evident from Figure 26 and Figure 27 that, on an even larger scale, the geology is complex with numerous discontinuities.

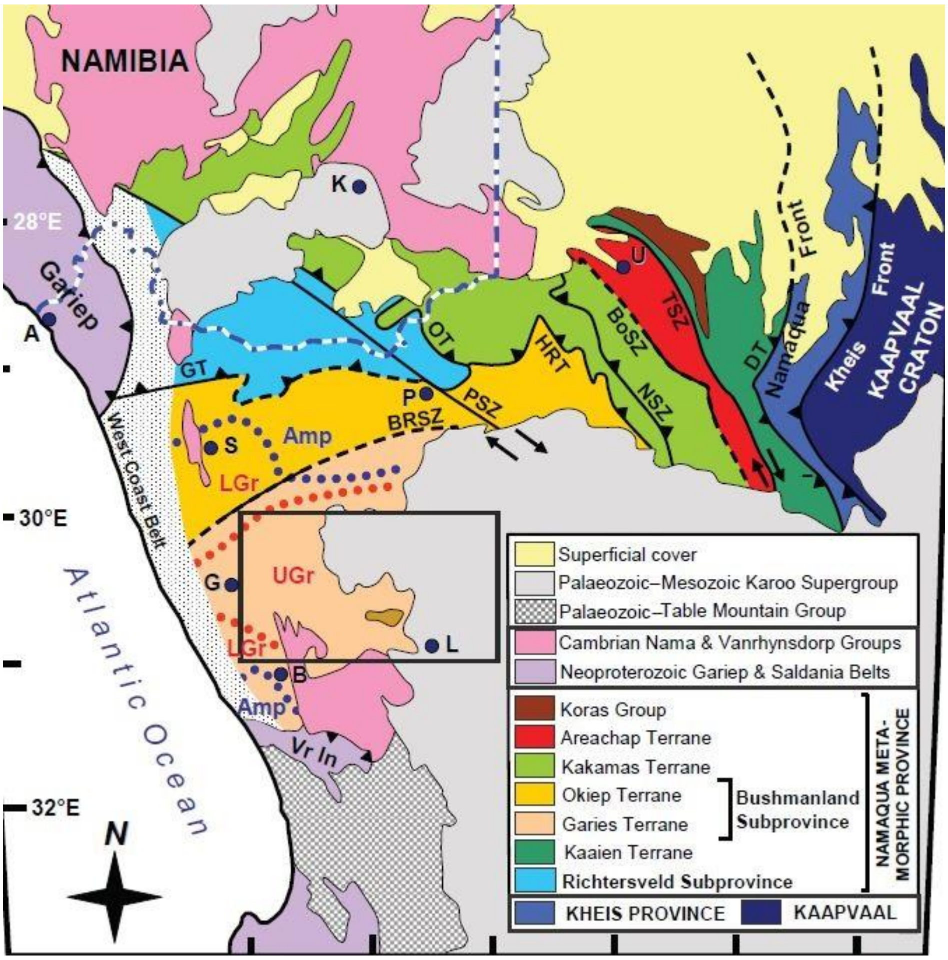

Figure 26 : A tectonostratigraphic subdivision of the Namaqua Metamorphic Province. Modified after Macey et al. (2011) - Rectangle shows the location of sheet 3018 Loeriesfontein

GT: Groothoek Thrust

OT: Onseepkans Thrust

PFSZ: Pofadder Shear Zone

SZ: Vogelstruislaagte Shear Zone

BPSZ: Brypaal Shear Zone

BRT: Hartbeest River Thrust

BoSZ: Bovenrug Shear Zone

BBSZ: Brakbos Shear Zone

DT: Dabep Thrust

Place names:

A = Alexander Bay; **B** = Bitterfontein; **G** = Garies **S** = Springbok ; **K** = Karasburg; **L** = Loeriesfontein; **P** = Pofadder; ; **U** = Upington

Metamorphic isograds after Waters (1986):

UGr = Upper granulite facies

LGr = Lower granulite facies

Amp = Amphibolite facies, Stippled region along the coast represents the **West Coast Belt**, a zone of tectonic reworking of the NMP by the **Neoproterozoic Pan African orogeny**, **Vr In**= Vredendal Inlier of the Gariep Belt.

Terrane boundaries of the NMP

Figure 27: Additional legend for a tectonostratigraphic subdivision of the Namaqua Metamorphic Province

On a Site-specific scale, lithostratigraphy or rock stratigraphy, where physical and petrographic properties of rocks are used to organise sub-surface geology into units, will be very important, as it can contribute to understanding local characteristics of parent rock formations close to surface. This will include both the consolidated, deeper lying part as well as any overlying unconsolidated overburden. A summary of the history of the Vaalputs geology is presented in Table 4, as interpreted by Andreoli and van Blerk in 2006.

Table 4: A summary of the most recent geological interpretation of the Vaalputs stratigraphic history (Van Blerk, 2008)

Group (Formation)	Lithology	Age (Ma)	Geological Process	Era (Epoch)
Kalahari (Gordonia)	Red unconsolidated Sand	0.013	Wind winnowing	(Late Pleistocene)
	Ferruginous red sand, hard		Wind winnowing, occasional flooding	Pleistocene
	Calcrete (I, II, III)	0.070 - > 0.4	Infiltration, evaporation	Plio(?)-Pleistocene
Unconformity				Late Tertiary?
Vaalputs*	Conglomerate, sandstone Feldspathic gritty greywacke Feldspathic pebbly greywacke	5 - 25	Fluvial; Unchannelized floodouts	Mid Tertiary
Unconformity	Erosion, kaolin-silcrete mesas	~70 - 38	Warm & humid climate	Latest Cretaceous-early Tertiary
Bushmanland-Namaqualand olivine melilitite province	Melilitite, kimberlite, carbonatite	67	Volcanic diatremes	Latest Cretaceous
Dasdap*	Cross-bedded arkosic grit Conglomerate	~70 - 38	Fluvial	Early Tertiary-Late Cretaceous
Unconformity				Cretaceous
Karoo	Dolerite, basalt	~180	Hypoabyssal,volcanic	Jurassic
Karoo (Dwyka)	Diamictite	300	Glacial	Permian
Unconformity				Neoproterozoic
Southern Megacrystic Suite	Gneissic granite, charnockite	1000 - 1070	Basement: Namaquan orogeny & metamorphic complex	Mesoproterozoic
Garies	Supracrustal granulites	1170		

4.2. GEOLOGICAL MAP 3018 – LOERIESFONTEIN

The CGSSA printed an updated geological map with its explanation booklet in 2011. The authors mapped and interpreted an area between longitude 18° and 20° East and latitude 30° and 31° South. The map covers parts of the Northern Cape Province as well as the Western Cape Province. Magisterial districts of note are Calvinia, Vanrhynsdorp and Namaqualand.

The previous work done by Van Blerk on the hydrogeology of the VRWS in 2006 and in 2008, although much earlier than the 2011 Loeriesfontein map, has in essence captured similar geological aspects in terms of lithostratigraphy as well as of tectonics and folding, thrusting and fracturing. From a purely hydrogeological perspective, it would be very difficult to add any new geological components to the conceptual model proposed by Van Blerk in 2008 when developing the saturated groundwater flow model. This would be mostly because of the fact that the conceptual model is a simplified representation of the groundwater flow regime, which - in geological terms - allows a small margin for improvement as most major structural and lithological characteristics that will influence groundwater related phenomena have already been identified. Any more recent geological information would be on a scale small enough that it will not influence the output from the constructed numerical flow model.

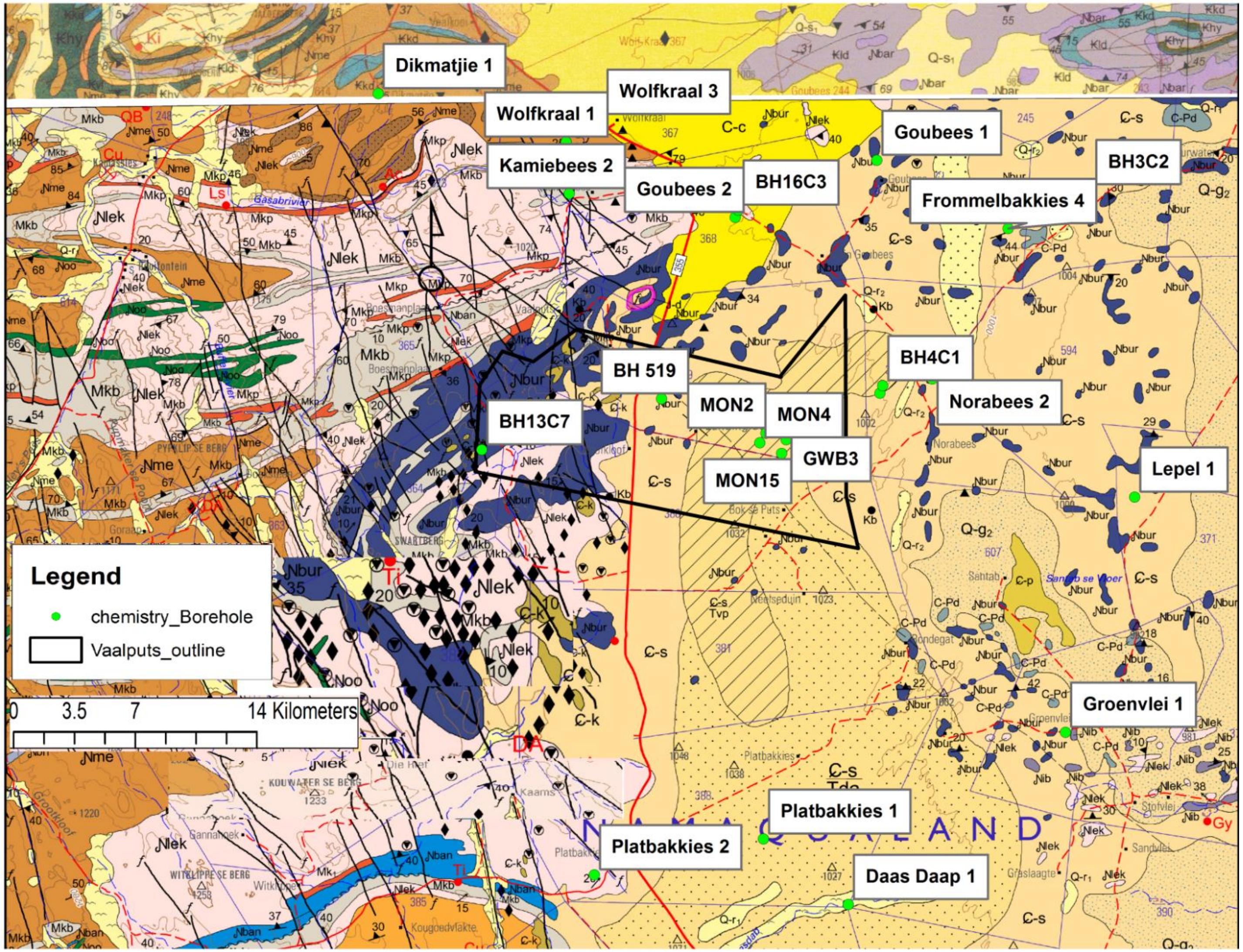

Figure 28: VRWS outline and chemistry sampled boreholes superimposed on the most recent 1:250,000 geological map –3018 Loeriesfontein (legend on Appendix D)

4.3. TECTONIC SUBDIVISIONS

The Namaqualand metamorphic complex attained high grade metamorphism during the Namaqualand event. The main division in the Namaqualand metamorphic complex according to Kroner and Blignaut (1976) are:

- The Richtersveld Subprovince;
- The Bushmanland Subprovince; and
- The Gordonia Subprovince.

Other tectonic subdivisions in the area of note are:

- The Kheis Subprovince;
- The West Coast Belt; and
- Surficial deposits of the Gariep Belt, Nama Group, and Karoo Supergroup.

The Kheis Subprovince underlies the Namaqua province in the East (Figure 29) with the eastern boundary defined by the cratonic margin or Brakbos fault. The Bushmanland Subprovince is located to the East of the West Coast belt, to the West of the Pofadder shear zone and to the South of the Orange River (Figure 29) and is divided into Okiep and Bushmanland groups, which have common lithologies (Joubert 1986a). The gross structural trend in the Bushmanland Subprovince is East-West entering the Gordonia Subprovince, swings North-East due to the dextral movement along the Pofadder shear zone. The Bushmanland Subprovince can be further subdivided into terranes separated by large scale strike-slip shear zones, the Putsburg shear zone subdivides the Bushmanland Subprovince into the Okiep terrane in the North and the Garies terrain.

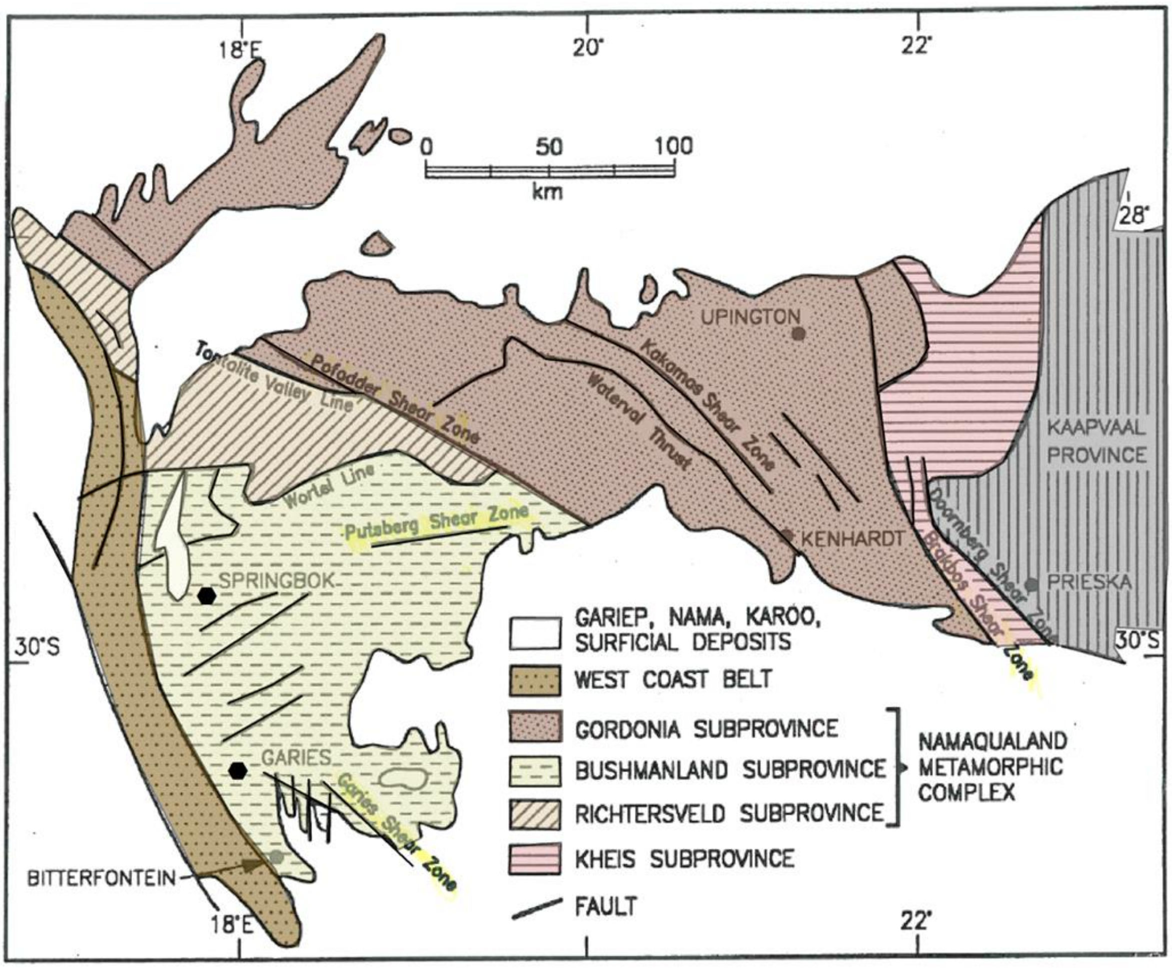

Figure 29: Namaqualand-Bushmanland tectonic subdivisions and structures (adapted after Joubert 1986a)

4.3.1. Basement complex

The basement granitic rock formation in the Vaalputs Site is unconformable, overlain by an unconsolidated sedimentary package that may reach depths of approximately 15 meters below the surface (Brandt et al., 2003, 2005). The lower zone of the transition, from the underlying basement granite-gneiss to the sedimentary units, is a marked palaeo-weathered basement which may grade over two meters. The upper zone of the transition, from the basement to the sediment lying above, is usually silicified and abrupt, occurring within half a meter (Brandt, 2006). The lower zone of the Vaalputs formation has been interpreted as being depoSited from channelised flood-outs, whereas the upper zone is thought to indicate fluvial origin under wet conditions. Overlying the Vaalputs formation are dorbank horizons and occasionally calcareous materials, which are usually over a metre thick.

4.3.1.1. Kalahari-Gordonia formation

Brandt, (1998) noted that red sands are predominantly Fe-oxide coated quartz grains and possess a heavy mineral content similar to the basement rocks and clays including smectite kaolinite and illite.

4.3.1.2. Vaalputs Formation

The Vaalputs formation consists of sediments that accumulate in the so-called Vaalputs basin, the origin of which may be tectonic (Brandt 2005). These sediments are classified as clayish feldspathic greywacke (Andreoli et al., 2006a) and are exposed in the waste trenches (Figure 30). The succession contains numerous calcrete horizons consisting of distinct bands or scattered nodules. Vaalputs sediments are typical pale olive-green to light brown very poorly sorted (McCarthy et al., 1985).

4.3.1.3. Dasdap Formation

The Dasdap Formation is characterised by kaolinised, locally silicified, arenaceous sediments exposed within the Dasdap drainage ~20 km South of the Vaalputs Site where they directly overlie the palaeo-weathered basement (McCarthy et al., 1985; Brandt 1998 and Brandt et al,. 2003). Levin 1988 identified the Dasdap formation on the farm Banke outcrops, referred to as Kookoppe Dasdap drainage, on the farm Burton Puts. The Dasdap formation also intersects the domestic waste trenches slightly South of the main facility ~100m (Logue 2009).

The conglomerate at Kookoppe is typically oligomictic and clast supported with a maximum thickness of 1-2 m. The upper gritty layer has a sharp contact with the lower conglomerate and, when fully developed, has a thickness of up to 4 m in northern outcrops (Logue 2009). The sediments may be red in color, due to the formation of Fe-oxide nodule development. The Dasdap Formation can be divided into a kaolinised lower section and silicified upper section. According to Brandt 1998 and Brandt et al (2003), this formation likely represents an immature, alluvial fan deposit due to high clay and feldspar content, angularity of grains and poor sorting (Figure 30).

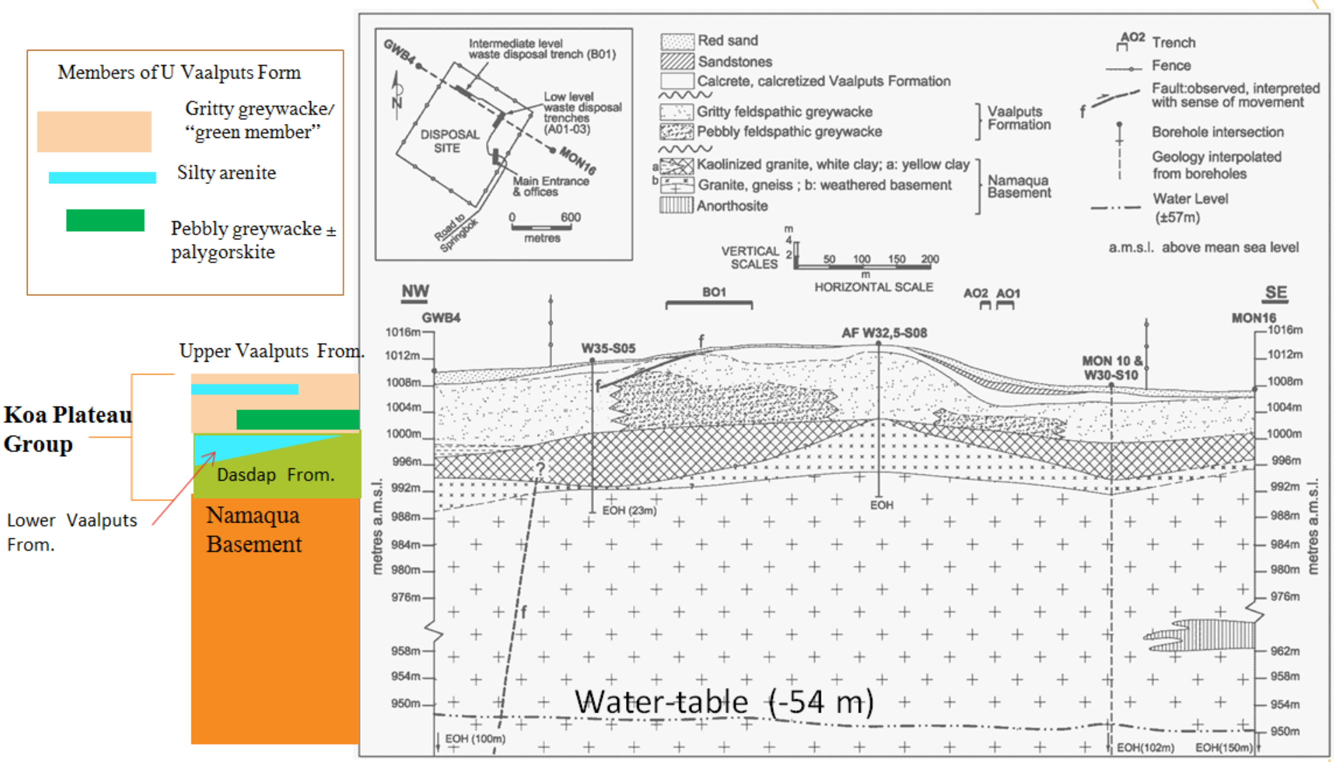

Figure 30: North West to South East cross section of Trench AO2 in the VRWF showing the location of Vaalputs and the Dasdap formation.

4.3.2. Borehole geology

Most of the boreholes pass through layers of surficial material consisting of loose sand (1 m), calcrete (to 5 m), 15 to 20 m of fluvial brown clayey grit, and 10 to 15 m of white kimberlitic clay. Below this, the basement rocks of Norabees granite and related rocks are found with occasional vertical and sub-horizontal faulting. The basement rocks of the Vaalputs area include the Namaqualand Metamorphic Complex of Proterozoic age, the Karoo Sequence of Permo-Triassic age and kimberlitic and related intrusions of Tertiary age. Further explanation of the rocks is found in Moore et al (1987).
MON9, MON10, MON12, MON14, MON15 (Figure 31) were drilled on the granite-gneiss of the Koperberg Suite. Boreholes MON1 and MON2 were also drilled on the granite gneiss. EM8, FW35 and PBH22 were drilled on the granite gneiss overlain by the Vaalputs formation (Figure 32). Borehole BH13C5 was drilled on Burtons Puts granite of the Spektakel Suite, BH3C2 and BH4C1 on the Vaalputs formation, BH13C7 on the megacrystic granite biotite, and BH519 was drilled on the Vaalputs formation. Most of the boreholes on the surrounding farms were drilled on the granite-gneiss overlain by the Vaalputs formation. Borehole Platbakkies 2 was drilled on the Lekkerdrink gneiss, Platbakkies 1 on the Dasdap formation, Frummelbakkies 2 on the Diamictite (Tillite), Lepel 1 and Kamiebees 1 were drilled on the grey migmatitic biotite gneiss, Wolfkraal 3 on granite gneiss overlain by calcrete and Wolfkraal 1 on the Mesklip gneiss. See

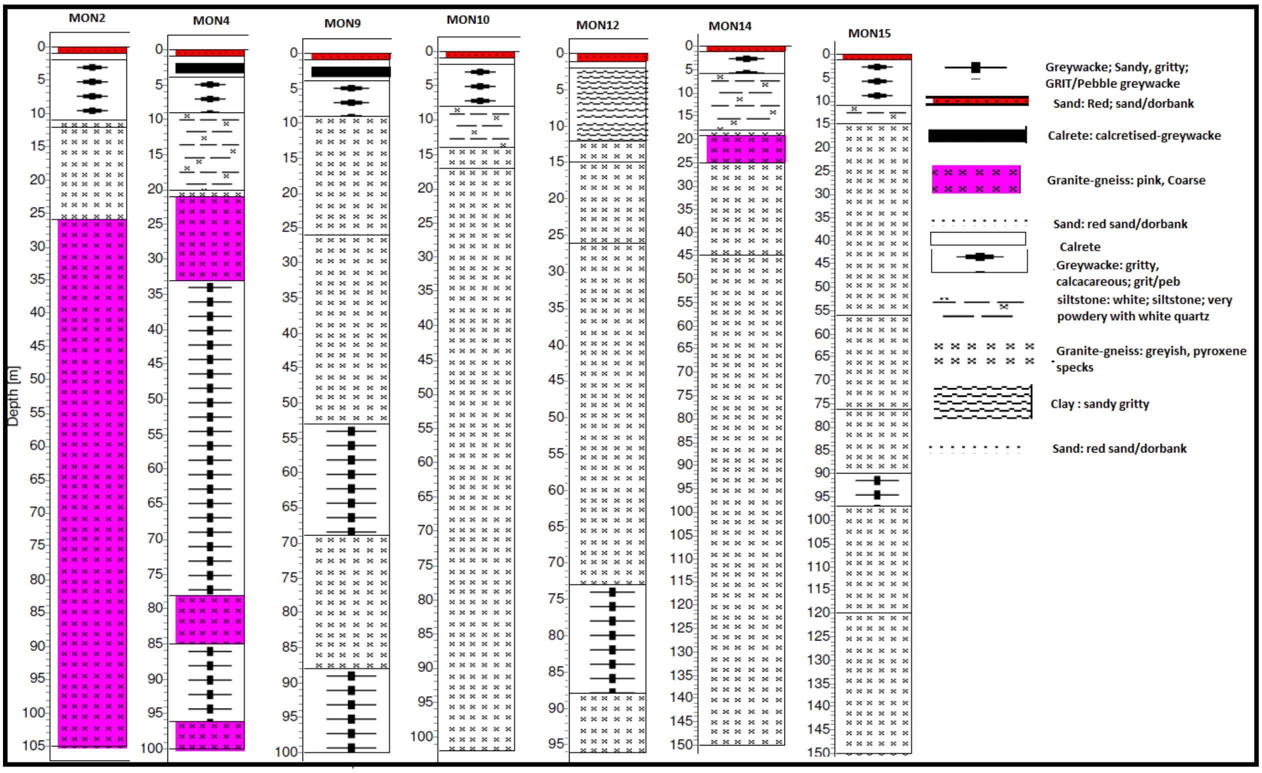

Figure 31: Borehole logs for borehole MON2, MON4, MON9, MON10, MON14, MON15 located on VRWS (Figure 33 for locality of these boreholes)

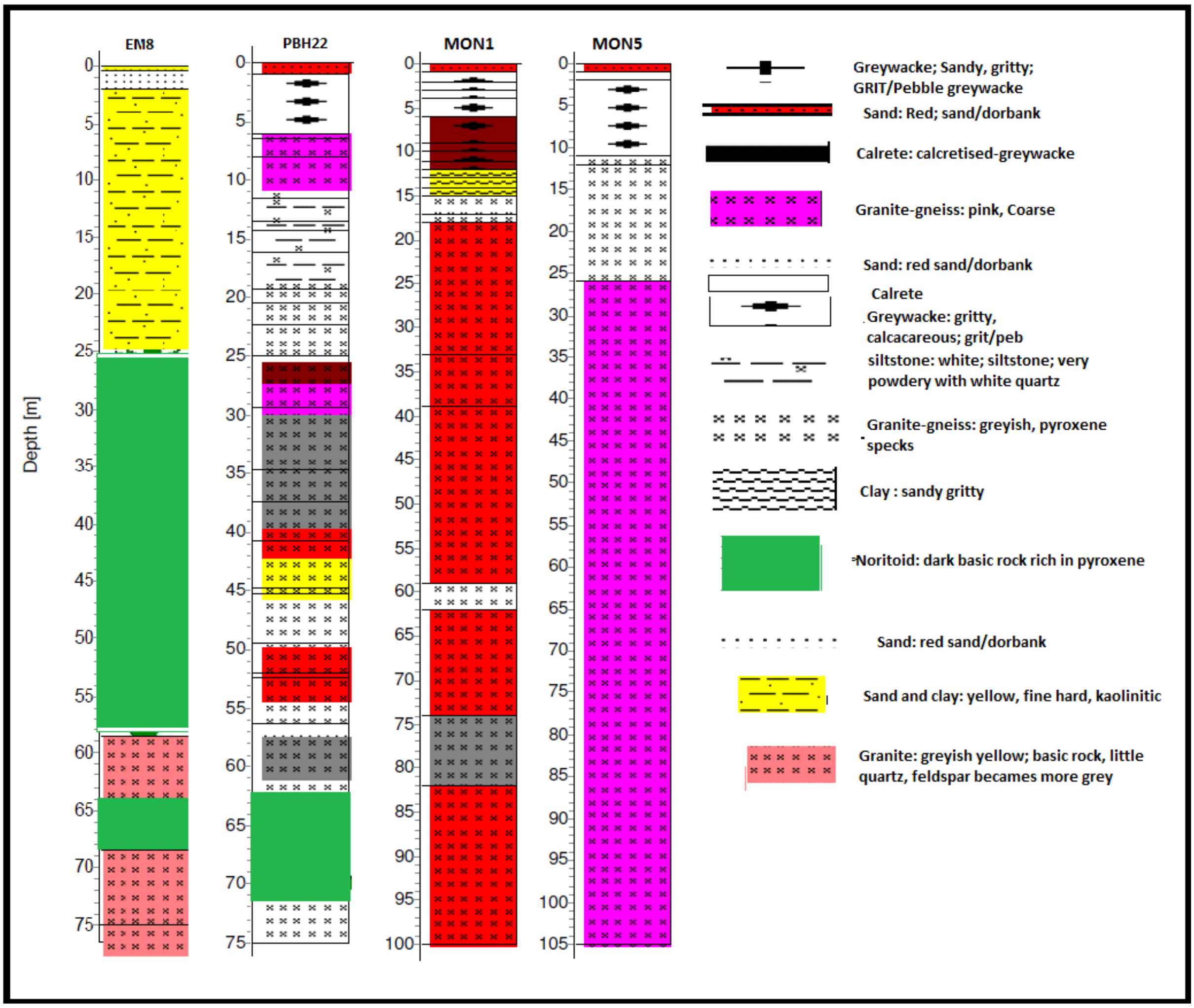

Figure 32: Borehole logs for EM8, PBH22, MON1 and MON5 located on VRWS (Figure 33 for locality of these boreholes)

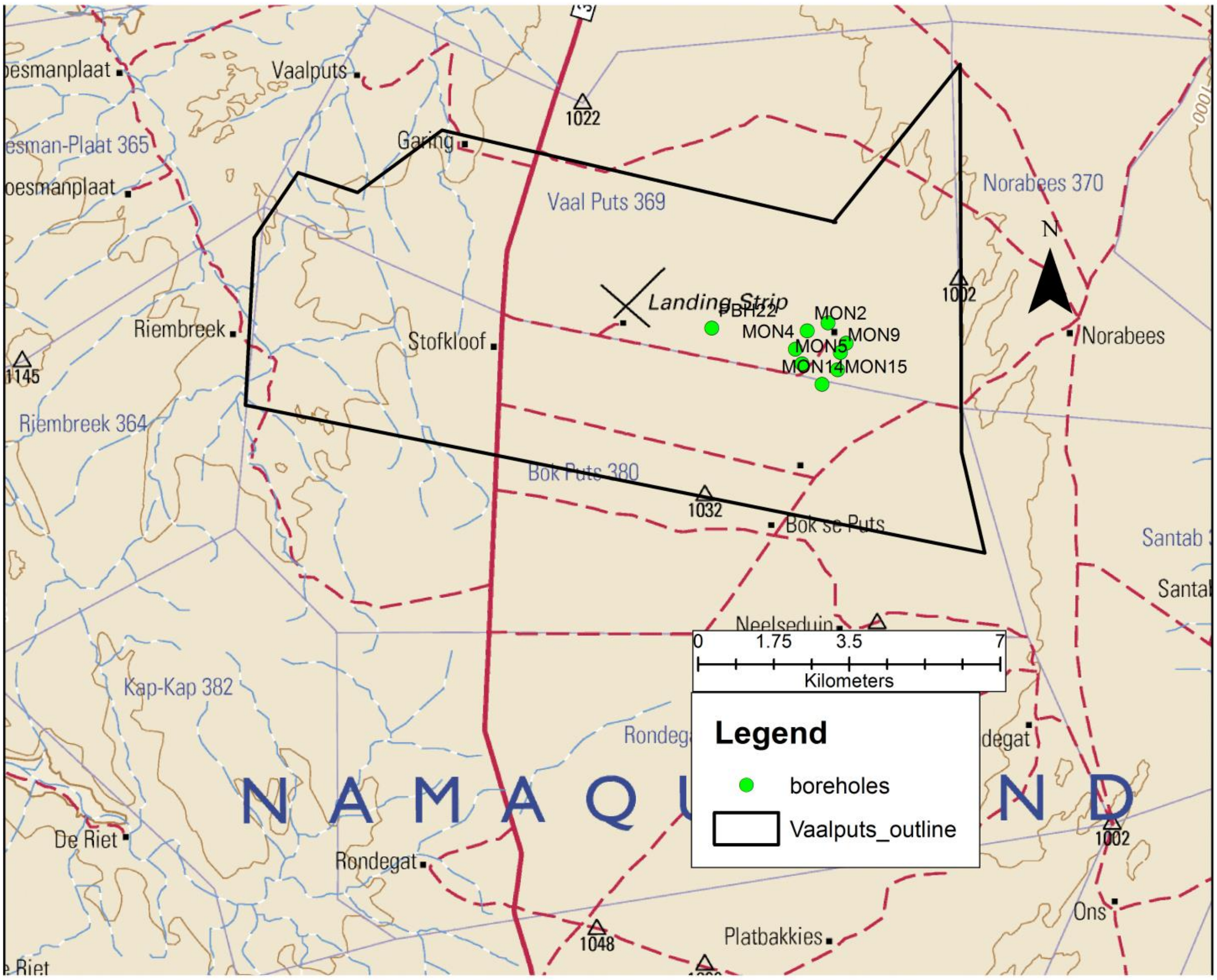

Figure 33: shows borehole location overlain by a 1:250 0000 Topocadastral Map produced by CGS

4.3.3. Structural and tectonic history

According to Andersen (1992), Mouri, (2003) and Andreoli 2006, about one billion years ago, the Namaqualand region experienced a protracted period of high temperature deformation that involved collision, crustal shortening and thrusting of tectonic units. In-situ radioactivity was the cause of unusually high metamorphic temperatures. The causes of the thrusting are less clear, yet probably traceable to the collision of smaller continental fragments and assemblage of the supercontinent called Rodinia (Andersen 1992, Mouri 2003, Andreoli 2006). Despite the magnitude of this process, most of the joints between these crustal blocks have been intensely recrystallized.

The large-scale neotectonic structural grain of Namaqualand is characterized by faults that strike N/NNW or NW (Figure 35, Viola, 2005). The age of these faults is constrained by age of the rocks which they dissect, namely late Mesozoic and Cenozoic arenaceous sediments (Brandt 1998, Brandt et al., 2003). In Figure 15, an uplift axis that is reconstructed on the basis of geomorphic analysis is evident. The Griqualand-Transvaal axis is almost perpendicular to the horizontal depression stress, possible suggesting a causative link between creation and the current stress field (Viola, 2005).

The age of the fault can only be established on the basis of relative criteria, because it must postdate the age of the calcrete, ferricrete and the associated dune forms. The age of these formations is not absolutely certain, yet the calcrete is tentatively related to the regionally extensive Miocene (5.2-22.3 Ma) calcrete horizon described elsewhere on the Bushmanland plateau (GEA-1440). The possibility of a neotectonic, Pliocene (5.2 - 1.64 Ma) or younger age for the fault is a clear possibility. Current geological literature, in fact, reports that widespread tectonic reactivation affected large tracts of southern Africa (including the Bushmanland plateau) during the Pliocene (GEA-1440).

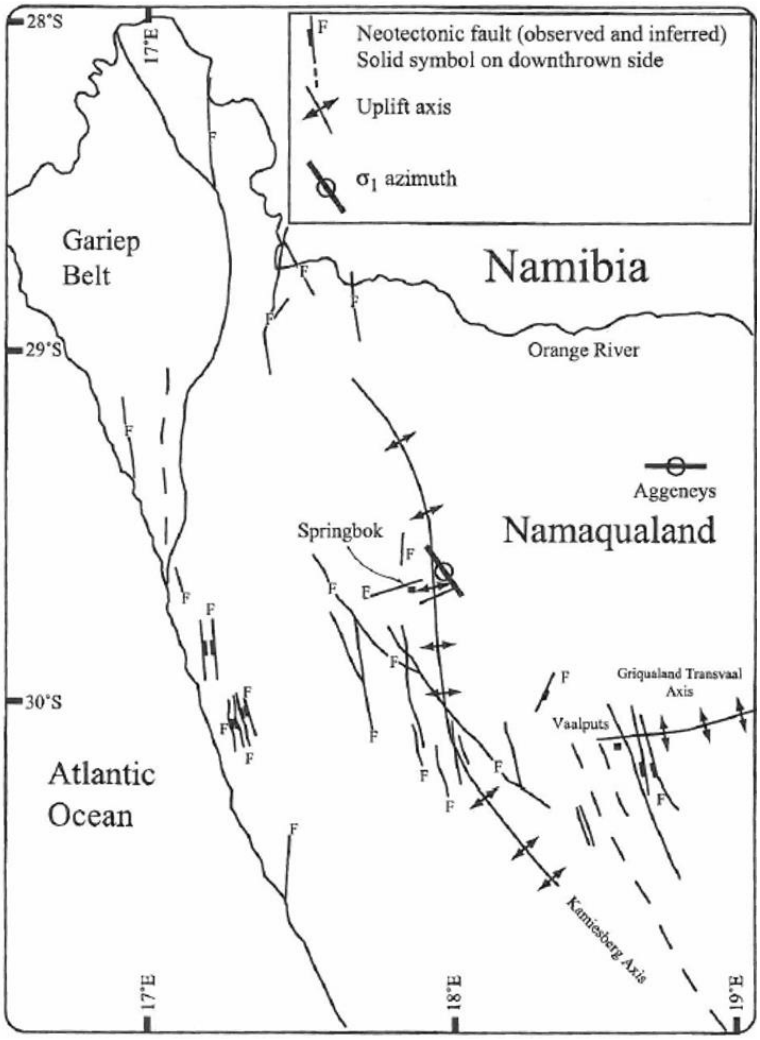

Figure 34: Neo-tectonic lineaments map of Namaqualand (adapted after Viola 2005)

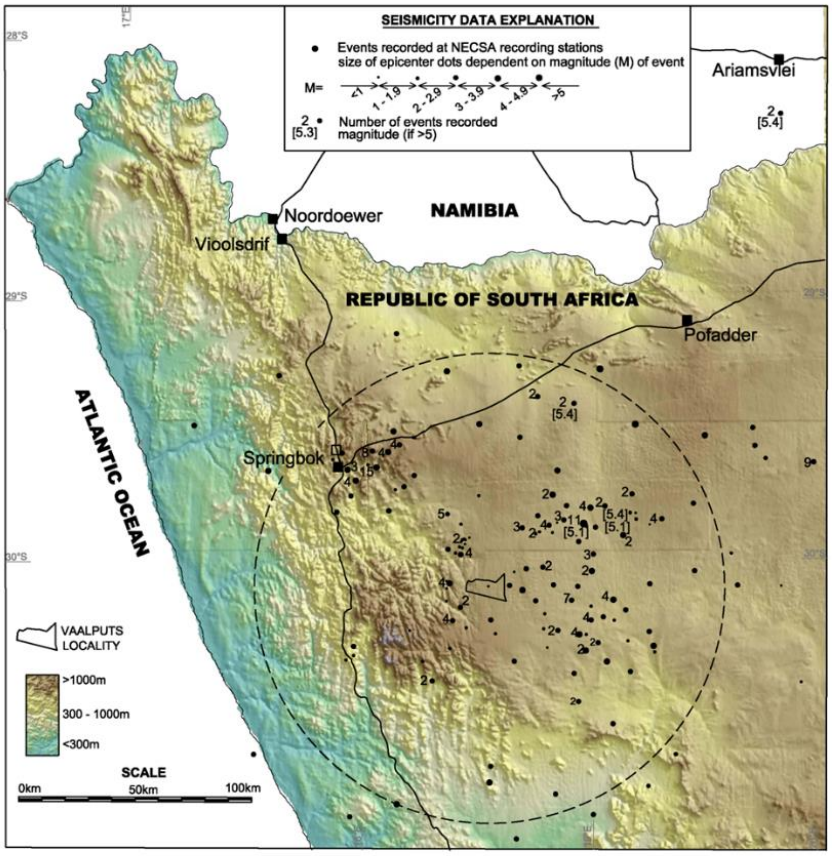

Figure 35: Seismic activity recorded at Necsa Seismic Recording Station overlain on SPOT Imagery (adapted REF)

5. GROUNDWATER QUALITY

Reviewing of the natural chemistry at the VRWS and selected surrounding farms has taken place during the construction and operational phases of the facility in support of its environmental monitoring program. During early stages of sampling was conducted in 1980, according to Necsa's database, measurements were taken only for temperature, pH and EC. Initial a comprehensive analysis study were conducted in 1988 by Levin. It is only in 1992 onwards that Necsa continued with a comprehensive analysis for groundwater in the study area. Data for the period of 1985 to 2013 will be used to gain an understanding of groundwater quality and chemical characteristics in order to add to the existing conceptual groundwater model for the VRWS and surrounding farms.

The current monitoring and sampling program, that is done twice a year at the VRWS and selected surrounding farms, includes analysis of pH, EC and temperature. Major cations include Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}, while anions include Cl^{-}, HCO^{3} , SO^{4}, and NO^{3} . Trace elements Fe, Mn, U, Al are also included. Alkalinity is measured in order to complete the dataset for ion balance determination and drafting of chemical diagrams.

5.1. DATA QUALITY

As mentioned above, a database was initialised from existing Necsa data and the dataset generated was specifically geared for this investigation. As part of the compilation of data, an ion balance was performed on every result for all the selected locations. At the start, 36 locations totaling 527 analyses were selected. After performing the ion balance, only 35 locations and 169 analyses were left after all data with an error of more than 5% were omitted. However, some more flaws were observed within this dataset, where data indicated an acceptable error but one or more of the cations or anions that are required for an ion balance calculation were missing. After rectifying this disconcerting observation, only 25 sampling locations and 29 analyses were found to be acceptable. Of this set of 25 borehole locations, merely 12 are from the original Necsa dataset.

Due to the limited, reduced dataset, trends regarding pH, temperature and other macro- elements will be influenced. Discussion on long-term trends will therefore only be included where enough data is available.

5.2. BOREHOLE GROUP SELECTION

In a radioactive waste facility, sampling and monitoring is essential to trace any contamination from the waste. Accurate groundwater data will assist to improve the existing conceptual model and to build a sound safety case assessment. Therefore, a monitoring programme should be designed to strengthen the safety case assessment. For this particular study 25 boreholes were selected for natural chemistry analysis. These boreholes are located on the VRWS and farms in a 20 km radius therefrom (Figure 28).

Evaluation of basic chemical analysis by means of chemical diagrams indicates two distinct groups. While both groups exhibit characteristics of groundwater associated with marine and a deep ancient environment, as indicated by Figure 36, no definite trends could be established for an association with specific geology (Figure 28). Coupled to the inadequacies mentioned above with regard to data quality, it was difficult to divide locations based purely on chemistry and geology.

After the revised dataset was evaluated, it was decided to divide the sampling locations into 4 groups using Cl concentrations as primary guide, due to the fact that Cl can be considered as a conservative parameter.

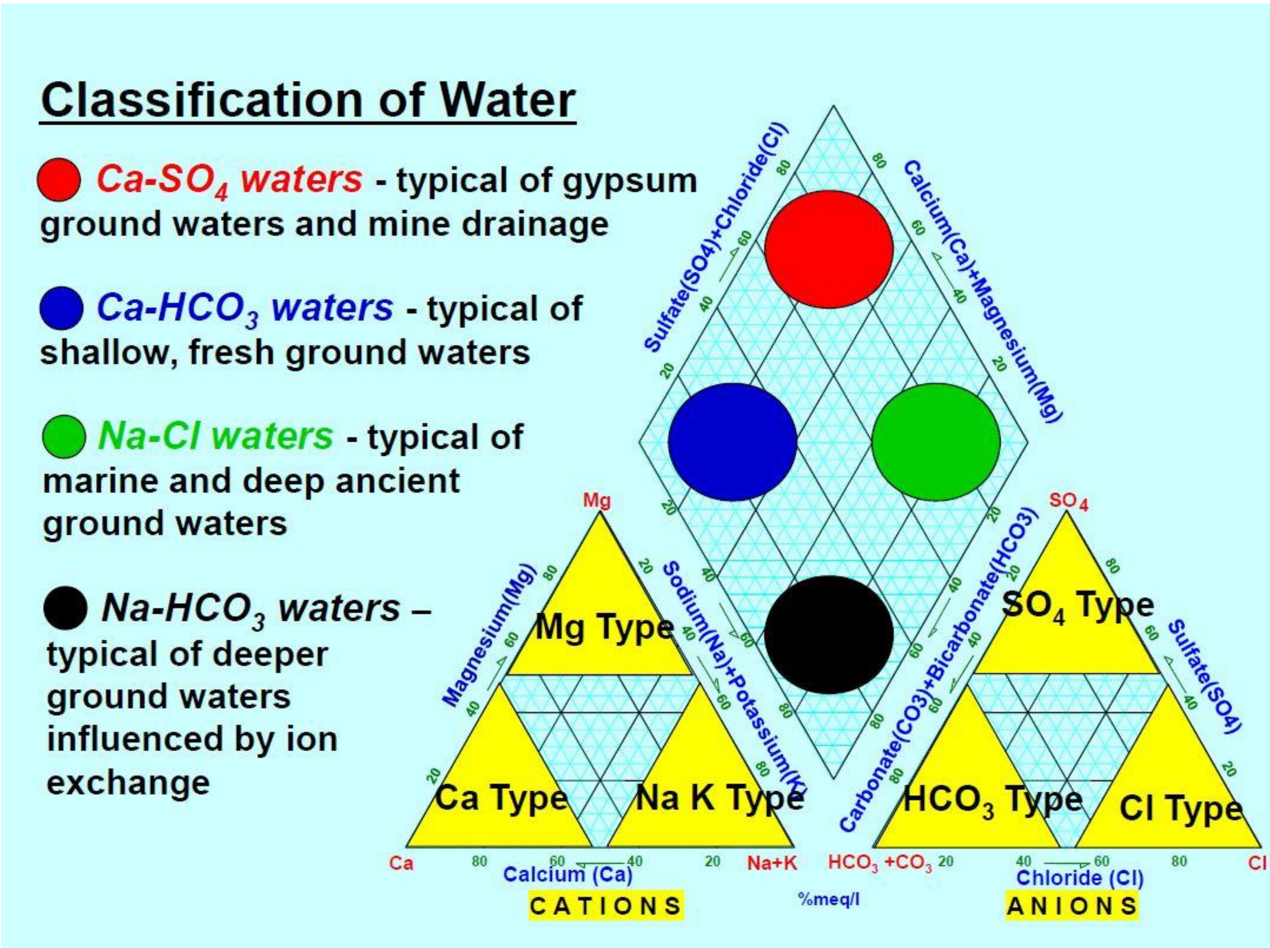

Figure 36: Piper diagram – Classification of Water

5.2.1. Group A

Figure 37 indicates the borehole locations with their associated average Cl concentration values.

Table 5: Summary of Group A boreholes

BH13C5	Burtons Puts granite of the Spektakel Suite	4 003
Platbakkies 2	Lekkerdrink gneiss	9 458

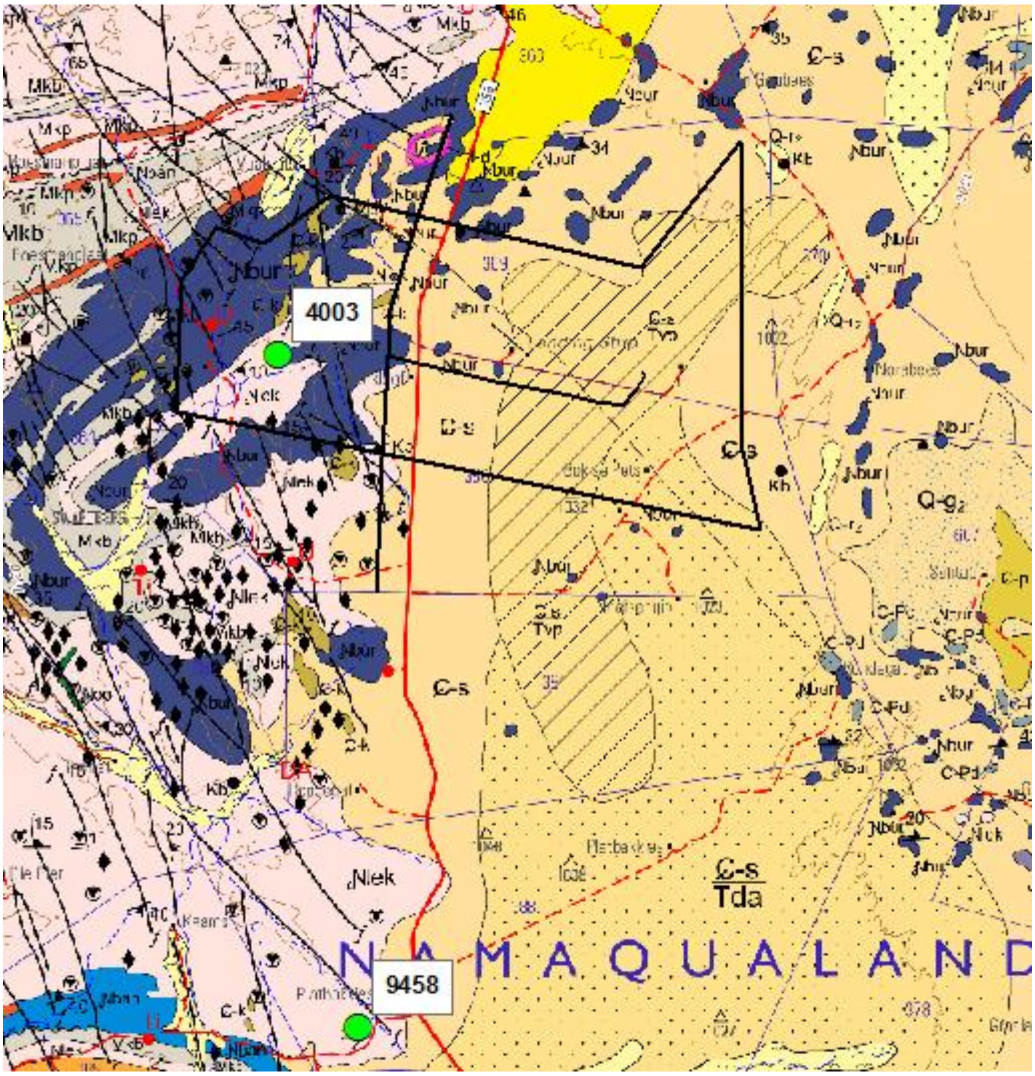

Figure 37: Group A borehole locations, indicating average Cl concentration

5.2.2. Group B

Table 6: **Summarizes the geology and average Cl concentration values of boreholes assigned to group B.**

Figure 38 indicates the borehole locations with their associated average Cl concentration values.

Table 6: Summary of group B boreholes

Borehole ID	General geology	Average Cl concentration (mg/l)
Frommelbakkies 4	Vaalputs Formation	946
Goubees 1	Burtons Puts granite of the Spektakel Suite	1708
Goubees 2	Vaalputs Formation	2110
Groenvlei 1	Vaalputs Formation	1503
GWB3	Granitic Gneiss	1460
MON2	Granitic Gneiss	1530
MON4	Granitic Gneiss	1058
MON10	Granitic Gneiss	1513
MON15	Granitic Gneiss	2234
Norabees 1	Vaalputs Formation	1508
Norabees 2	Vaalputs Formation	1490
Platbakkies 1	Dasdap Formation	1707
Lepel 1	Vaalputs Formation	1975

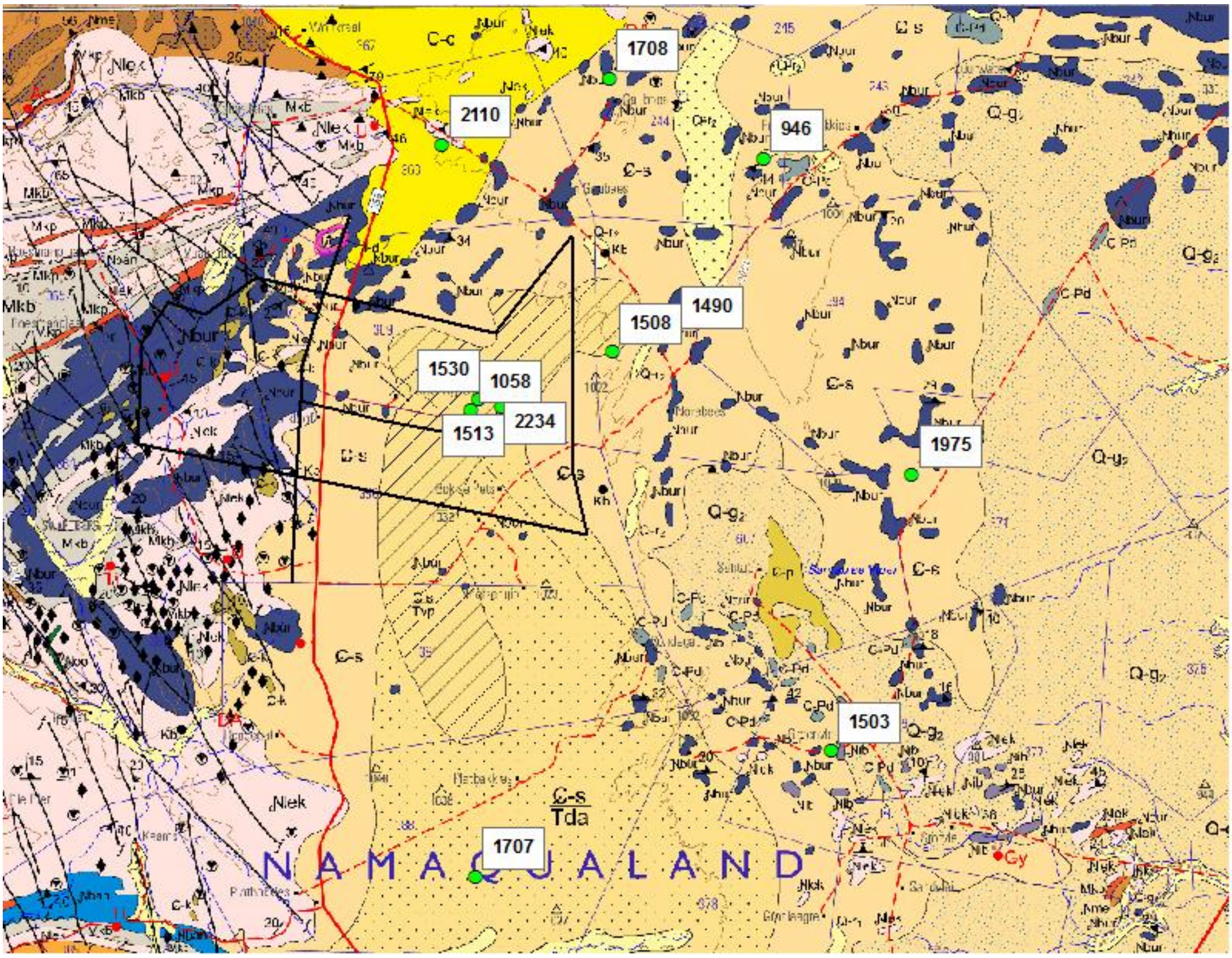

Figure 38: Group B borehole locations, indicating average Cl concentration

5.2.3. Group C

Table 7 summarizes the geology and average Cl concentration values of boreholes assigned to group C. Figure 39 indicates the borehole locations with their associated average Cl concentration values.

Table 7: Summary of group C boreholes

Borehole ID	General geology	Average Cl concentration (mg/l)
BH16C3	Vaalputs Formation	1397
BH3C2	Vaalputs Formation	891
BH4C1	Vaalputs Formation	1457
BH13C7	Burtons Puts granite of the Spektakel Suite	1441
BH519	Granitic Gneiss	1022
Dasdap 1	Dasdap Formation	924

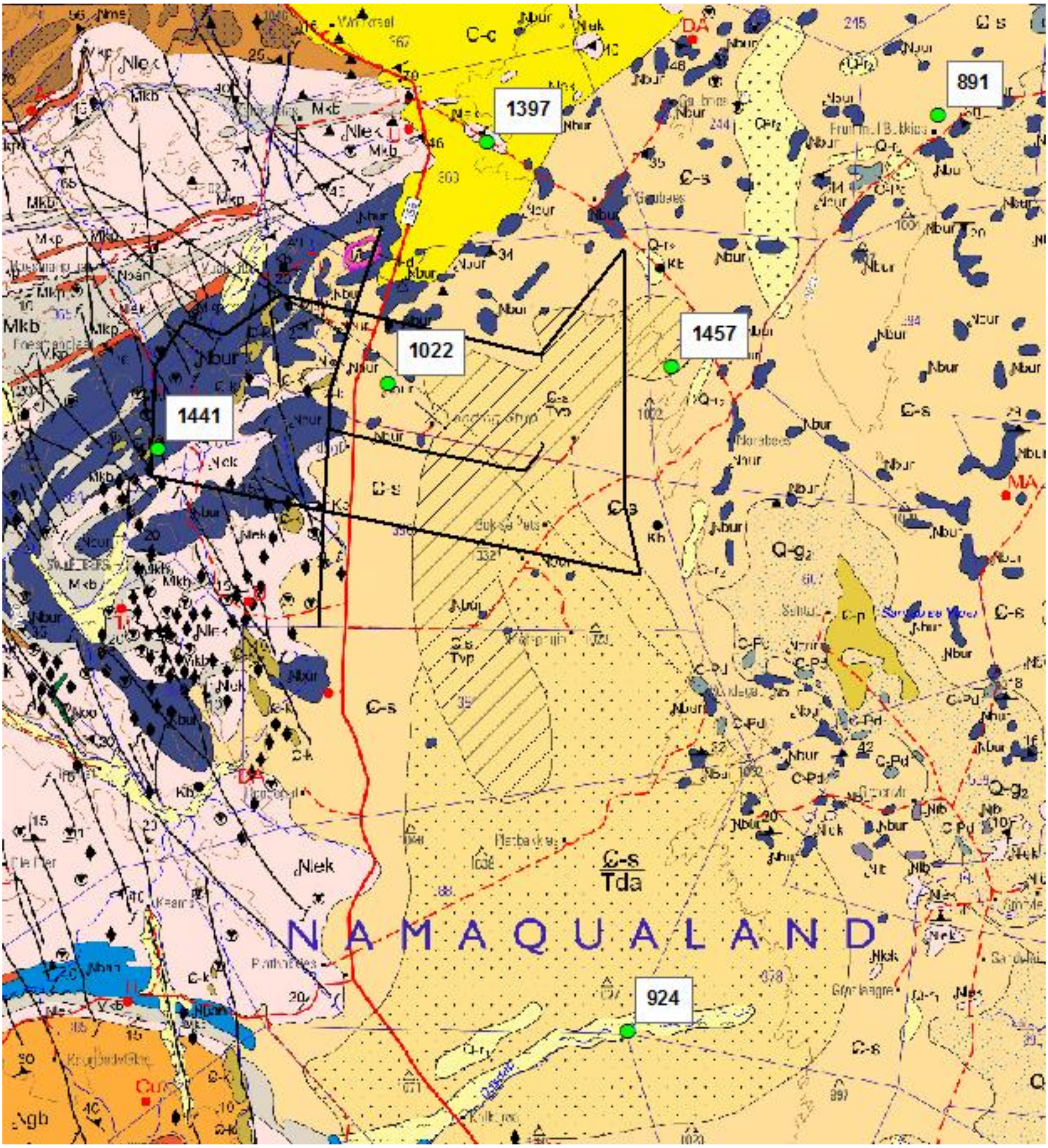

Figure 39: Group C borehole locations indicating average Cl concentration

5.2.4. Group D

Table 8 summarizes the geology and average Cl concentration values of boreholes assigned to group D. Figure 40 indicates the borehole locations with their associated average Cl concentration values.

Table 8: Summary of group D boreholes

Borehole ID	General geology	Average Cl concentration (mg/l)
Dikmatjie 1	Mesklip gneiss	465
Kamiebees 2	Lekkerdrink gneiss	548
Wolfkraal 1	Mesklip gneiss	173
Wolfkraal 3	Vaalputs Formation	570

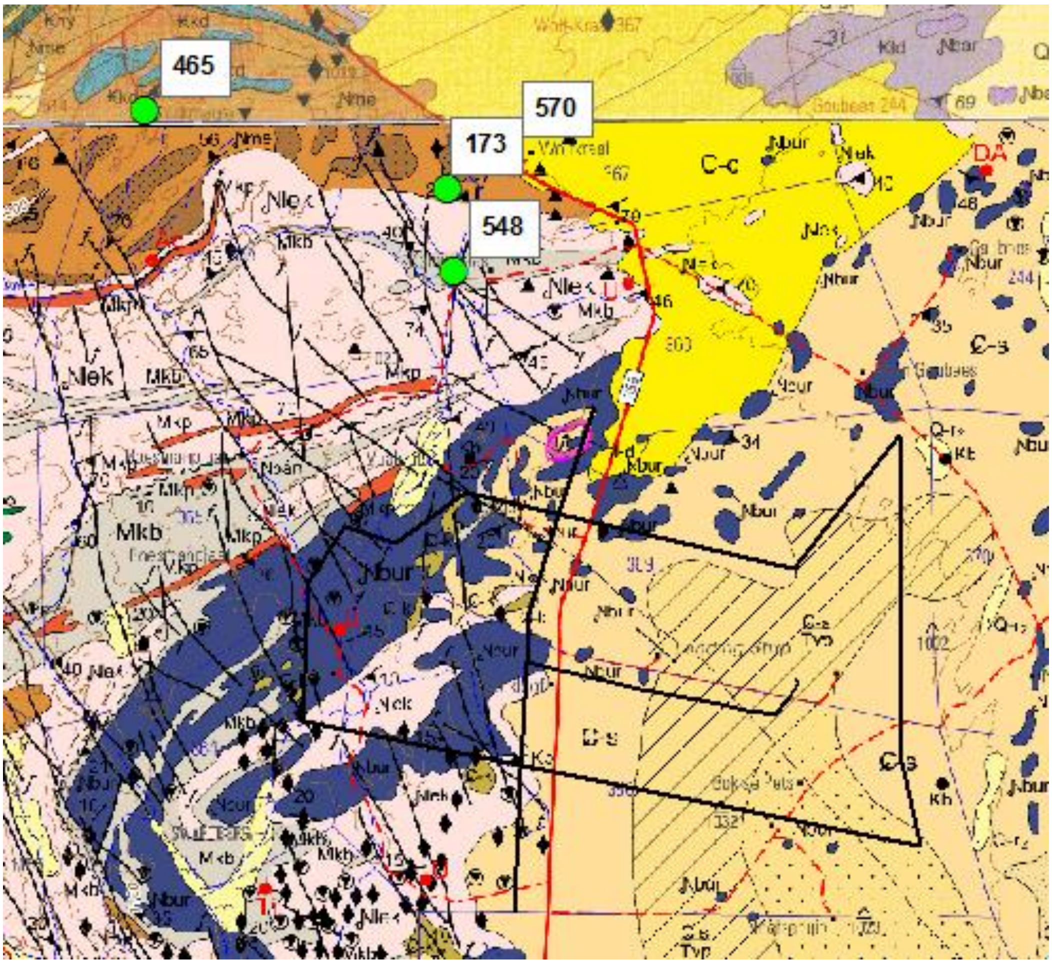

Figure 40: Group D borehole locations, indicating average Cl concentration

5.3. PH, EC AND TEMPERATURE

pH is defined as a degree of acidity or alkalinity. It is influenced by the degree of cations and anions found in groundwater. According to Shivshankar and Pawar (2012) groundwater in granitic aquifer has pH values ranging from 7.2 to 10.32. The study area is dominated by granitic gneiss which has a groundwater pH ranging between 6.5 and 8.9, with an average value of 7.65 (Figure 41). This falls well within the range of the South African National Standard for drinking water (SANS241: 2005/2011). The SANS requires drinking water in South Africa to have a pH value of between 5.0 and 9.7.

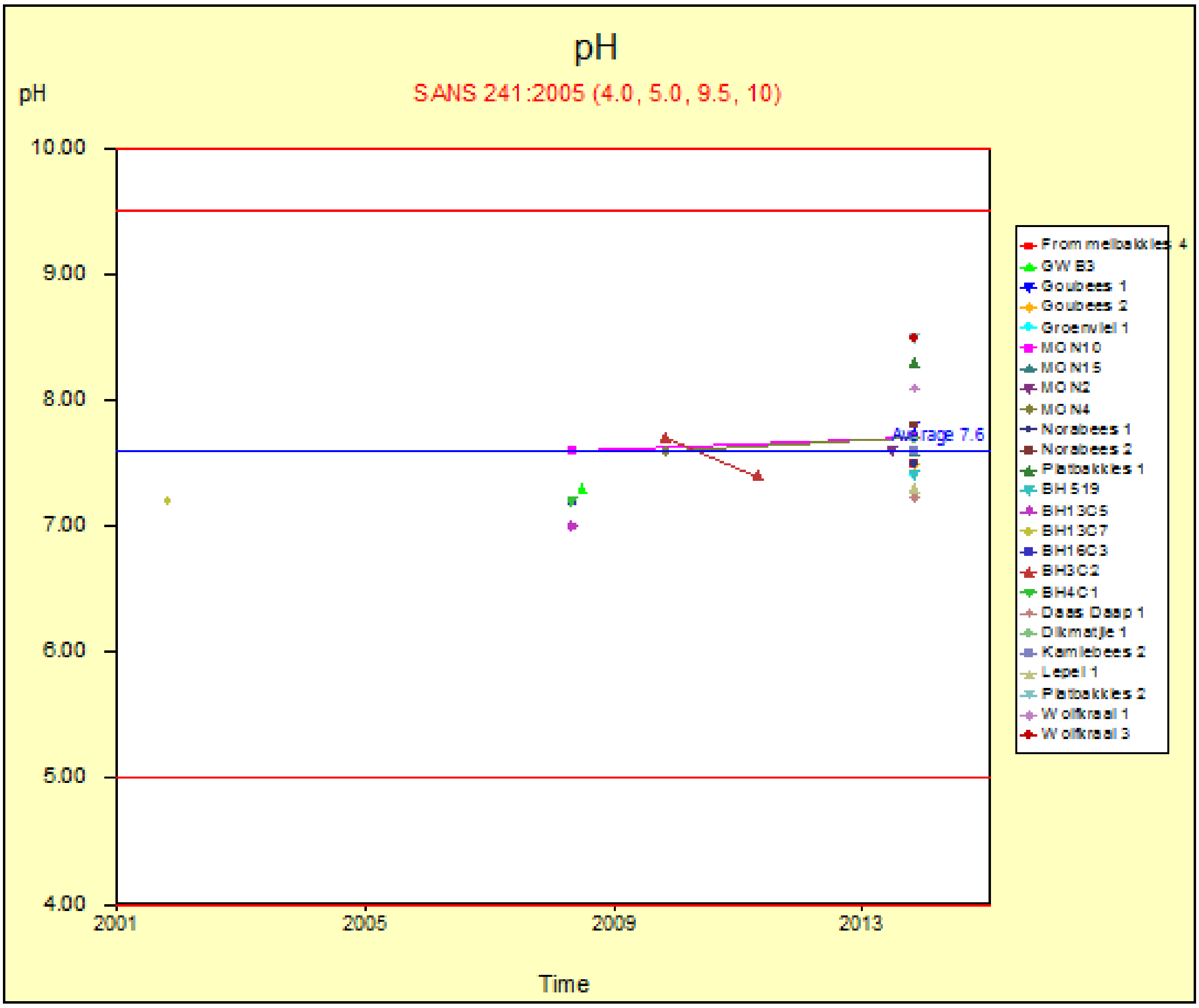

Figure 41: pH values for Groups A, B, C and D

Vertical EC profiling was conducted on 30 boreholes in total. Unfortunately, the logs of only 13 of these boreholes were available for a comparison needed to identify possible fracture zones. Figure 44 represents EC profiles that were done on boreholes within the VRWS lease area. Temperature of groundwater on selected boreholes was recorded using a YSI 600 XLM logger. Groundwater temperature at the VRWS ranges between 19°C and 24°C. These temperatures were recorded in a number of boreholes. The groundwater temperature, according to the YSI logger, increased with depth. The geological log at 50 to 60 m shows granitic gneiss formation, which has high temperature values ranging from 22.8 to 23^0 C. Temperature measurements show no indication of manmade contamination, which at times increases temperature of groundwater. APPENDIX C See Table 18 for the full set of data.

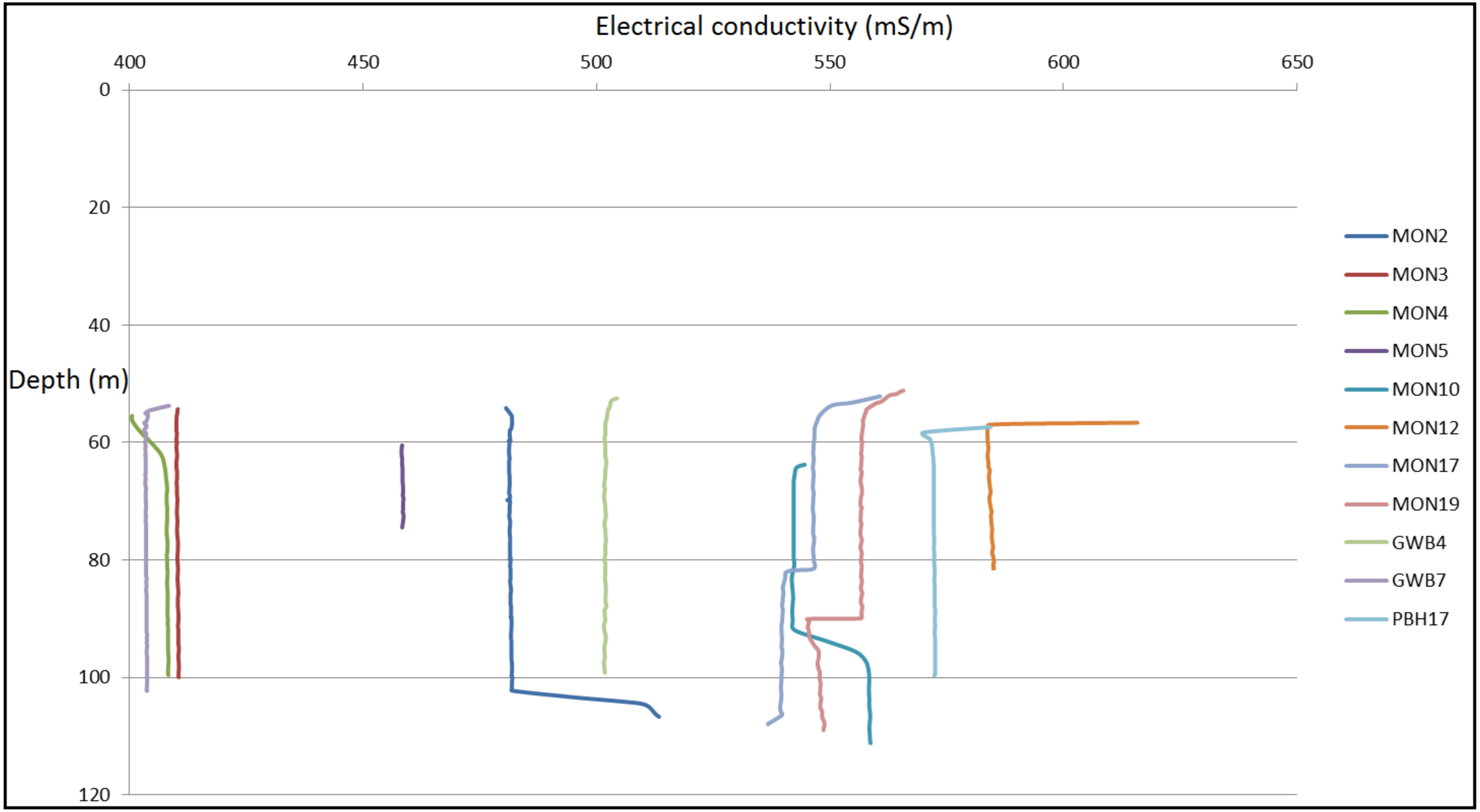

Figure 42: Combined smoothed graph of EC profiling

5.4. MACRO ELEMENTS

5.4.1. Data presentation

5.4.1.1. Chemical diagrams

Figure 43 and Figure 49 represent chemical diagrams constructed by using the limited dataset. Although the dataset is limited, confidence in the accuracy can be considered high. During further discussion regarding the major anions and cations, they will be referred to frequently.

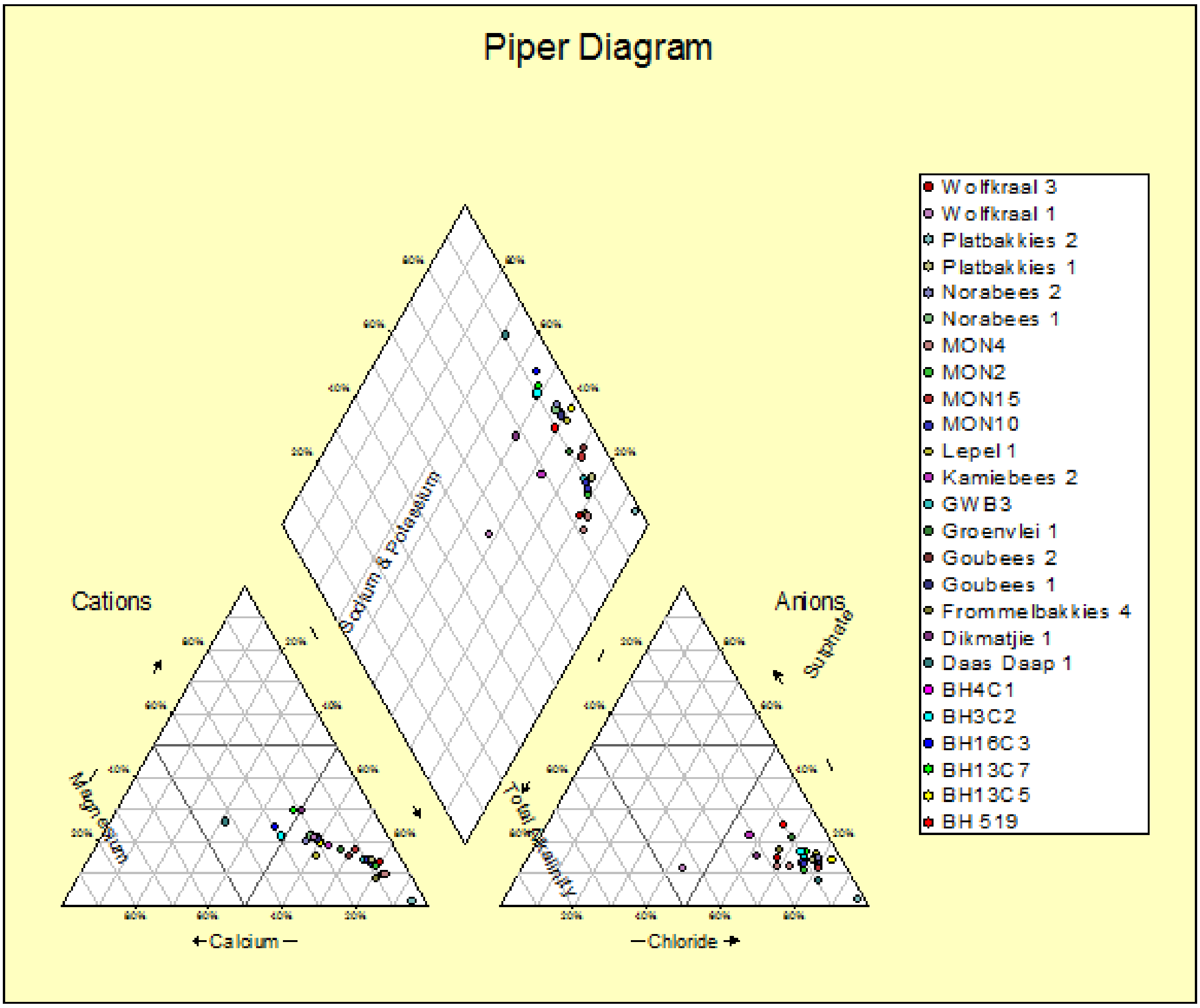

Figure 43: Piper diagram for groups A to D

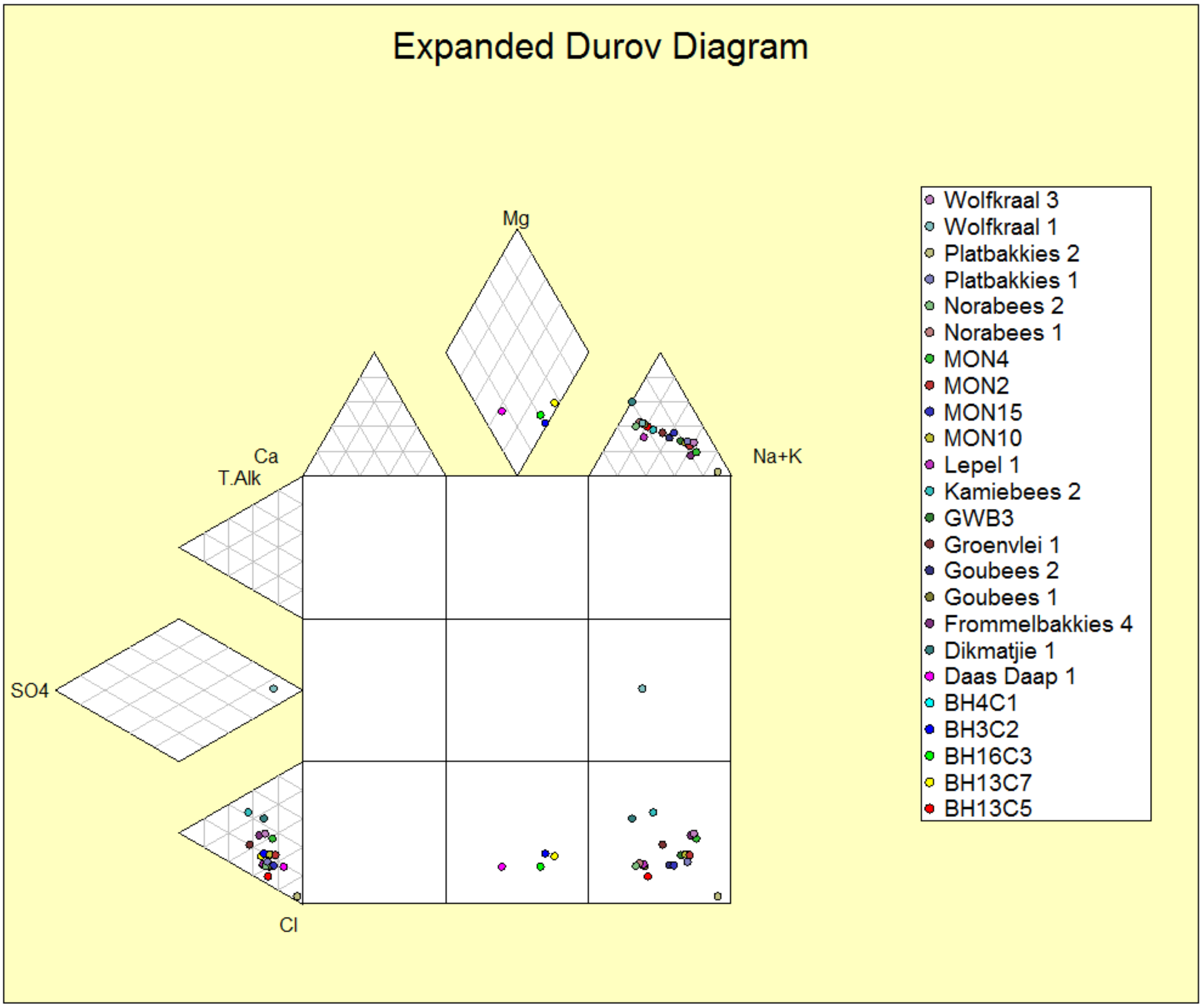

Figure 44: Expanded Durov diagram for groups A to D

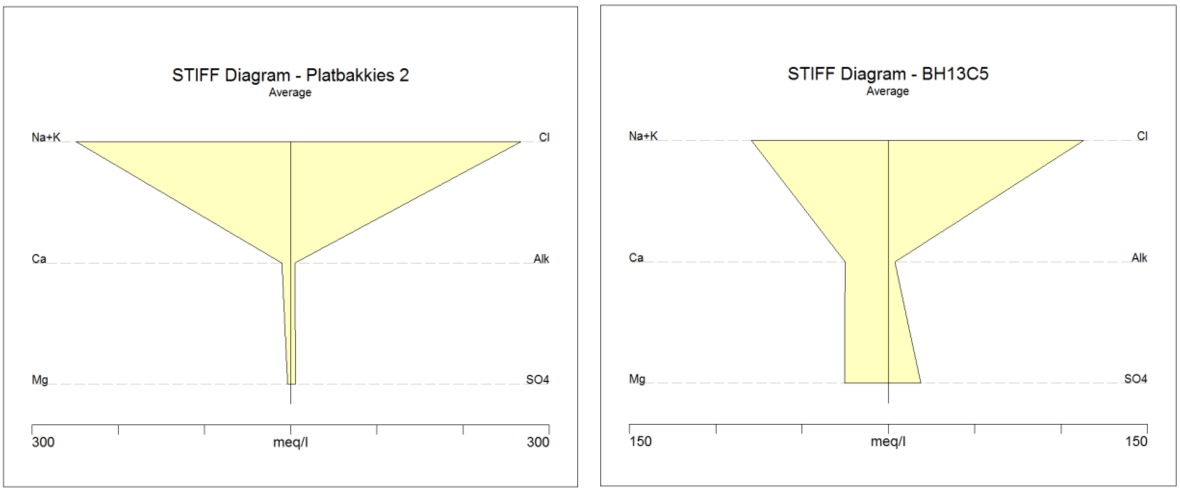

Figure 45: Stiff diagrams for group A (Note difference in scale)

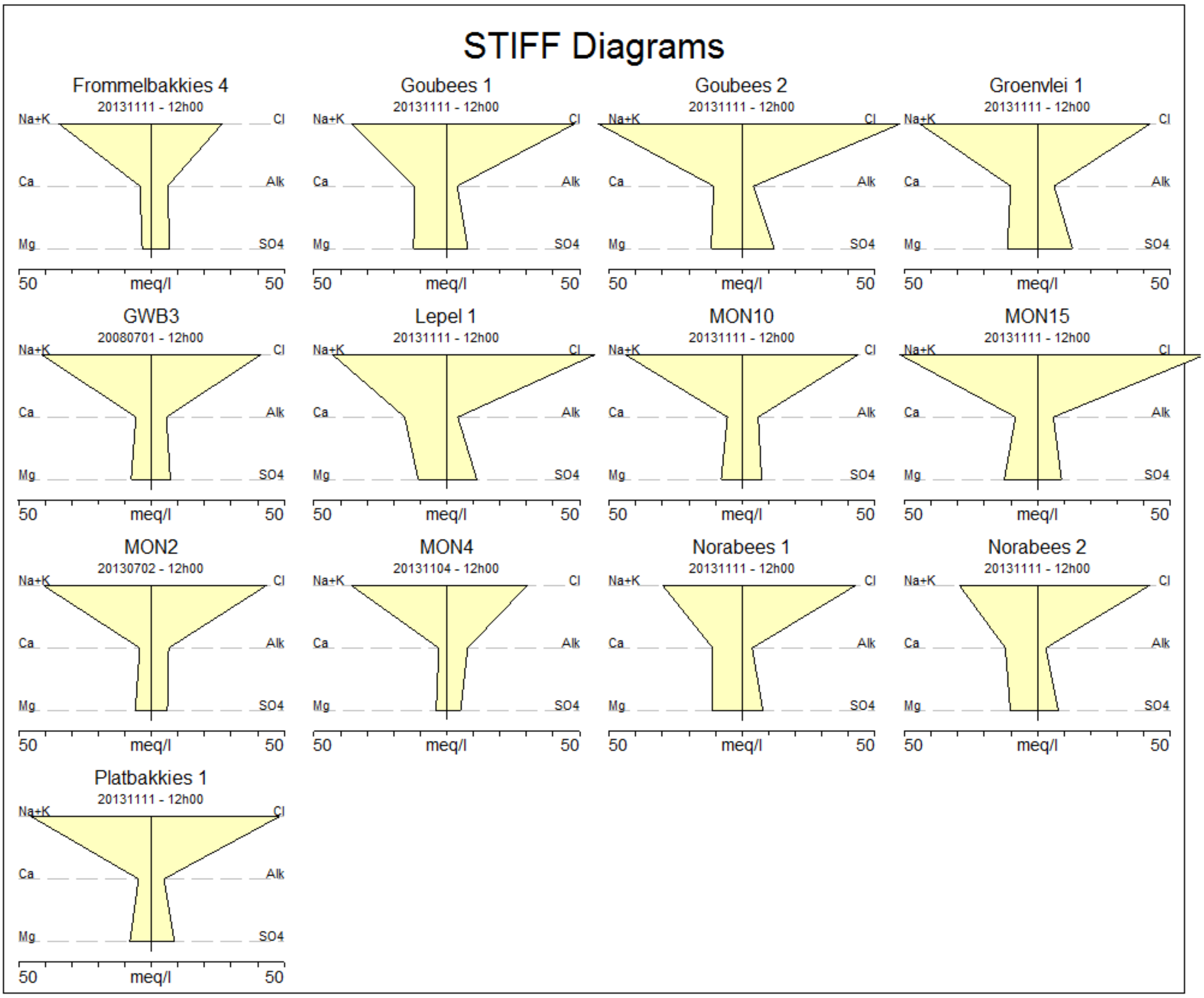

Figure 46: Stiff diagrams for group B

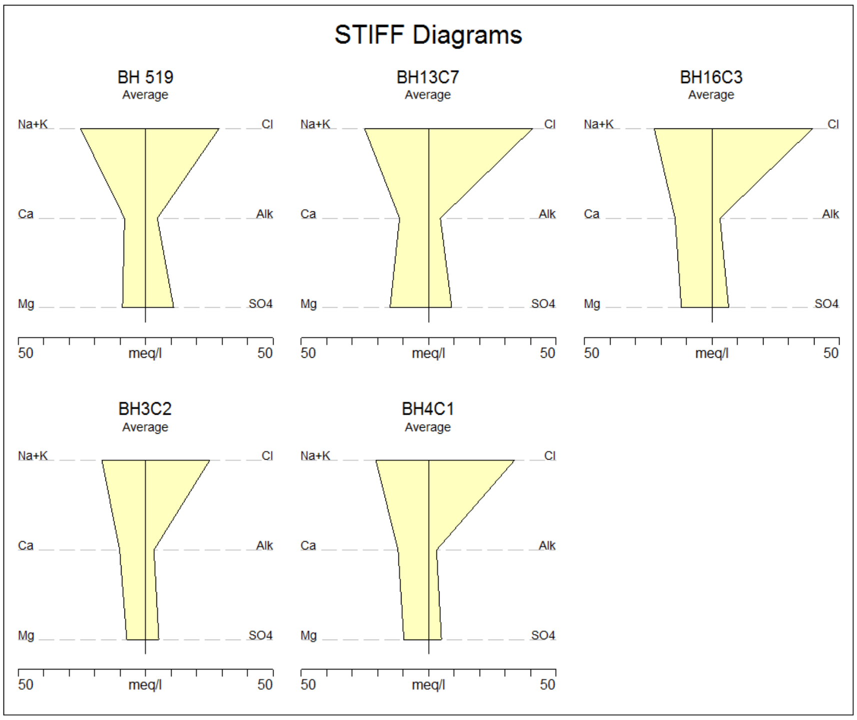

Figure 47: Stiff diagrams for group C and the Dasdap borehole (Note difference in scale)

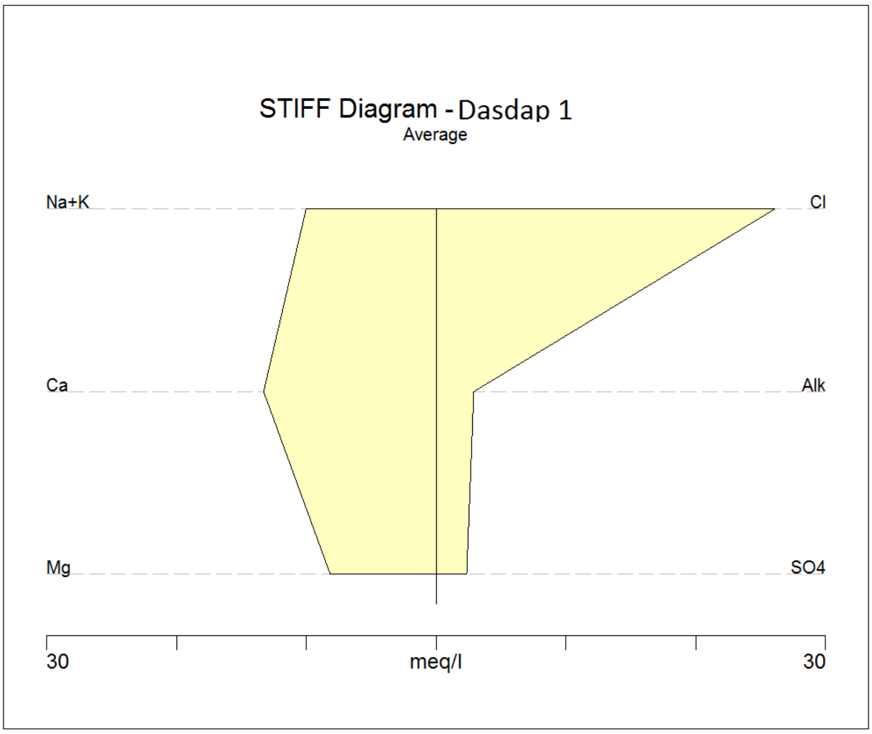

Figure 48: Stiff diagrams for group C (Dasdap borehole)

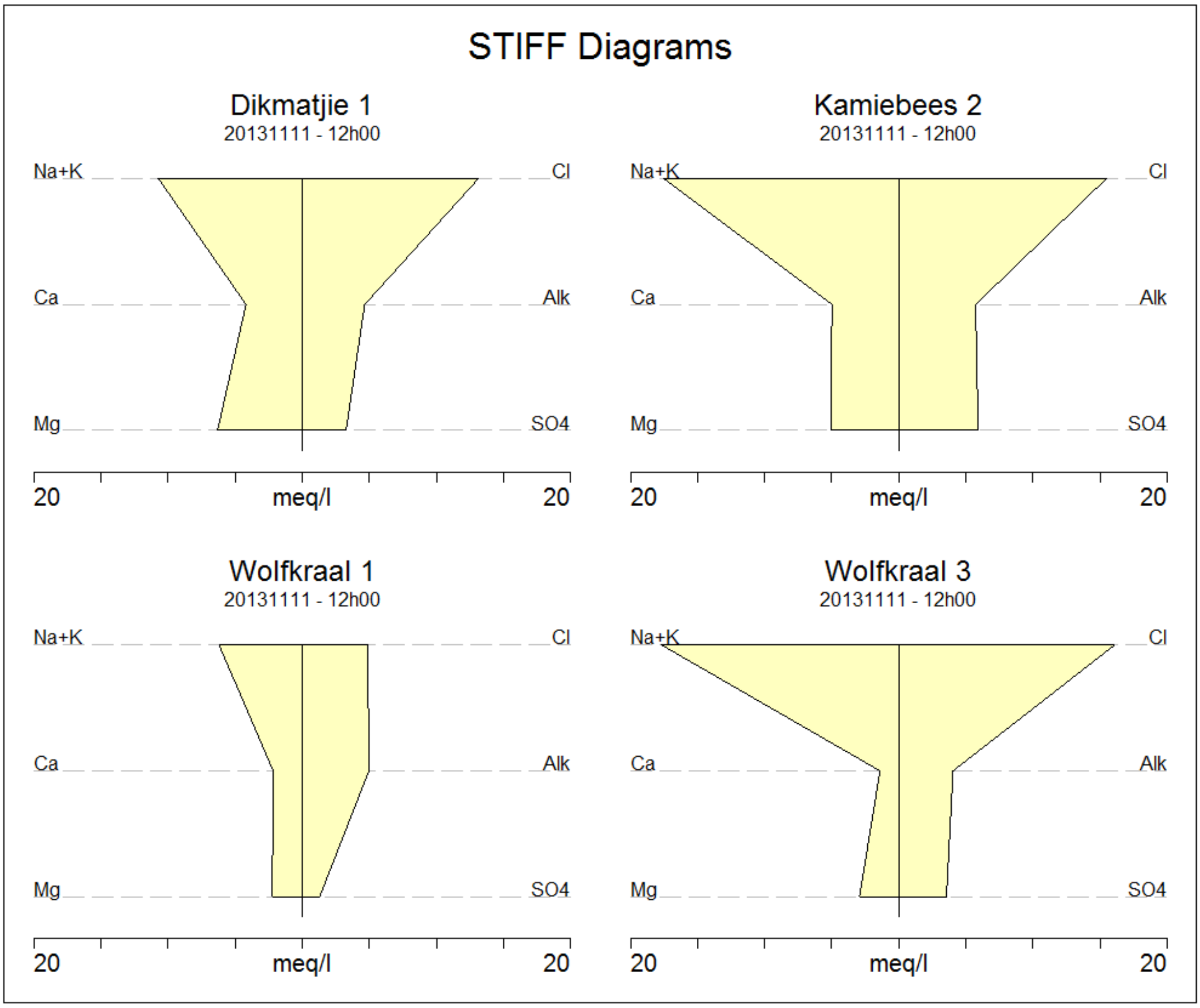

Figure 49: Stiff diagrams for group D

5.4.2. Anions

5.4.2.1. Chloride

When chloride enters groundwater through recharge it is not easily removed. Chloride is classified as an ion that is very conservative (Allison, GB and Hughes, MW (1978)) and it is commonly used to estimate groundwater recharge from rainfall. The average chloride value for all boreholes is 1,729 mg/ℓ and the minimum chloride measurement is 173 mg/ℓ. Boreholes in group A show relatively high chloride values. Group A has an average chloride concentration of 6,354 mg/ℓ. This is extremely high when compared to 1,200 mg/ℓ, which is the set water quality standard maximum and it is therefore not suitable for human consumption (WQG, 1996). In 2013, the chloride concentration measured in borehole Platbakkies 2 was recorded at 9,458 mg/ℓ, which is the highest concentration in the study area to date. It is located in Platbakkies farm (Figure 28). According to the Piper diagram, its groundwater can be classified as Na-Mg-Cl type groundwater (Figure 43). Group B has an average chloride concentration of 1,548 mg/ℓ and a minimum value of 946 mg/ℓ.

This position is usually associated with groundwater rich in Na, K and Cl, which supports the assumption that groundwater in the area is old or stagnant water that has reached the end of the geohydrological cycle or groundwater that has migrated through the aquifer over a long time. Group B is dominated by sodium and potassium cations, while the anion content is dominated by chloride.

The group C and D expanded Durov diagram (Figure 44) indicates that almost all the boreholes fall within the lower centre and lower right squares, with only one borehole, Wolfkraal 1, plotting within the middle right square. This confirms results found in Levin (1988) and Pretorius (2012). Borehole Wolfkraal 1 groundwater is dominated by sodium, potassium cations and bicarbonate anions. This borehole is located on red-brown, weathered, strongly foliated biotite metamorphic rock and streaky gneiss (Figure 28).

5.4.2.2. Sulphate

Sulphate crystallises as gypsum, which leaves groundwater as sulphate brine. What is clear from the data of the study area are low sulphate and high chloride concentrations. Group A and Group B sulphate average concentrations are 443.17 mg/ℓ and 367.05 mg/ℓ respectively. Group C and Group D sulphate average values are 314.16 mg/ℓ and 168.15 mg/ℓ. These concentrations are slightly higher in comparison with other South African averages of about 300 mg/ℓ (Pirow, 1999). The high averages of sulphate and chloride concentrations maybe due to the aridity of the study area. Other reasons for high sulphates in the study area are: the leaching of sedimentary rocks and the reaction of calcium from calcrete to produce calcium sulphate; hence also the high concentration of calcium. Group B boreholes are above the water quality standard and can be dangerous for human consumption. Using Piper's method of calculation (Figure 43), sulphate represents 33% of the anion, compared to 75% for mean chloride value. This confirms that groundwater in the VRWS and surrounding farms has reached the end of the geohydrological cycle and is highly saline. There is a borehole in Group A with sulphate concentrations well above water quality standards: BH13C5 at 613.54 mg/ℓ. In Groups B, C and D there are three boreholes that are over the limit: Groenvlei 1, BH519 and Lepel 1. BH13C5 is drilled on the granitic gneiss on the Namaqualand plateau rugged terrain; Groenvlei 1 and Lepel 1 are drilled on granitic gneiss overlain by the Vaalputs formation.

5.4.2.3. Nitrate

According to the EPA in the United States, nitrate is very soluble and does not bind to soil; it potentially migrates to ground water. Nitrates do not evaporate and are likely to remain in water until consumed by plants or other organisms. Nitrate concentrations in the VRWS are slightly high, but within the water quality standards. Group A has the highest average nitrate value of 1.53 mg/ℓ. The average value for all the boreholes within the study area is 14.45 mg/ℓ. Nitrate concentrations in the study area are elevated compared to the rest of Southern Africa.

5.4.3. Cations

5.4.3.1. Calcium and Magnesium

In saline soils the percentage of Ca^{+2} is lower and the values of K^{+}, Mg^{2+} and Na^{+} are higher (cf. Eriksson, 1958). Group A average calcium value is 333.01 mg/ℓ, while group C has the second highest average calcium value of 227.28 mg/ℓ. Group B average calcium value is 167.58 mg/ℓ, followed by Group D at 63.98 mg/ℓ. BH13C5 calcium concentration is above the water quality standard, but there are no health hazards associated with this concentration. The Piper diagram in Figure 43 shows boreholes Platbakkies 2 and 13C5 plot 40% to 50% calcium concentrations in Group A. This suggests hard water, similar to that of sea water. Group B MON10, MON15, MON2, MON4 and GWB3 boreholes' calcium concentrations are associated with clay minerals found in the Vaalputs formation. The calcium from clays percolates with water in different soil layers and reaches the unsaturated water. The concentrated water then moves to the saturated zone. According to Albert Galy (2004), magnesium abundance is second to that of oxygen among the rock-forming elements and it is an important element for the hydrogeological system. Group A's average magnesium concentration is 139.05 mg/ℓ. BH13C5 has the highest average magnesium concentration at 232.1 mg/ℓ. According to the water quality standards for domestic use, this value is toxic for drinking water. Group B's average magnesium value is 106.77 mg/ℓ. GroupC boreholes with high magnesium values are 4C1 at 128.73 mg/ℓ, 16C3 at 121.28 mg/ℓ and 13C7 at 137.45 mg/ℓ.

5.5. Discussion of water quality

The Stiff Diagram for group A and B Figure 45 and Figure 46 illustrates a similar distribution. Group A and B Stiff Diagram show a similar and symmetrical area, with dominance of Na+K and Cl however borehole Norabees 1 Norabees 2 showing slight Calcium and Magnesium dominance. Group C Stiff Diagram Figure 47 illustrates an asymmetric shape for borehole BH13C7 and BH16C3 with a slight dominance of Chloride. Figure 48 borehole Dasdap shows a different plot from all the boreholes, with less Na+K and high Ca and also high Chloride. Overall the Stiff Diagram for the study area shows similar trend as the Piper Diagram, dominance of Na+K type of groundwater.

The Piper Diagram in Figure 43 shows that groundwater is Sodium + Potassium type water and this is verified by the cations and anions that plot on the far bottom left of the triangle. The groundwater cations are subsequently dominated by Sodium + Potassium while the anion content is dominated by Chloride and Nitrate anions. According to the classification of water type Figure 36, these groundwater exhibits marine and deep ancient groundwater. The Expended Durov diagram Figure 44 depicts most boreholes plot on field 8 and 9 which indicates the end of geohydrological cycle and stagnant saline groundwater. Boreholes plotting on field 8 represent Sodium Chloride rich groundwater mixed with Magnesium rich groundwater. Borehole Wolfkraal 1 plots on field 6 which indicates a dominance of Sulphate anion compared to other boreholes.

It can be seen from the Piper and Expended Durov Diagram that groundwater collected at the Vaalputs Site and surrounding farms shows Na, Cl and slight SO_4. This type of water was mentioned before in previous studies indicates saline stagnant water. As groundwater migrates through the granite gneiss, it dissolves some of the minerals in the rocks; this can be observed in Sodium and Potassium concentrations. Several mechanical processes (advection, molecular diffusion, mechanical dispersion, chemical reaction e.t.c) are all controlled by hydro geochemistry. Groundwater in the study area has high salinity. This could be associated with groundwater long resident time in the granitic rock. The Piper diagram analysis show similar water type as in past studies with no significant chemical groundwater difference. Sampling done for this study has not revealed any groundwater pollution.

6. RECHARGE

The study of groundwater, its age, movement/recharge dynamics and interaction with the naturally occurring radioactive minerals of the granitic rocks has taken centre stage in recent years at the VRWS and surrounding farms. Two studies, done by Levin (1988) and Vivier (2003), both confirmed groundwater age of the VRWS to range between 6,200 to 12,700 years. These studies were focused on the Vaalputs disposal area and not on the entire waste facility. This study will be calculating recharge for the entire VRWS and surrounding farms.

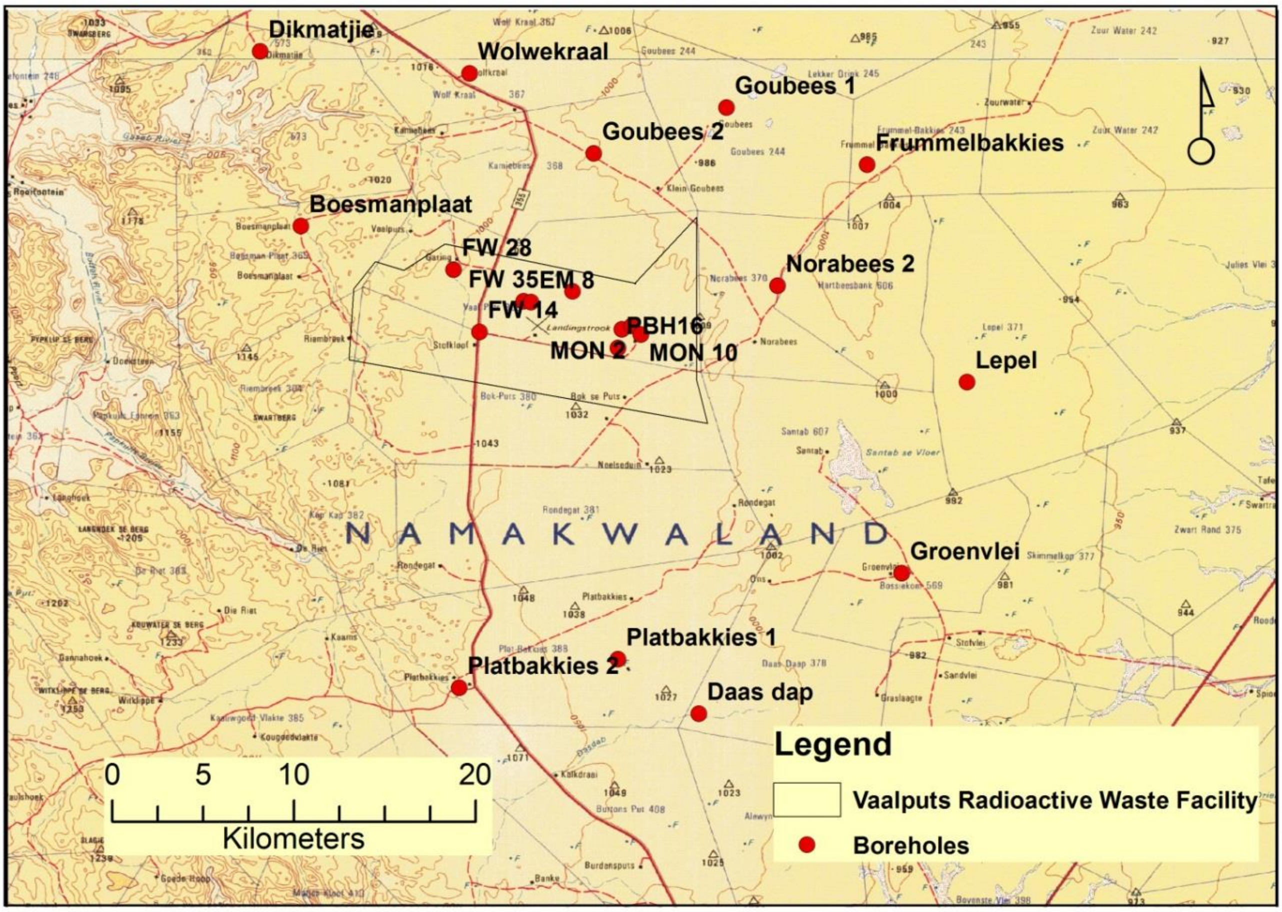

Figure 50: VRWS outline map with surrounding boreholes showing overlain by 2918 and 3018, 1:250 000 Topo-Cadastral Map

6.1. RADIOISOTOPES

According to Levin (1988), measurements of stable isotopes (18O and 2H) and radiogenic natural isotopes (3H and 14C) can be useful for resolving cases related to groundwater age, groundwater mixing and groundwater reaction in more complex situations. Radioisotope studies at the VRWS and surrounding farms have been performed three times to determine recharge. These studies will be used to gain understanding of recharge at the VRWS and surrounding farms. Figure 50 shows all the boreholes that were sampled for radioisotope analysis.

6.1.1. Tritium

Groundwater age estimation using tritium only provides semi-quantitative estimation as it requires other groundwater dating methods. Concentrations greater than 0.8 T.U, indicate sub-modern water prior to 1,950 (Motzer, 2015).The presence of tritium in a groundwater system, in concentration similar to present day rainwater, indicate rapid recharge takes place. Absence of tritium in groundwater means that no water less than 50 years old is present (Levin 1988). Table 9 illustrates that boreholes MON2, FW14, FW35 and FW28 have no tritium concentration in the groundwater. These boreholes are located on VRWS. There is also no tritium concentration in boreholes Frommelbakkies, Goubees (1), Wolwekraal and Goubees2. When comparing tritium concentrations in Table 9 and Table 10, MON2 tritium concentration in year 2000 was 0.4, which decayed to 0.0 in year 2014; MON10 tritium concentration also decayed from 0.2 T.U to 0.1 T.U, while MON12 tritium concentration remained constant. Borehole PBH16 has increased its T.U. concentration of 0.3 to 0.7 in 2014, which is an indication of tritium replenishment. This borehole has also replenished 14C of 87.5 pmc (Table 9).This borehole is located on a fracture, which acts as a water bearing structure. When it was pump tested by Levin (1988) it showed a response of a homogeneous and isotropic medium. Boreholes with tritium concentrations above 0.6 T.U indicate a mixture of old and young groundwater. These tritium concentration values are similar to the tritium values recorded in 1985 and 2000, low to no tritium in other boreholes. These concentrations confirm low recharge.

Table 9: Tritium values obtained through sampling of Vaalputs boreholes and 20km surrounding farms

Sample Identification	Tritium (T.U.)		Sample Identification	Tritium (T.U.)	
MON2	0.0	±0.2	Frommelbakkies	0.0	±0.2
FW 14	0.0	±0.2	Norabees (2)	0.5	±0.2
FW 35	0.0	±0.2	Goubees (1)	0.1	±0.2
Mon 10	0.2	±0.2	Boesmanplaat	0.6	±0.2
EM 8	0.2	±0.2	Wolwekraal	0.0	±0.2
FW 28	0.0	±0.2	Dikmatjie	0.4	±0.2
PBH 21	0.7	±0.2	Kamiebees	0.3	±0.2
PBH 16	0.7	±0.2	Goubees (2)	0.0	±0.2
Dasdap	0.3	±0.2	Groenvlei	0.4	±0.2
Mon 12	0.6	±0.2			

Table 10: Tritium values obtained through sampling of Vaalputs Site (adapted after Vivier and Van Blerk 2000)

Sample Identification	Tritium (T.U.)
MON 2	0.4±0.2
MON 10	0.1±0.2
MON 12	0.6±0.2
MON 21	0.4±0.2
GWB 3	0.2±0.2
GWB 5	0.4±0.2
EM 8	0.0±0.2
PBH 16	0.3±0.2
FW 35	0.5±0.2

6.1.2. Carbon 14

Carbon 14 dating is based on a theoretical decrease in isotope concentration with time from an initial of C_0 to a concentration of C_t at the time of sampling (Pirow, 2000). For this study, carbon 14 dating was estimated using standard values for a crystalline rock of 0.90-1.00 and rainfall data recorded at the Vaalputs weather station from 1985 to 2013. The mean annual rainfall for the Vaalputs Site is 132mm. Carbon 14 samples were analysed and the groundwater age was found to be between 1,103 and 12,042 years. These values are slightly different from carbon 14 data collected and analysed by Vivier and Van Blerk (2000), where age-dating in the Vaalputs Site ranged from 6,000 to 13,000. This could be due to a number of reasons, e.g. different boreholes used for this study, the sampling method applied and also the geological formation used to calculate the age; it could also be the replenishment of the carbon 14 over the years.

Table 11 And Table 12 show carbon 14 data collected for the VRWS and selected farms in year 2000 and in year 2014. Borehole MON12 was sampled for Carbon 14 in 1986 and the age was 1,131 years. In 2000 age estimation was 12,600 years and in 2014 the age was estimated at 10,523 years. There is a significant increase of carbon 14 concentration from year 2000, i.e. from 18.6 pmc with an error margin of 1.5, to 28.0 pmc with an error margin of 1.8. This means that there is a gradual but slow mixture of fresh and old water, which indicates recharge. In 1985, borehole PBH16's groundwater age was estimated at 14, 175 years (Levin 1985). In 2000 Vivier and Van Blerk estimated the groundwater age to be 7,100 years and in 2014 the age estimation was 4,113 years. This borehole shows potential groundwater recharge over the years. In 1985, the pmc for PBH16 was 18 pmc; 15 years later, in 2000, the pmc increased to 35.9 pmc and, in 2014, the pmc increased to 60.8 pmc. Figure 52 results indicate that this borehole gets direct recharge from the rainfall. EM8 age calculation in 2000 was estimated 12,745 years and, in 2014, the age estimation was 12,042 years, while FW35 age in 2000 was estimated at 10,523 years and for 2014 it was estimated at 10,552 years. Both these boreholes' pmc shows no significant change over the past 14 years and therefore no sign of recharge.

Table 11: Isotope values for the selected Vaalputs boreholes and surrounding farms sampled in year 2014.

Laboratory Number	Sample Identification	Carbon-14 (pmc)		Crystalline Rock Conv.C-14
IGS 497	Mon 2	26.0	±1.8	11136
IGS 498	FW 14	64.4	±4.3	3638
IGS 499	Mon 12	28.0	±1.8	10523
IGS 500	FW 35	27.9	±1.8	10552
IGS 501	Mon 10	27.6	±1.8	10642
IGS 502	EM 8	23.3	±1.8	12042
IGS 503	FW 28	81.2	±2.4	1722
IGS 504	PBH 21	87.5	±2.4	1104
IGS 505	PBH 16	60.8	±2.2	4113.
IGS 506	Platbakkies (1)	83.3	±2.4	1511
IGS 507	Das Dap	56.5	±2.1	4720
IGS 508	Frommelbakkies	59.5	±2.2	4292
IGS 509	Norabees (2)	61.9	±2.2	3965
IGS 510	Platbakkies (PB2T)	10.5	±1.6	18631
IGS 511	Goubees (1)	25.9	±1.8	11167
IGS 512	Boesmanplaat	79.0	±2.4	1948
IGS 513	Wolwekraal	19.3	±1.7	13599
IGS 514	Dikmatjie	84.1	±2.4	1432
IGS 515	Kamiebees	45.9	±2.0	6437
IGS 516	Goubees (2)	52.6	±2.1	5310
IGS 517	Groenvlei	67.8	±2.3	3212
IGS 519	Lepel	33.7	±1.9	8991

Table 12: Carbon 14 dating for selected boreholes at the Vaalputs radioactive waste Site (adapted after Vivier and Van Blerk 2000)

Laboratory Number	Sample Identification	Carbon-14 (pMC)	Conv. C-14 "age" (yrs)	Crystalline rocks Conv. C-14
NUC 575	MON 12	18.6±1.5	12600	13905
NUC 576	MON 21	40.2±1.7	6200	7533
NUC 577	GWB 3	21.2±1.5	11500	12823
NUC 578	GWB 5	27.5±1.6	9300	10672
NUC 579	EM 8	21.4±1.5	11400	12745
NUC 580	PBH 16	35.9±1.6	7100	8468
NUC 581	FW 35	28.0±1.6	9200	10523

Three boreholes selected for carbon dating analysis were not included in the previous studies, i.e. FW28, PBH21 and FW14. These boreholes are located on the western side (Garing farm) of the VRWS (Figure 51), with their ages at 1,300 to 4,500 years according to carbon 14 dating. FW28 is located in the rugged terrain to the western side of the VRWS.

The water level for this borehole ranges between 4 to 6 m below the surface. Observing the water level, the rainfall pattern and looking at the carbon 14 age dating, one can assume that this borehole is quickly recharged by rainfall.

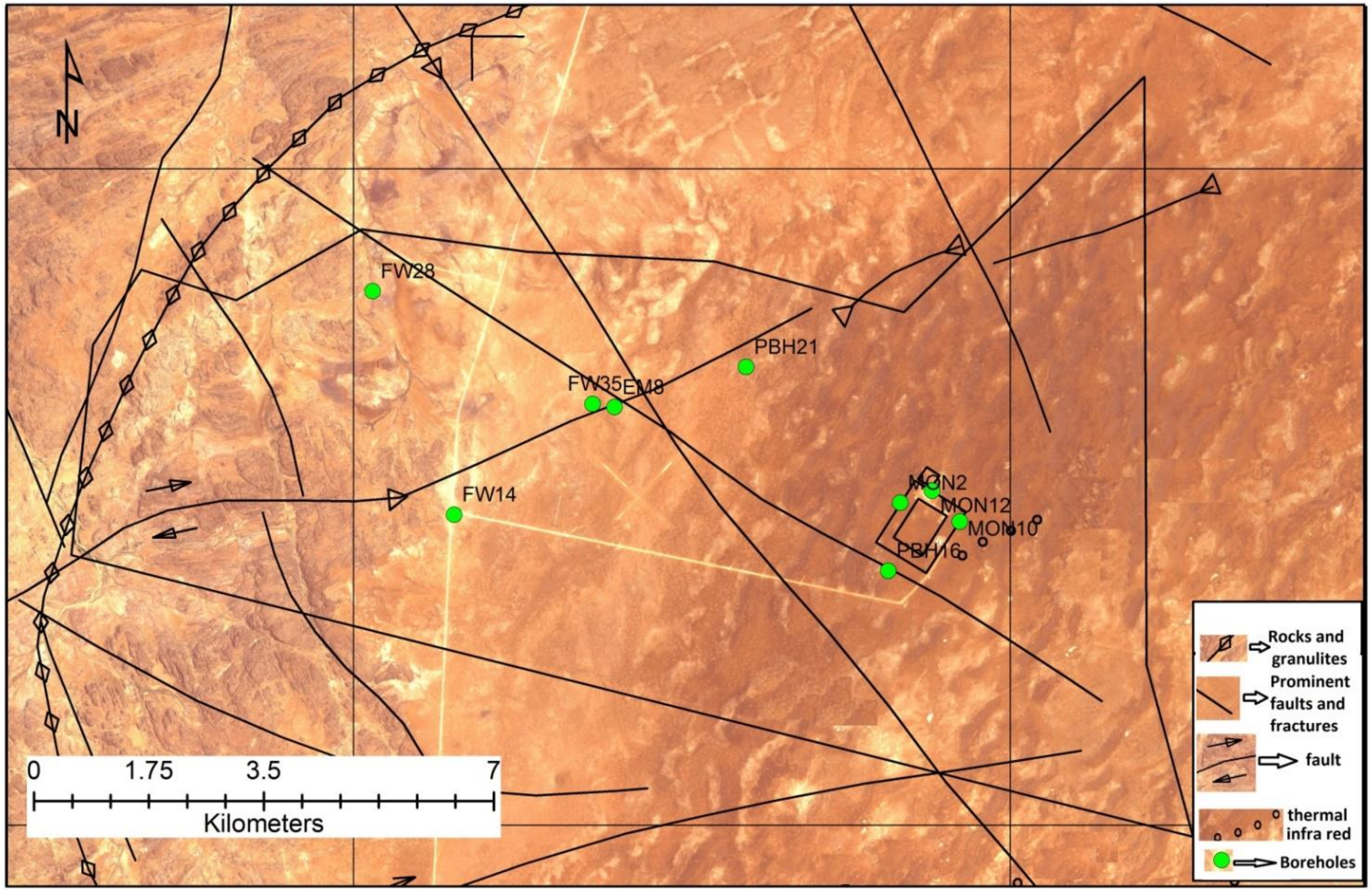

Figure 51: Vaalputs Site with faults and lineaments overlain with Site boreholes (adapted after Andreoli 2002, modified by M. Mandaba)

FW14 bears no evidence of tritium, which suggests that no direct rainwater is recharging this particular borehole. Borehole FW14 is located on the watershed on a relatively flat elevation where the groundwater potentially drains. The calculated age for this borehole is 4,209 years. In the disposal Site, MON12, MON2, MON10, EM8 and FW35 boreholes' groundwater ages range from 11,000 to 12,800 years. These ages confirm the past studies by Levin 1985 and Vivier and Van Blerk 2000. The data confirm that boreholes drilled on the disposal Site (MON, GWB) are not being directly recharged by rainfall.

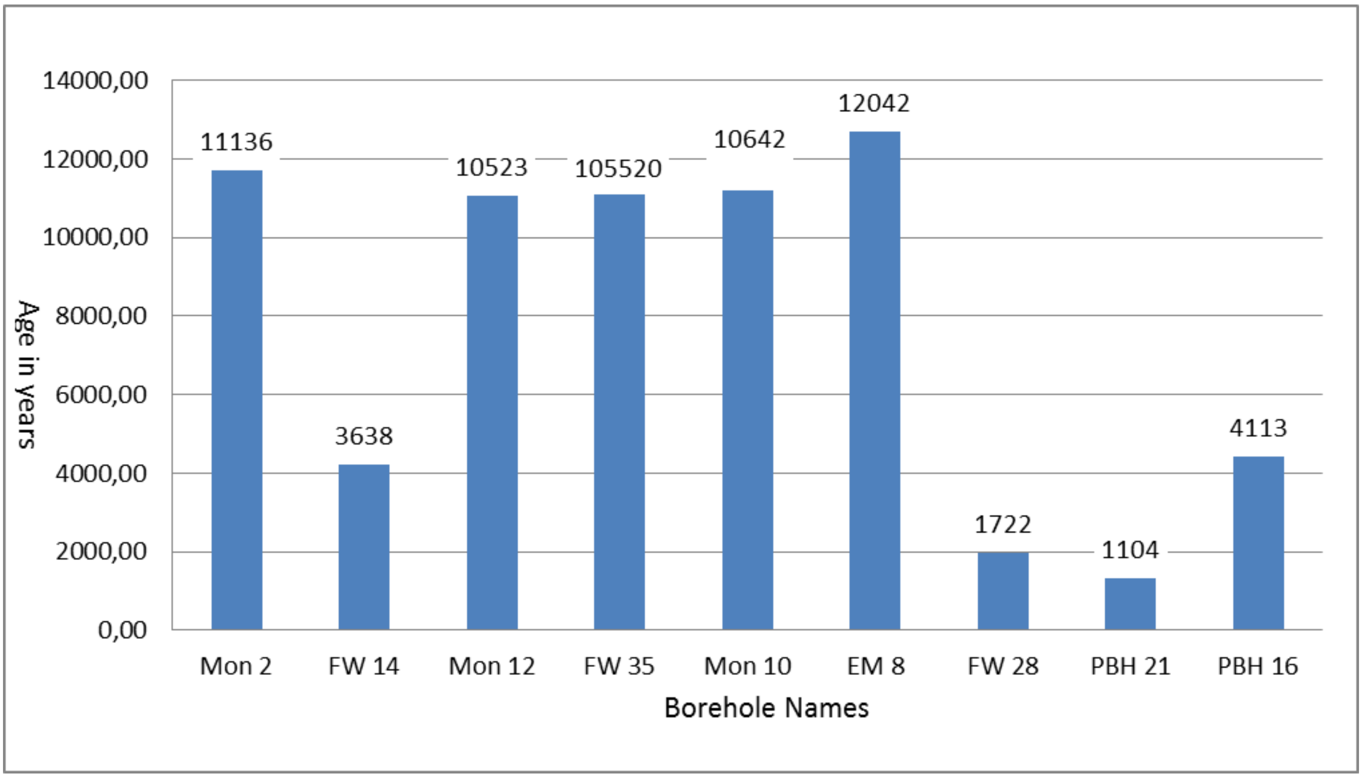

Figure 52: Carbon 14 groundwater age for boreholes at the VRWS recorded for 2014

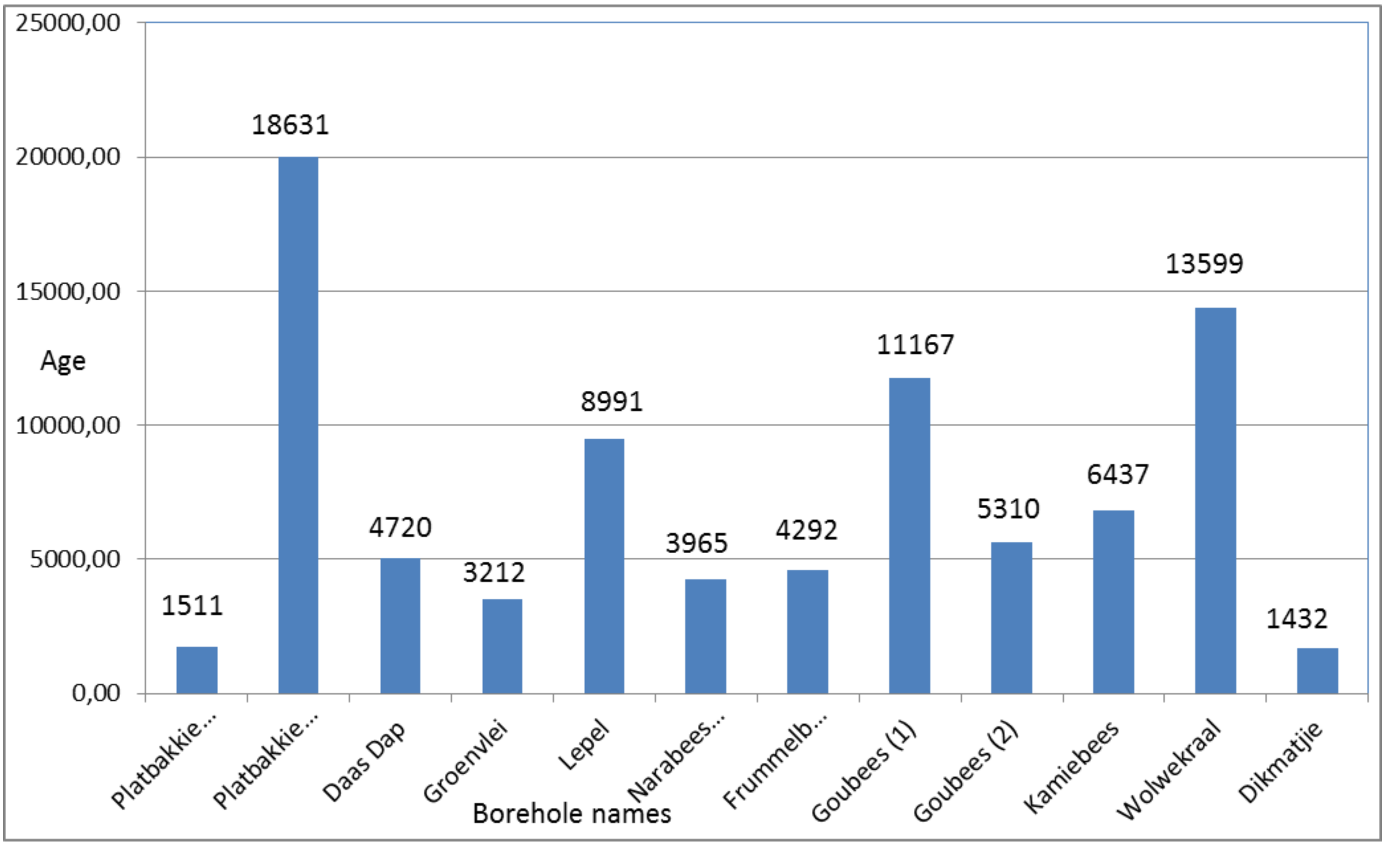

Figure 53: Carbon 14 age dating for selected boreholes in the 20 km radius surrounding farms, recorded in 2014

Platbakkies farm has two boreholes: Platbakkies1, aged 1,510 years, and Platbakkies (PB2T), aged 18,631 years. Lepel farm borehole was also age-dated to be 8,991years and, in 1985, another borehole in Lepel was age-dated to be 6 200 years. The following farms show no change in carbon 14 age estimation: Platbakkies1, Boesmanplaat and Dikmatjie. The overall results of the Carbon14 dating in the study area indicate dominance of old water of between 6,000 to 19,000 years old. There is evidence of potential recharge in some boreholes, with age-dating ranging from 1,300 to 4,000 years, but no indication of fresh groundwater.

6.1.3. ^{18}O and ^{2}H

Oxygen has three stable isotopes ^{18}O, ^{18}O and ^{18}O. ^{18}O is used for radioisotope analysis. The enrichment δ ^{18}O value is calculated as follows:

$$\delta^{18}O‰ = [^{18}O/^{16}O\ (sample) - {}^{18}O/^{16}O\ (standard)/\ {}^{18}O/^{16}O\ (standard)] * 1000$$

Equation 3

When the $\delta^{18}O$ value is +10 the groundwater is enriched in ^{18}O and when the value is -10, it means the sample is depleted in ^{18}O (Rollinson, 1993). $\Delta^{18}O$ values vary in nature by about 100‰, about half of this range occurs in meteoric water (Figure 23). According to Rollinson (1993) most granites, metamorphic rock and sedimentary rocks are enriched in $\delta^{18}O$ relative to mantle value whereas seawater and meteoric water are depleted. In order to analyse the groundwater results for the Vaalputs Site and the surrounding farms, two natural occurring waters will be used as a standard, meteoric water (precipitation water) and sea water. Present day sea water has 0 value $\delta^{18}O$ and 0 value δD, while meteoric water is represented by the equation below:

$$\delta D\text{‰} = 8\delta^{18}O + 10$$ Equation 4

For the interpretation of δ1⁸O and δD in the study area, an excel spreadsheet developed by Van Tonder and Xu (2000) was used for recharge estimates. Figure 54 and Figure 55 shows a graph of $\delta^{18}O$ versus δD. On the Vaalputs Site, eight boreholes were selected for ^{18}O and deuterium analyses see full dataset on Appendix D, Table 25. The ^{18}O concentration in the Vaalputs Site ranges from -3‰ to -5‰ indicating depletion of ^{18}O in groundwater. Deuterium concentration ranges from -26‰ to -33‰ due to long residence time of groundwater. On the surrounding farms within the 20km radius around the Vaalputs Site, ^{18}O concentration groundwater ranges from -5‰ to -3‰ and deuterium ranges from -30‰ to -40‰ at the centre of the graph below the meteoric line which indicates field formation water. This indicates that the recharge is seasonal possibly during the winter rainy season. Field formation groundwater is affected by evaporation and precipitation and as a result small amounts percolate to the saturated zone. The Vaalputs Site ^{18}O and deuterium concentration are also indicative of deep groundwater and flat elevation.

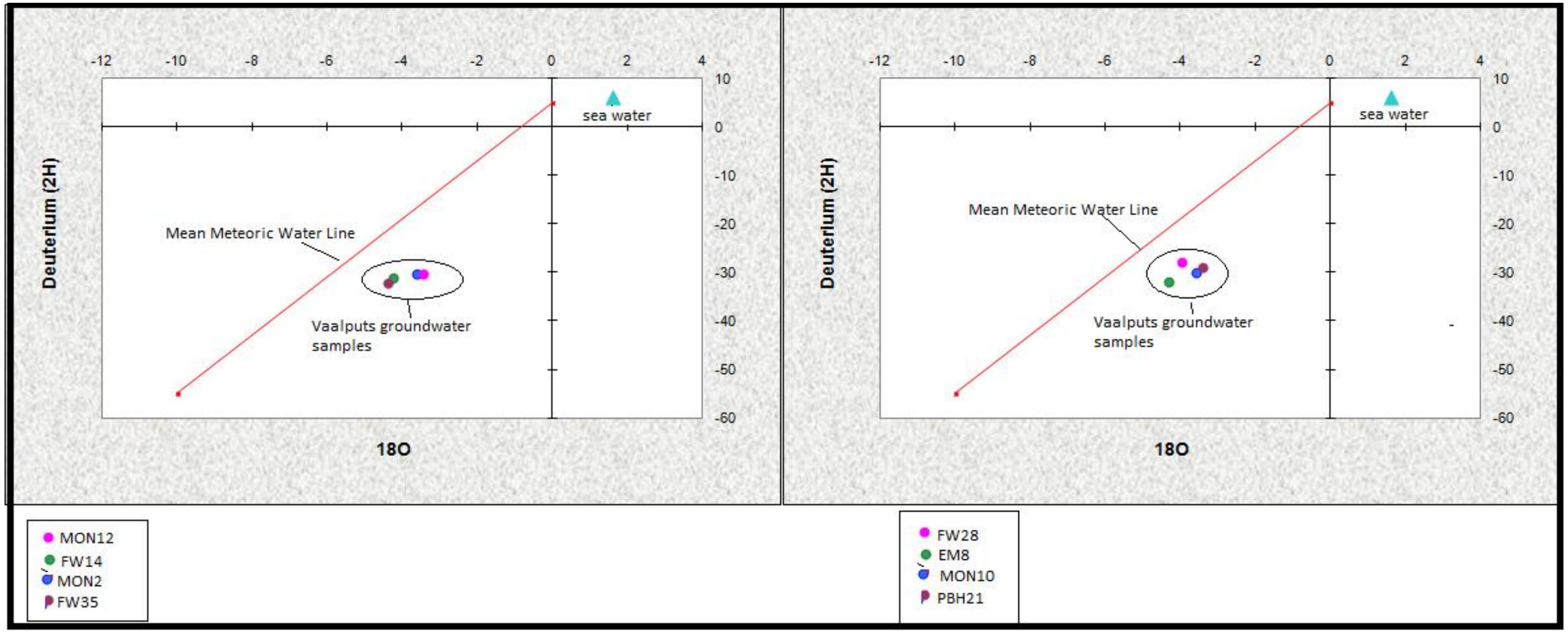

Figure 54: Oxygen-18 and deuterium values of the boreholes located on the Vaalputs Site with meteoric water line

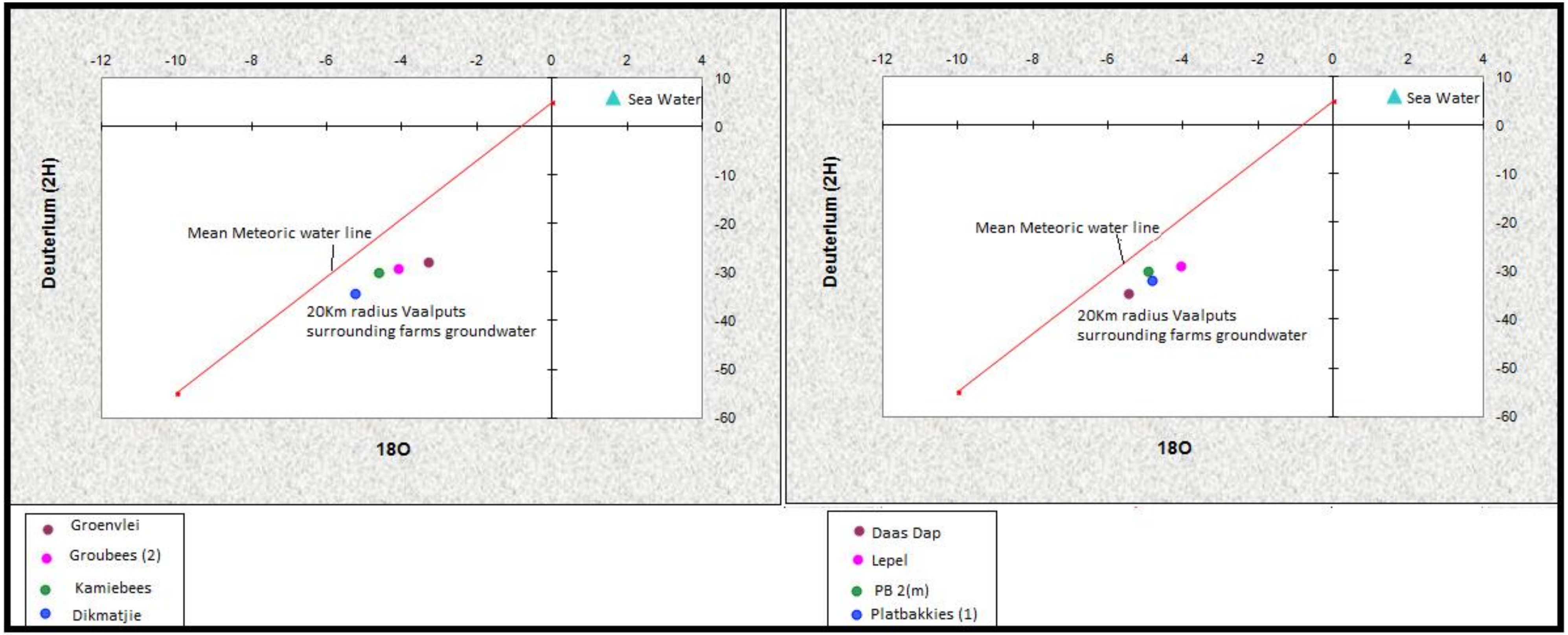

Figure 55: Oxygen-18 and deuterium values of the boreholes located on the 20Km radius surrounding farms with meteoric water line

7. GEOHYDROLOGY

7.1. INTRODUCTION

The hydrogeology of any given region or area can generally be described by the following components:

- Geology;
- Unsaturated subterranean zone;
- Saturated subterranean zone, which will include the aquifer(s); and
- Recharge and recharge mechanisms.

Relevant field recordings and measurements that will contribute to identifying the components above include:

- Lithology;
- Groundwater levels;
- Rainfall,
- Evapotranspiration; and
- Drawdown measurements as part of a slug test or longer term aquifer test.

As one component will influence the reactions and behavior of all the others, care must be taken to evaluate the hydrogeology of a specific region or area in a holistic manner and not as different entities of their own.

7.2. GEOLOGY

7.2.1. Unsaturated zone

As groundwater originates from precipitation, the initial interaction with the subsurface environment will be the first obstacle to overcome in order to end up as recharge in an aquifer. The unsaturated zone at the VRWS has been determined as 57 mbgl (Pretorius, 2012). Groundwater levels observed during 2013 and 2014 support this evidence of a very thick unsaturated zone. According to Van Blerk (2006) this layer can be sub-divided into 4 distinct stratigraphic successions:

- A 0.5 to 1 m layer of loose and partially ferrunginised aeolian sand (sand; dorbank).
- A 1 to 5 m greywacke layer that is calcrete/calcretised with some silcrete nodules- previously referred to as calcrete; and
- A 10 to 15 m kaolinitic/montmorillonitic clay layer that developed in situ from the underlying basement - previously referred to as white clay;
- A 15 to 20 m fluvial red/brown to greenish/greyish feldspathic greywacke layer, grit to pebbly - previously referred to as red clay;

7.2.1.1. Geohydrological impacts

Groundwater movement through the unsaturated zone can be primarily considered as a downward pathway due to rainfall and gravitational forces. However, a water balance in the area will also involve a possible upward migration due to evapotranspiration.

Some uncertainty still exists as to the saturated hydraulic conductivities, due to a lack of reliable data. Simulated values by Van Blerk (2006) indicate higher values than those determined by Van der Watt for the period 1984 to 1986.

Previously assumed recharge rates of 1 to 2 % of the MAP as a constant flux, indicated advective groundwater travel times of between 2,000 and 10,000 years. This does not include migration via possible preferential pathways.

A zero flux plane develops at a depth of 0.5 to 1 m below surface and, only during periods of prolonged and continuous drought, moisture from deeper layers will be drawn towards the surface, with the effect that the zero flux plane migrates downwards to greater depths of a maximum of 5 m.

The thick unsaturated zone associated with the area where most of the activities take place at the VRWS is therefore very suitable and will inhibit fluid as well as any possible pollutant migration towards the groundwater table.

7.2.2. Saturated zone

The saturated zone includes the rock formations below the water table and will include both more and less permeable strata. An aquifer is defined as an underground layer of water- bearing permeable rock, rock fractures or unconsolidated materials from which groundwater can be extracted for use in economic quantities. A successful borehole is a relative entity depending on the expectations of the borehole owner. Irrigation farmers will require much higher yielding boreholes than a farmer looking for water for his animals.

In the Vaalputs area, the most prominent aquifer is associated with the weathered and hard granitic, charnocktic orthogneisses of the newly proposed Southern Megacrystic Suite underlying the Site (Andreoli et al., 2006; Levin, 1988). This aquifer is regarded as semi-confined to confined, which would indicate impermeable rock formations above and below this aquifer.

On a regional as well as local scale, groundwater flow directions and velocities are influenced by zones of higher permeability, such as fault zones and intrusive rock formations. These structural controls can either be conducive or inhibiting to groundwater flow, depending on the original mechanisms that were responsible for its geomorphological development. Compartmentalisation can therefore occur and the system can be regarded as a double porosity system where weathered conduits will have higher transmissivity than the matrix rocks, but lower storage capabilities. Each compartment will have its own characteristics that will influence the hydraulic properties, but, on a regional scale, transfer between compartments do occur (Van Blerk, 2008).

Major boundaries of the groundwater regime include:

- A topographical groundwater divide in the West;
- The Kamiebees Shear Zone in the North;
- The Platbakkies Shear Zone in the South; and
- A physical boundary in the East, which is due to the presence of the Koa River Valley drainage system. Some of the flow ends up in a pan or surface depression called Santab se Vloer.

7.2.2.1. Groundwater levels

Figure 56 shows the water level graph of boreholes drilled next to the watershed; their water levels range between 34 to 38 m. There is a distinct separation between boreholes drilled on the western side of the disposal Site, with shallow water levels, and those drilled on the watershed, with low average water levels. The water level graph (Figure 57) shows boreholes with deep groundwater located on the disposal Site. Most of these boreholes have water levels below 50 m. The Vaalputs disposal Site elevation is between 1,015 m to 1,005 m from east to west. There is one borehole (PBH21) in the disposal Site with shallow water level of 33.35 m. This borehole is drilled North-West of the disposal Site, close to the watershed. The overall trends of these boreholes, especially the MONs and GWBs, have stable water levels between 50 to 55 m (Figure 57). Figure 58 is a water level contour map for selected boreholes on the VRWS. The contour map indicates water levels range between 950 mamsl to 1050 mamsl. On the disposal area, a dark pink shade is dominant, indicating water levels of +1050 mamsl. These low water levels are important in a radioactive waste Site to slow down any possible contaminant.

Some definite trends can be observed from the groundwater level data:

- The disposal Site is dominated by summer rainfall, with high evaporation rates due to high summer temperatures;
- The saturated zone is between 50 to 60 m deep, which suggests long resident time before the rainwater reaches the water table;
- The geochemical Piper diagrams suggest that the dominant water is old, stagnant and saline water; and
- The radioisotope results confirm long residence time with minimum to no tritium concentration in some of the boreholes in the study area.

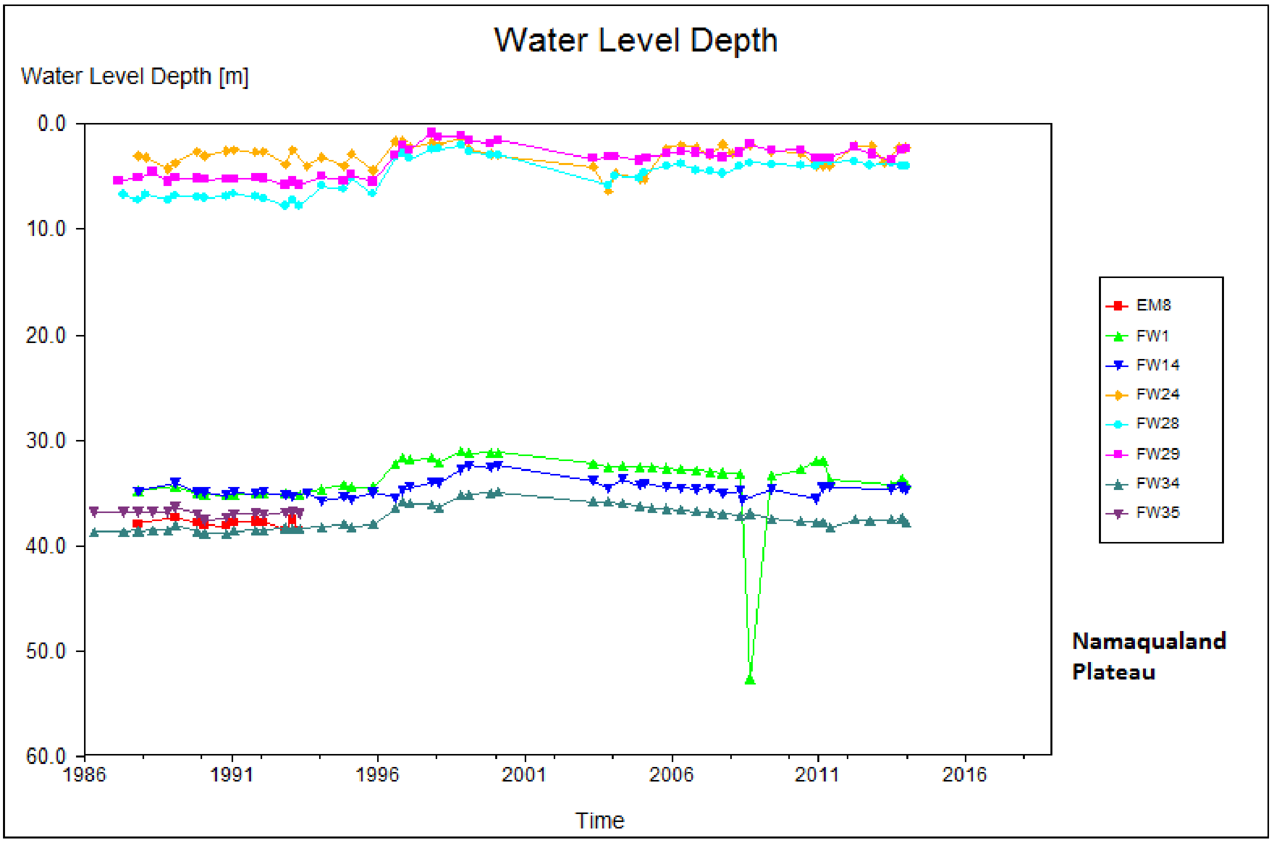

Figure 56: Groundwater levels of boreholes located on the Namaqualand Plateau to the western side of the VRWS

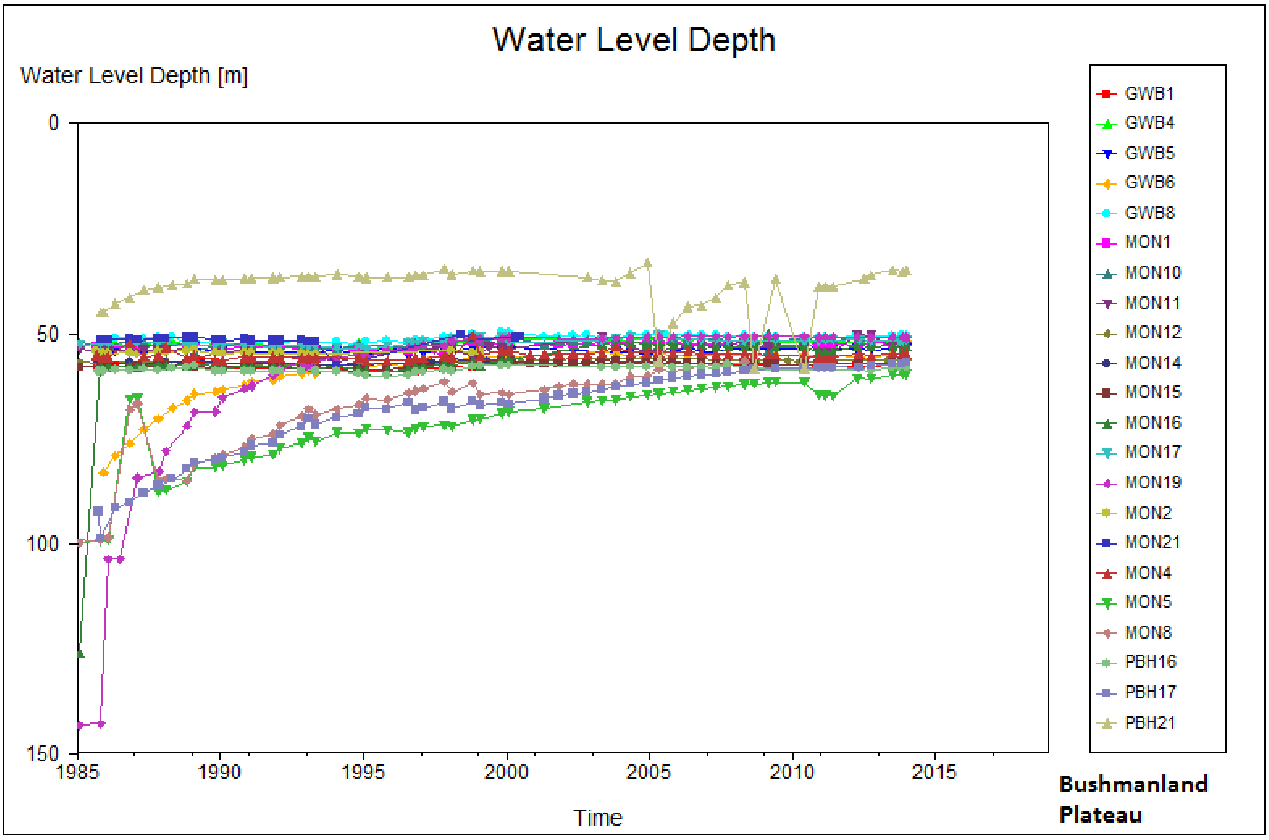

Figure 57: Groundwater levels of boreholes located on the Bushmanland Plateau to the eastern side of the VRWS

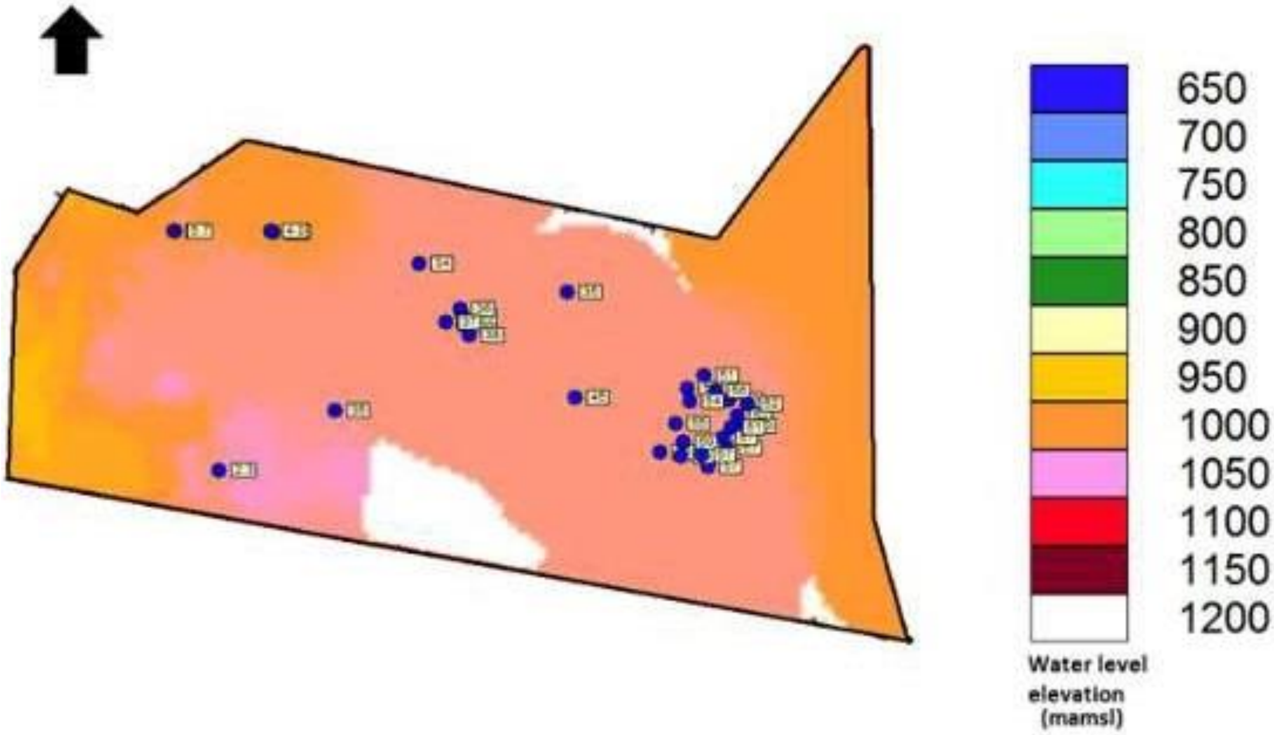

Figure 58: VRWS contoured groundwater level map

7.2.2.2. Slug and aquifer test

There were four boreholes ,FW26, FW28, FW27 and Garing1 selected for a slug test at the Vaalputs Site. The slug test was performed to estimate the aquifer parameters see Table 13 for slug test results. As mentioned on the methodology chapter, the volume of the slug used is 0.943 m³, the raduis of the Slug is 0.0655m and the length is 0.7m. Taking into consideration the volume of the slug and the time it took for these boreholes to recover, one would conclude that these boreholes are low yielding boreholes. The results show these boreholes took more than 3 min to recover to their initial water levels which gives an indication of low yields, low transmissivity and high storativity.

Table 13: slug test results of four boreholes located on the VRWS

Borehole Name	Initial water level (m)	Slug test (min)
FW26	5.05	+3min
FW28	3.94	+3min
FW27	5.99	+3min
Garing1	5.61	+3min

Aquifer tests were conducted on two boreholes, Garing1 and FW28 within the Vaalputs Site. These boreholes were each pump tested at 0.06l/s for approximately 14 minutes using a pump test method known as the contant rate test. The constant rate test was performed on borehole FW28 for 13.30 min. The initial water level was 3.94m and after pumping drawdown was 21.25m. Figure 59 shows the cooper jacob diagram used to diagnose the aquifer test. The transmissivity of the matrix was estimated to be 0.4m²/d.

A constant rate test was performed on borehole Garing1 for 10min with an initial water level of 5.61m. After pumping for 10 min, the drawdown was at 19.27m with a constant pump rate of 0.6l/s. Figure 60 Cooper Jacob method was used to diagnose the aquifer test. The transmissivity of the matrix was estimated at 0.5m²/d. Garing1 took more than 4 hours to recover to its initial water level. A longer pump test is not recommended for this borehole due to slow recovery. FW28 took longer than three hours to for a 90% recovery level. The recommendation for Garing 1 also applies to FW28. Table 14 shows transmissivity values for borehole Garing 1 and FW28.

Table 14: Transmissivity values diagnosed using Cooper Jacob method

Boreholes	Garing1	FW28
Transmissivity	0.5m²/d	0.4m²/d

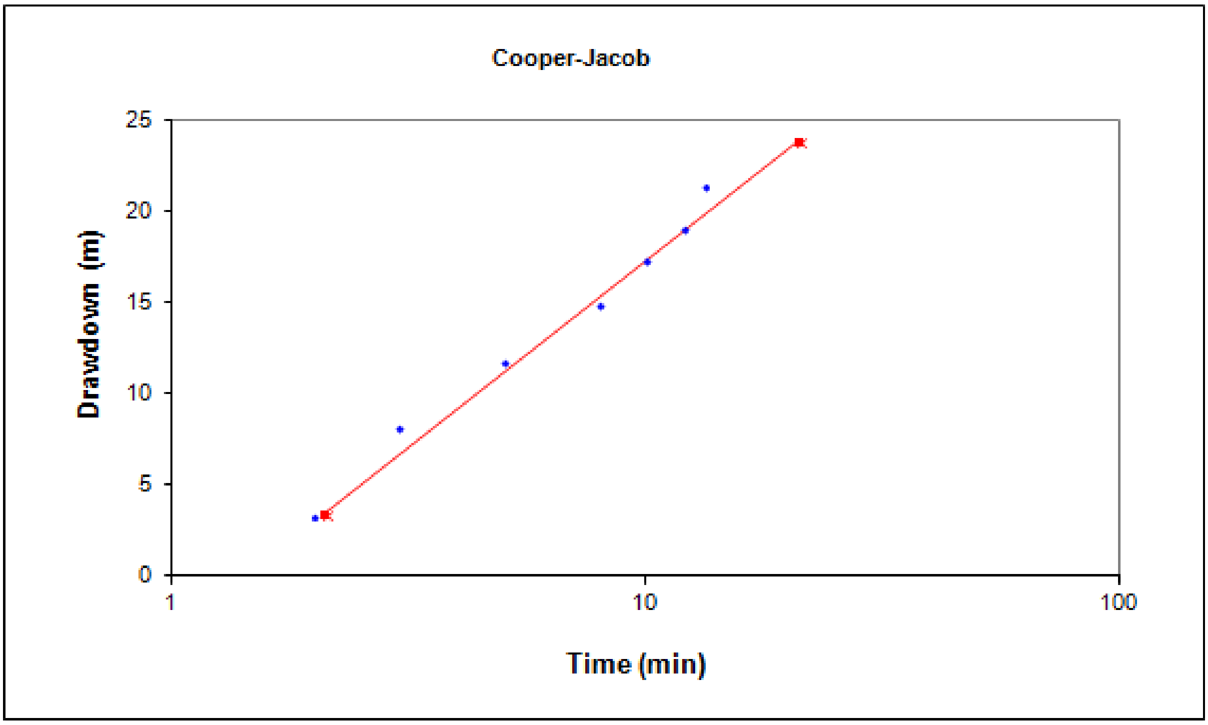

Figure 59: diagnostic of aquifer test for FW 28 using the Cooper Jacob method

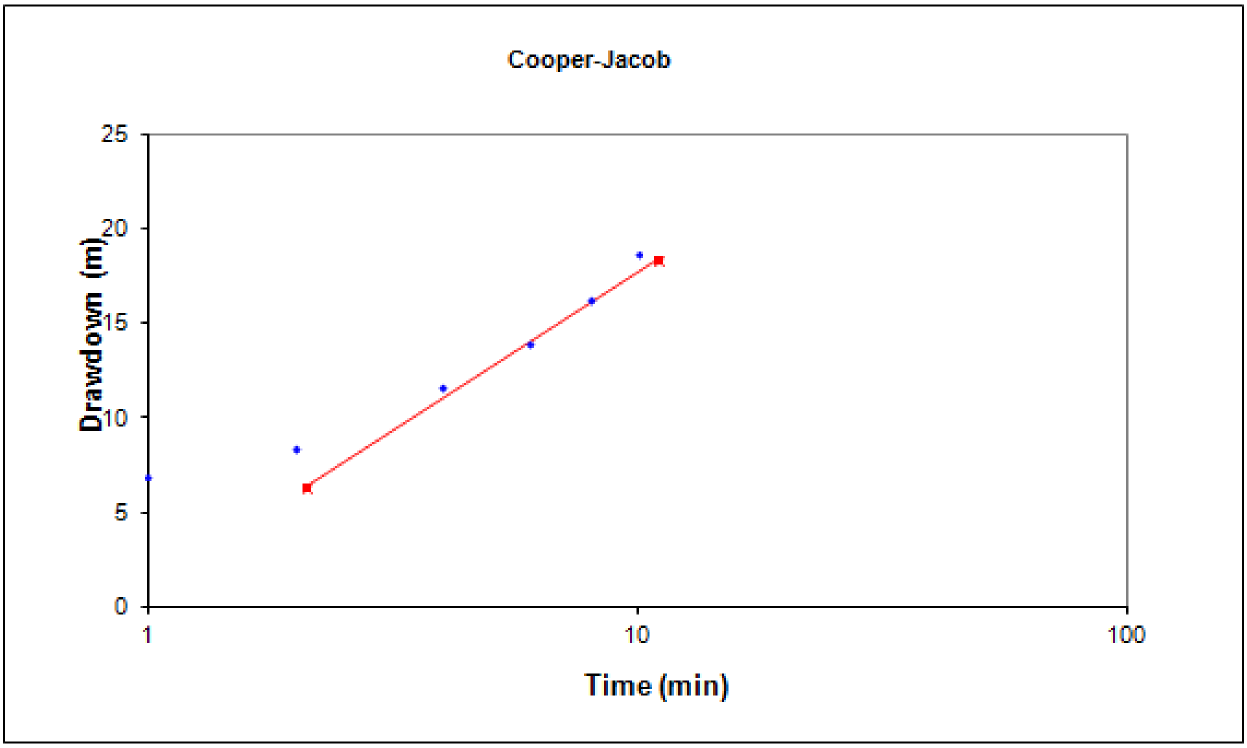

Figure 60: diagnostic of aquifer test for Garing1 using the Cooper Jacob method

8. CONCEPTUAL MODEL

A conceptual model consists of a set of assumptions that describe the aquifer systems composition, based on field observations and data interpretation (WRC 1093/1/04). A conceptual model is a pictorial representation of the ground-water flow system. A conceptual model is frequently in the form of a simplified diagram or hydrogeological cross section. The conceptual model defines the dimensions of a numerical model, how the grid is designed and how the grid is oriented. According to NRC (2003), a conceptual model is an evolving hypothesis identifying the important features, processes and events controlling fluid flow at a specific field Site. The assumptions that constitute a conceptual model should relate to the following items (EPA/540/S-92/005, 1992):

- The flow regime,
- The matrix of the aquifer with reference to its homogeneity, heterogeneity, anisotropy and isotropy.

According to (REF: eng.ucmerced.edu), homogeneous is if the hydraulic conductivity K is independent of position within a geologic formation. If K is dependent on position within a geologic formation, which is always the case in groundwater systems, the formation is heterogeneous. In a homogeneous formation, $K(x, y, z) = C$, C being a constant; whereas in a heterogeneous formation $K(x, y, z) \neq C$.

If the hydraulic conductivity K is independent of the direction of measurement at a point in a geologic formation, the formation is isotropic at that point. If the hydraulic conductivity K varies with the direction of measurement at a point in a geologic formation, the formation is anisotropic at that point (REF: eng.ucmerced.edu).

Constructing a representative conceptual model and the degree of simplification in any particular case depends on available resources and information. Elements of a comprehensive conceptual model development process include (Van Blerk, 2008):

- The geological formation and aquifer type,
- The boundary conditions,
- The groundwater quality,
- Geometric structure of the system.

Although a conceptual model is by necessity a simplification of information, it should relate to the problem being addressed. The context in which the model is developed constrains the range of applicability of the model.

8.1. GEOMETRIC STRUCTURE OF THE SYSTEM

The geology of the Vaalputs Site and surrounding farms has been described as charnocktic orthogneisses with quartz-feldspathic gneiss, possibly supracrustally intensely deformed and metamorphosed during the Namaqua Orogeny (Brynard, 1988).

The granitic gneiss is overlain by the Karoo Dwyka, but to the south of the Vaalputs Site there are sedimentary rocks from the Dasdap formation. Across the Vaalputs Site there is Vaalputs formation and a thin layer of unconsolidated sand from the Gordonia formation which completes the stratigraphy.

8.2. BOUNDARY CONDITIONS

Boundary conditions normally occur at the edge of the model area, i.e., rivers, wells and leaky impoundments. Hydraulic boundaries are selected primarily on topographic, hydrological, recharge, discharge and geological assumptions. The study area is divided by the North-south watershed escarpment into two broad regions, the Namaqualand and the Bushmanland plateaus. The drainage basins of the Buffels River occupy the West, the Olifants River the South to South-West and the Koa River the North-East. In the North, Vaalputs is bounded by the Kamiebees Shear Zone and in the south by the Platbakkies Shear Zone. There is one depression in the South-East of the disposal area which acts as a drainage system, the Santab se Vloer pan. All rainfall onto the area will drain away from the disposal site to one of these large depressions. It is known from previous studies that daingage courses in the study area are largely inactive and end up in pans e.g Santab Se Vloer.

8.3. THE GROUNDWATER QUALITY

Sampling performed for this study has not revealed any indication of pollution of groundwater in the Vaalputs Site and surrounding farms. Chemical diagrams used to interpret data shows similar water type as in the past. The nature of the study area is that of semi-arid desert, most of the anions and cations results are elevated, most of them are above the water quality standard. The groundwater is very saline, brittle due to its resident time.

8.4. STRUCTURAL LINEAMENT IN THE STUDY AREA

Figure 51 shows a structural map with major faults and lineaments for the Vaalputs Site and surrounding farms. It is noticeable that the aquifer in the study area is controlled by fault zones which may be permeable and impermeable, depending on location and the magnitude of the faults. The resulting effect is a division into compartments; some of the faults or fracture zones therefore act as conduits and some as groundwater flow barriers. The weathered zone will have higher hydraulic conductivities than the hard fractured granite, the latter of which consists of a matrix with a low hydraulic conductivity and the fractures with a higher hydraulic conductivity. This is evident in groundwater level data where a number of boreholes are dry and some have groundwater level 50 m below the surface.

The weathered granite in the study area has higher hydraulic conductivity than the hard fractured granites. This was proven by the pump test done with matrix hydraulic conductivity values higher than the hydraulic conductivity of the fracture granites (adapted after Vivier and Van Blerk 2000). Figure 61 is a graph of topography versus water levels of 12 boreholes located on the VRWS. The measured water levels versus topography show an 87% correlation. Deviation from the straight line indicates a match between the measured water levels and topography. This indicates water level or unconfined aquifer in the Vaalputs disposal area. Figure 62 shows a 61% correlation between water levels and topography. What is quite clear from the graph is that the aquifer located on the Namaqualand to the watershed resembles a semi-confined aquifer.

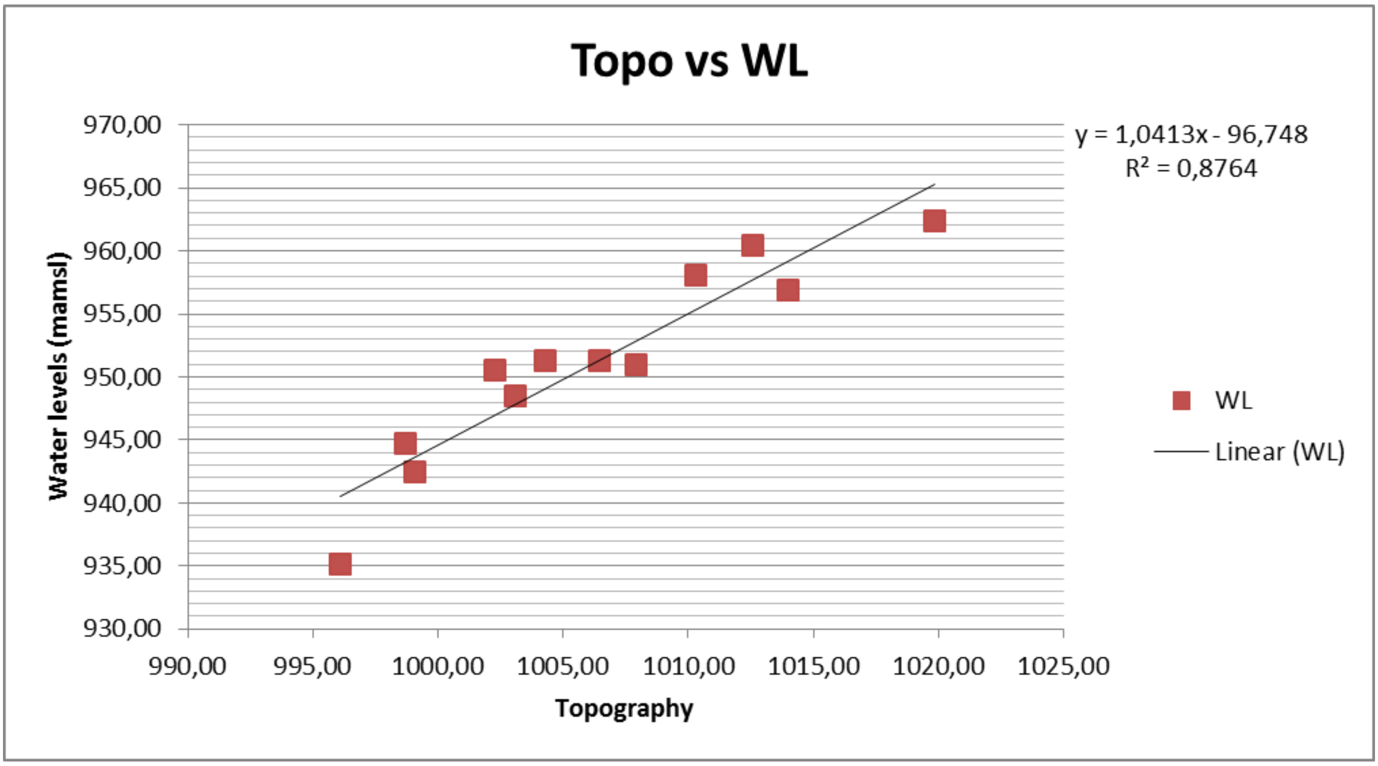

Figure 61: Graph of topography vs. groundwater level of boreholes in unconfined aquifer

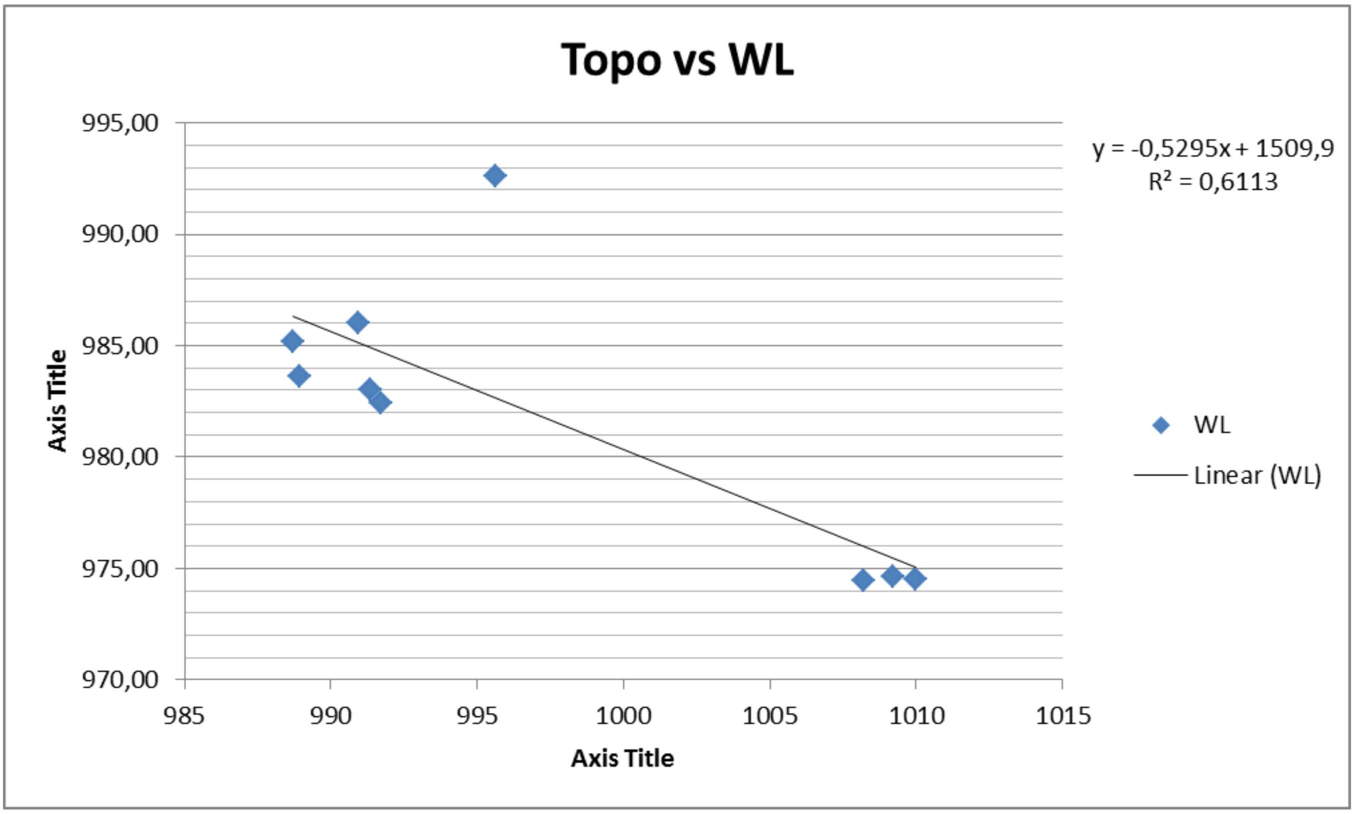

Figure 62: Graph of topography vs. groundwater level of boreholes in semi-confined aquifer

8.4.1. Piezometers

There are four boreholes drilled in excess of 150 m in the study area, i.e. MON14, MON15, MON16 and MON19. The remaining boreholes in the Vaalputs Site are drilled in excess of 100 m below the surface. The deepest water level recorded in the study area was 130 m in borehole MON19 in 1987, but rose to 50 m below surface over the years. The shallow water levels recorded in borehole FW24 and FW29 were in excess of 1.57 m and 1.11 m. The Vaalputs disposal Site elevation ranges from 1,008 m to 1,015 m with topographical variance of less than a metre.

8.4.2. Recharge

Recharge in the Vaalputs area and surrounding farms was estimated using numerous methods. Carbon 14 dating estimation for the Vaalputs disposal Site ranges between 1,300 and 12,700 years. VRWS and surrounding farms' groundwater age estimation is between 1,600 to 19,900 years. Two boreholes in the study area, PBH21 and PBH16, show alarming carbon 14 replenishment. Table 15 shows a comparison of carbon 14 age estimate for year 2000 and 2014, there is carbon replenishment in three boreholes. The remaining boreholes show constant carbon 14 concentration when compared with the 1985 and 2000 results. These results further confirms low recharge in the disposal site, however borehole PBH16 needs to be monitored. The tritium data for the study area is dominated by concentrations ranging from 0.0 to 0.2 T.U., which indicates the majority of boreholes in the study area. The concentration of ^{18}O in VRWS ranges from -3‰ to -5‰ meaning groundwater is depleted of ^{18}O. Deuterium concentration ranges from -26‰ to -33‰ due to long residence time of groundwater. These ^{18}O and deuterium concentrations are similar to those of surrounding farms. These results confirm low recharge in the study area.

Table 15: ^{14}C age dating comparison for year 2000 and year 2014

Boreholes	^{14}C (age)	Boreholes	^{14}C (age)
MON 12	12600	Mon 12	10523
EM 8	11400	EM 8	12042
PBH 16	7100	PBH 16	4113
FW 35	9200	FW 35	10552

8.4.3. System processes

Precipitation plays a crucial role on the soil moisture content. The subsurface has the ability to retain water for a considerable length of time. In the study area, the soil moisture content study had been undertaken to understand water retention mechanisms of the various soil types. The soil moisture results showed moisture due to impact of rain could only be detected in the first 3m to 3.5 m below the surface. Figure 63 shows 7 m of soil types in the VRWS. The soil types are important in understanding how long it takes for the three physical processes (infiltration, internal drainage and redistribution) to occur in the unsaturated zone. This is important for the recharge estimation.

It is clear from the geometric system that the aquifer in the study area is of dissimilar structure and composition. When an aquifer is heterogeneous, it means that parameters may very over short distances. This has been evident in hydraulic conductivity values that range from 0.75 ℓ/s to 3.6 ℓ/s within the disposal site.

Aquifer transmissivity (T) is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It is expressed as the product of average hydraulic conductivity and thickness of the saturated portion of an aquifer. The transmissivity values obtained from aquifer tests in the VRWS are 1.51 m²/d, 0.83 m²/d, 0.5 m²/d and 0.4 m²/d. these transmissivity values are of the eastern side of the study area in the disposal site. On the western side of the study area where the granitic gneiss is severely fractured a slug test was conducted on four boreholes (FW26, FW28, FW27 and Garing1). All four of these boreholes took more than 3 minutes to recover. The results proved these boreholes were not suitable for 6 hour aquifer test. Unfortunately was a parameter uncertainty that could not be resolved in this study.

Storage coefficient (S) is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. The storativity values obtained from the aquifer tests are 4.25E-02, 3.40E-04, 2.19E-04 and 1.21E-04.

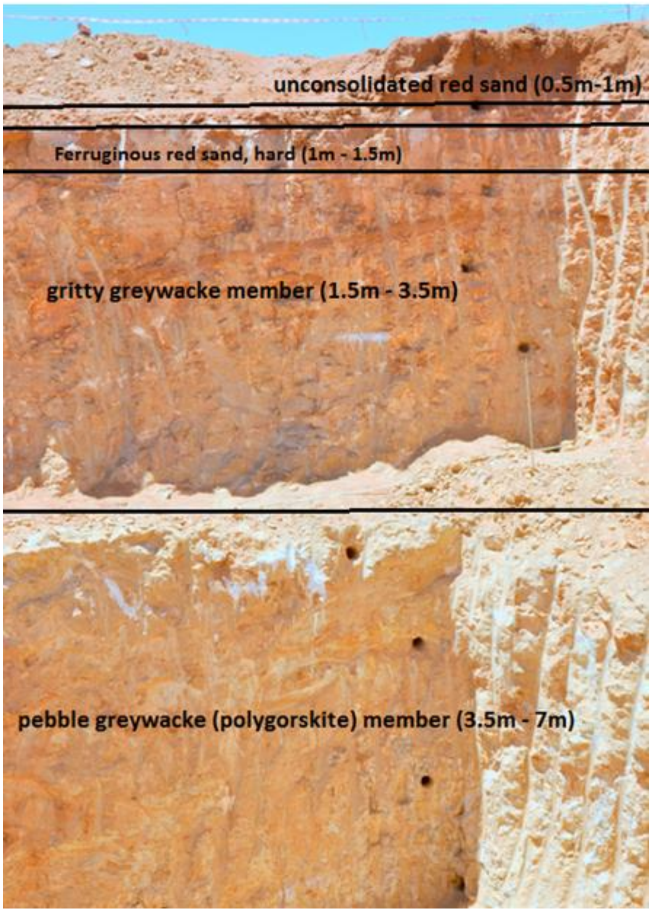

Figure 63: Trench CO1 at the Vaalputs Site displaying soil types (not to scale)

8.4.4. Simplified assumptions

The most important aquifer in the study area is located in the fractured crystalline rocks which underlie the disposal Site. The aquifer, according to Levin (1988), is of tectonic origin. Groundwater is confined to fractures and weathered joints and constitutes a confined aquifer.

The unsaturated zone in the study area is different in structure and composition throughout. This has been evident in the hydrological, geochemical and recharge results.

The aquifer assumes different aquifer types according to different locations within the VRWS. Figure 61 and Figure 62, display that the correlation between topography and water level ranges from 87% and 61%, respectively, with boreholes located within the disposal Site. This, in turn, influences why the model has different parameter values within a short span of time.

The study area experiences anticyclonic conditions throughout the year. It is dominated by both winter and summer rainfall. The disposal Site experiences summer rainfall and the Namaqualand experiences winter rainfall. The mean rainfall is 130 mm, with winter rainfall (April to September) at an annual average of 10.7 mm. This indicates a slight, yet visible dominance of winter rainfall. The recharge estimations in the study area do not reflect the rainfall pattern. The disposal area's ^{14}C age estimate ranges from 11,728 to 12,706 years with no tritium present. The entire study area experiences extremely low recharge.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1. HYDROCENSUS

- Except for borehole PBH21 all boreholes (MONs and GWBs) located on the disposal Site show stable groundwater levels for period 1986 to 2014. These low piezometric heads are important in a radioactive waste Site to slow down any possible contaminant.
- Boreholes FW1, FW14 and FW34 were drilled on the water shed, their water level ranges between 34-38m, these boreholes also shows signs of stability over the monitoring period.
- A Slug test was conducted at the VRWS to establish a first estimate of localised parameters. This test was conducted on four boreholes and results showed these boreholes took more than 3 min to recover to their initial water levels which gives an indication of low yields, low transmissivity and high storativity. Due to these results a longer efficient aquifer test could not be performed in risk of dewatering these boreholes.
- A constant test for maximum of 14 min was performed on Garing1 and FW28 at a pump rate of 0.06 ℓ/s. Both these boreholes took more than 4 hours to recover. A longer pump test is not recommended for these boreholes.

9.2. GROUNDWATER QUALITY

The groundwater chemistry is a vital aspect to consider and understand for the conceptual model and recharge consideration. Due to the lack of macro data in the early years, results presented in this dissertation should be judged qualitatively rather than quantitatively. The geochemistry limitations that were identified were:

- The total alkalinity of the groundwater (MALK) was not determined regularly over the sampling period for most boreholes. The unavailability of this parameter made it impossible to calculate the ionic balance for most samples, which could have been useful in checking the analytical correctness of the chemical analysis.
- Those samples with MALK analysis were selected to calculate ion balance, which, after the calculation, left only a handful of boreholes for proper chemical interpretation.
- What is mostly evident in the groundwater chemistry data is a Na-Mg-Cl type groundwater according to the Piper diagram. This groundwater type confirms results performed in the early construction phase, which was determined by the geohydrologist.
- However, there are two boreholes in the study area which have alarmingly high ions, i.e. Platbakkies2 and 13C5. These boreholes have high EC, calcium, sodium, chloride, sulphate and nitrate concentrations. BH13C5 is currently used for sampling purposes. This borehole is located on the Namaqualand plateau in the VRWS, while Platbakkies1 is located in Platbakkies farm and not in use.
- Chloride concentration in the study area is extremely high; with Platbakkies2 chloride concentration range of 9458 mg/l. borehole drilled on the Vaalputs formation have high chloride concentration. Most of the boreholes in Group B and C plot at the bottom right hand corner of the expanded Durov diagram.

- Sulphate concentration for Groups A, B, C and D is higher than the average South African mean of about 300 mg/ℓ. Reasons for high sulphates in the study area are: the leaching of sedimentary rocks and the reaction of calcium from calcrete to produce calcium sulphate, hence the high concentration of calcium. The high sulphate confirms that groundwater in the VRWS and surrounding farms has reached the end of its geohydrological cycle and is highly saline.
- Nitrate was sometimes reported as N and at other times as NO_3. These are two different elements and could affect the development of the conceptual model. A standardised approach for this element needs to be adopted. Even though specific elements do not reflect an indication of contamination; elements such as chloride, electric conductivity, sulphate and nitrate need to be constantly monitored for both winter and summer seasons.

9.3. RECHARGE EVALUATION

- In the early 1980s, radioisotope studies done by Levin (1983a) showed ^{14}C groundwater age for VRWS to be between 6,000 to 13,000 years. It was reported that no water less than 50 years was found to be below the top 4 m of soil.
- These results were later verified by Vivier and Van Blerk (2000) when they conducted a radioisotope study and found the groundwater age of the VRWS to be 6,200 to 12,600 years old.
- Both these studies were conducted on the Vaalputs disposal Site and not the entire VRWS. In 2014, however, the radioisotope studies showed different results, with ages ranging from 1,300 to 12,700 years. There is evidence of ^{14}C replenishment in the two boreholes PBH16 and PBH21. The remaining boreholes, MON12, MON21, GWB3, GWB5, EM8 and FW35, show similar ^{14}C, which confirms results from previous studies.
- In surrounding farms, groundwater age ranges from 1,600 to 19,900 years. Boreholes Dikmatjie, Platbakkies 1, Groenvlei, Norabees 2 and Frommelbakkies show signs of potential recharge. This is also evident in their tritium concentration values, which range from 0.4 to 1.2 T.U.
- Tritium concentrations around the disposal area range from 0.0 to 0.2, which indicates little to no tritium present. There are however two boreholes in the VRWS with high tritium concentration, PHB16 and PBH22, with tritium concentration of 0.7 T.U.
- With the exception of PBH16 and PBH21, and additional boreholes that were not sampled in the past, ^{14}C age dating and tritium concentration results are similar to those of Levin (1988) and Vivier (2000).
- ^{18}O and ^{2}H concentrations for groundwater of the study area confirm the natural chemistry results, where cation and anion levels indicate stagnant, saline groundwater.

9.4. CONCEPTUAL MODEL

- Precipitation plays a crucial role on the soil moisture content. The subsurface has the ability to retain water for a period of time. In the study area the soil moisture content study had been undertaken to understand the water retention mechanisms of various soil types. The soil moisture results showed moisture due to impact of rain could only be detected in the first 3 to 3.5 m below the surface. This is important for the recharge estimation.
- The VRWS aquifer type is both confined and semi-confined. This is based on two graphs correlating water level and topography (Figure 56 and Figure 57). What is quite clear from the graphs is that the aquifer located on the Namaqualand to the watershed resembles a semi-confined aquifer and the Bushmanland aquifer displays signs of a confined nature. The aquifer at the study area is heterogeneous, but parameters may vary over short distances. These parameters include the storativity, transmissivity, recharge and piezometric head.
- Storage coefficient (S) is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. The storativity values obtained from aquifer test are 4.25E02, 3.40E-04, 2.19E-04 and 1.21E-04
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9.5. RECOMMENDATIONS

- A proper pump test that includes the drawdown test, constant discharge test and recovery monitoring needs to be performed at the VRWS for estimation of different parameters and to improve the conceptual model. Unfortunately, there were restrictions on Site which prevented these test from being done for this dissertation.
- Groundwater measurements need to be measured with the upper casing of the borehole included to maintain consistency. This is important in improving the Safety Case Assessment.
- The ion balance calculation done for this study revealed compromised geochemical data from an analytical point of view. A regular total alkalinity analysis should be done for all sampled boreholes to correct this error.
- Proper care should be administered at all times when sampling and analysing for groundwater chemistry, as this is the most important feature in the Safety Case Assessment.
- Radioisotope analysis must be performed annually for the proper understanding of groundwater recharge in the disposal Site. A number of boreholes were eliminated for the study due to restrictions. Those boreholes should be included in the next study to further improve the conceptual model.

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Summary

Radioactive waste, as a source of ionising radiation represents a potential hazard to health and must be managed in a regulatory manner, compatible with the internationally agreed principles and standards. Necsa (South African Nuclear Energy Cooperation) is responsible for the management of the Vaalputs Radioactive Waste Facility. VRWS is the only nuclear disposal Site in South Africa designed to dispose of Low and Intermediate Level Waste. The repository came into operation in the 1986. Near-surface disposal is an option used by many countries for the disposal of nuclear waste.

VRWS lies at an elevation of 1,005 to 1,012 m above sea level, with groundwater levels ranging from 1.11 to 7.89 m in the Namaqualand and 45 to 60 m in the Bushmanland. The study area experiences anticyclonic conditions with both winter and summer rainfall dominant. The mean annual evaporation pan for the VRWS is 2,383 mm. The mean annual precipitation for the study area was calculated as 129 mm for year 1986 to 2005.

There is minimum recharge and this was concluded by two studies done by Levin (1988) and Vivier and Van Blerk 2000, determining the age estimation using ^{14}C isotope data which range from 6,200 to 12,700 years. Tritium concentrations in the VRWS range from 0.0 to 0.2

T.U which further confirm slow recharge and old groundwater. When the chloride mass balance was calculated by Pretorius 2012, it showed recharge to be 0.10%.

Low recharge coupled with soil leaching had led to groundwater having very high EC, sulphates, calcium, and nitrates concentration. The groundwater in the VRWS tends to fall in the expended Durov on the last middle column and the last right end column which normally depicts groundwater that is at the end of geohydrological cycle. Groundwater type in the study area is a brackish (NaCl-rich) type which is old, stagnant water.

The VRWS is dominated by fractures faults and lineaments which act as water bearing structures, depending on location. The base rock is described by a number of geologists as granitic to charnockitic and is overlain by the Karoo formation, the Vaalputs formation and the Gordonia formation. The unsaturated zone in the study area is about 30 to 45 m while the water table lies between 50 to 55 m. The lithostratigraphy in the study area is a further restriction to recharge. Aquifer type at the VRWS resumes two types, i.e. the semi-confined and the confined aquifer, depending on location. A conceptual model should be developed with different parameter values over short time spans.

APPENDIX A

CLIMATE INFORMATION

Table 16: Rainfall data collected at the Vaalputs station between 1986 to 2012 (Necsa database)

VAALPUTS RAINFALL (mm)													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1986	2.6	0.0	1.8	9.8	0.4	0.0	0.4	14.0	2.6	-	-	-	31.6
1987	0.0	0.0	6.0	0.0	0.0	0.0	11.0	14.8	1.4	22.8	1.4	1.8	59.2
1988	0.0	4.4	7.4	6.0	3.4	9.6	1.2	11.4	0.8	1.0	0.0	0.0	45.2
1989	0.8	1.0	0.0	0.0	0.8	4.6	13.0	4.0	4.6	0.6	0.8	0.0	30.2
1990	0.0	16.0	5.0	40.1	5.0	13.0	7.0	15.9	0.0	0.0	0.6	8.6	111.2
1991	35.0	0.0	18.0	6.0	0.0	22.0	5.0	0.0	17.0	70.0	0.0	0.0	173.0
1992	0.0	1.4	2.4	3.5	2.4	31.6	7.9	4.6	1.8	19.0	4.9	0.0	79.5
1993	3.8	0.4	0.8	25.6	26.4	8.8	22.0	18.9	0.0	28.4	10.0	1.0	146.1
1994	23.4	11.6	54.6	17.2	0.8	19.8	15.8	1.2	1.0	4.0	1.2	0.8	151.4
1995	12.8	9.4	1.8	0.0	24.0	20.2	21.3	9.6	22.8	69.0	69.8	44.4	305.1
1996	0.4	14.4	1.6	1.2	4.6	3.8	72.2	21.2	16.4	31.0	36.6	0.0	203.4
1997	2.0	1.0	33.4	13.8	47.8	26.8	2.6	3.8	0.2	0.0	7.4	8.0	146.8
1998	16.4	5.8	12.2	0.0	9.4	1.0	2.8	3.2	7.8	0.2	12.2	0.6	71.6
1999	0.0	3.2	53.8	16.8	9.2	2.2	3.8	13.0	17.6	21.0	13.2	32.8	186.6
2000	48.0	37.2	22.2	3.8	16.4	2.8	30.6	2.0	2.8	0.0	6.2	0.0	172.0
2001	0.6	26.6	10.4	57.0	18.8	0.8	32.8	13.2	5.6	2.6	20.6	0.0	189.0
2002	2.0	18.8	14.0	29.0	29.0	7.4	9.0	10.8	7.0	5.4	0.0	0.0	132.4
2003	1.2	0.0	2.0	3.0	0.2	0.0	0.6	29.2	1.8	3.2	1.8	0.2	43.2
2004	28.8	10.0	0.2	25.6	1.0	9.6	0.0	1.6	4.8	25.4	0.0	2.6	109.6
2005	54.4	4.0	21.4	18.4	19.6	7.8	1.6	4.2	2.0	49.0	2.0	1.4	185.8
2006	0.0	17.6	4.0	32.2	61.4	6.8	5.4	16.6	2.0	1.8	24.0	0.2	172.0
2007	11.4	0.2	1.4	24.0	4.4	23.8	9.4	15.0	0.2	1.8	0.2	49.2	141.0
2008	2.0	5.6	41.2	0.0	30.4	18.6	27.2	8.4	2.4	0.4	0.0	0.0	136.2
2009	0.0	19.0	22.8	10.8	8.2	34.2	9.0	15.0	0.2	1.4	7.6	0.0	128.2
2010	0.6	28.6	26.6	1.0	2.4	8.8	7.6	2.0	2.6	5.6	3.0	7.6	96.4
2011	1.2	116.2	10.4	16.0	15.2	15.8	14.8	8.8	0.8	5.8	16.8	1.4	223.2
2012	2.0	2.0	12.6	15.2	1.4	10.8	2.0	22.2	4.0				72.2

2013	0.4	1.2	39.0	6.4	2.0	37.8	1.8	10.0	6.0	1.2	11.6	0.0	117.4
2014	0.0	9.4	22.6	3.4	3.5	7.8	12.	3.0	1.6	0.0	53.1	10.8	127.7
2015	3.2	0.0	12.2	0.0	0.0	27.8	7.6	13.0	0.2				64.0

Table 17: Evaporation collected at the Vaalputs station between 1990 to 2013 (Necsa database)

VAALPUTS EVAPORATION (MM)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	384	261	271	151	123	84	81	148	212	212	290	271	2488
1991	303	251	196	183	138	77	87	142	129	175	254	347	2282
1992	297	286	278	198	141	107	109	132	170	194	259	342	2513
1993	342	268	277	129	103	0	113	147	232	254	231	324	2419
1994	297	226	162	80	68	65	98	138	202	320	275	364	2293
1995	372	274	282	196	146	123	92	41	62	105	185	130	2005
1996	218	258	211	153	140	63	62	129	171	205	167	349	2125
1997	362	259	224	149	116	58	102	131	183	285	309	427	2603
1998	383	336	272	237	144	127	102	177	219	287	318	381	2979
1999	470	342	287	194	114	129	140	156	184	304	320	311	2948
2000	328	310	241	199	134	116	144	166	173	295	329	399	2830
2001	428	349	304	149	132	105	88	127	165	305	307	369	2825
2002	364	313	262	202	122	75	107	137	205	279	349	353	2765
2003	415	352	209	175	107	135	127	93	126	172	307	425	2642
2004	412	360	302	207	190	140	129	168	215	281	318	368	3086
2005	355	314	259	146	110	89	128	130	264	263	329	393	2779
2006	177	157	130	73	55	45	64	65	132	132	165	197	1389
2007	365	280	346	182	173	100	122	140	158	183	175	345	2569
2008	423	383	293	238	121	62	69	121	159	267	326	452	2914
2009	329	239	221	169	109	72	96	119	158	259	309	280	2360
2010	311	201	270	194	146	110	48	60	79	130	155	140	1843
2011	364	209	196	112	122	82	98	115	117	185	240	274	2114
2012	149	132	144	82	100	61	87	56	66	101	96	119	1193

2013	171	136	121	95	84	69	72	47	72	116	117	133	1233
2014	322	238	237	173	158	125	146	160	254	326	301	307	2744
Ave:	333	269	240	163	124	89	100	122	164	225	257	312	

Table 18: Mean monthly temperature at the Vaalputs station between 2002 to 2010 (Necsa database)

MEAN MONTHLY TEMPERATURES (°C)										
Month	2002	2003	2004	2005	2006	2007	2008	2009	2010	Mean
Jan	20.1	22.4	22.6	22.8	23.6	23.5	24.0	22.9	21.3	22.6
Feb	22.9	23.3	22.9	23.5	24.3	21.7	23.9	24.1	23.0	23.3
Mar	22.1	20.3	19.3	20.9	19.7	21.5	22.1	21.6	22.8	21.1
Apr	18.4	19.1	17.4	16.2	17.2	18.3	17.0	19.5	17.9	17.9
May	12.3	13.4	16.4	13.3	9.9	13.8	13.6	12.2	16.0	13.4
Jun	8.9	10.2	10.7	9.5	10.7	9.7	10.0	10.2	9.5	9.9
Jul	9.0	10.5	9.4	12.3	10.1	10.0	9.8	10.0	11.7	10.3
Aug	10.4	8.8	11.3	9.0	10.0	9.0	10.5	9.0	12.7	10.1
Sep	15.3	12.9	14.0	15.2	15.8	13.8	11.2	13.8	14.7	14.1
Oct	16.6	17.2	17.6	16.4	17.3	17.2	17.1	17.7	16.2	17.0
Nov	18.6	19.0	19.1	18.6	18.4	17.9	19.8	19.5	19.0	18.9
Dec	22.7	20.4	21.5	21.0	20.5	21.9	24.6	21.8	22.0	21.8

APPENDIX B

HYDROGEOLOGAL DATA

Table 19: Sampling location information - hydrocensus at the VRWS and surrounding farms (Necsa database)

SAMPLING LOCATIONS							
Site Name	Y	X	Z	Site Name	Y	X	Z
BH 519	-3333548.12	-46346.19	1021.09	MON7	-3336005.45	-41176.13	1010.28
EM8	-3333632.36	-46032.04	1010.76	MON8	-3335793.87	-41041.65	1012.74
Daas	-3349047.01	-34440.75	984.19	MON9	-3335587.17	-40906.37	1001.02
Daas Daap 1	-3356150.27	-37994.94	1018.90	MON10	-3335373.61	-40773.52	998.83
Dikmatjie 1	-3319907.00	-59012.00	912.68	MON11	-3335066.60	-40942.51	998.71
Frommelbakkies 3	-3326063.14	-30182.49	990.71	MON12	-3334905.25	-41194.13	999.10
Frommelbakkies 4	-3325945.83	-30854.01	994.69	MON14	-3336327.31	-41335.62	1007.91
FW 24 windpomp	-3335831.97	-49363.79	1032.88	MON15	-3335986.41	-40973.96	1019.86
FW1	-3332482.49	-46870.39	1008.20	MON16	-3335577.43	-40701.75	1014.02
FW14	-3335269.28	-48472.11	971.48	MON17	-3335141.36	-40561.52	1012.60
FW24	-3336394.34	-50705.20	995.64	MON19	-3334592.01	-41412.89	996.12
FW28	-3331865.90	-49713.65	990.96	MON21	-3335474.16	-39796.80	1002.26
FW29	-3331856.28	-51564.51	988.70	Norabees 1	-3333296.60	-36584.13	992.79
FW34	-3333839.82	-45902.25	1011.36	Norabees 2	-3332665.63	-34249.99	987.48

FW35	-3333581.90	-46366.09	1018.90	Norabees dam sample	-3332903.43	-37388.54	997.52
Garing 1	-3331382.36	-49199.46	994.35	PBH16	-3336126.54	-41859.96	1017.81
Goubees 1	-3322892.86	-36717.45	976.98	PBH17	-3336119.34	-41453.10	1004.21
Goubees 2	-3325441.82	-43050.18		PBH21	-3333020.66	-44025.52	1015.61
Goubees krip sample	-3322880.99	-36679.77	974.15	PBH22	-3335025.28	-43889.70	1009.99
Groenvlei 1	-3348451.13	-28285.96	978.78	PBH8	-3334517.30	-41472.72	995.39
GWB1	-3336069.10	-42261.57	1016.65	Platbakkies 1	-3353226.67	-41791.22	1025.09
GWB3	-3335114.04	-40788.83	997.55	Platbakkies 3	-3354818.34	-49347.38	1042.76
GWB4	-3334860.22	-41747.21	1010.31	PBAKKI	-3353033.68	-41833.90	1021.00
GWB5	-3335276.40	-42014.47	1005.38	W110N30	-3331716.55	-49090.20	988.62
GWB6	-3335693.80	-41927.74	1007.66	Wolfkraal 1	-3322074.79	-50611.40	965.49
GWB8	-3335106.48	-40802.18	1002.08	Wolfkraal 2	-3320937.49	-50536.53	996.89
Hartebeesbank 1	-3336019.82	-31584.94	994.45	Wolfkraal 3	-3321060.85	-49005.07	998.59
Hartebeesbank dam s	-3336021.28	-31590.71	993.77	Wolfkraal 4	-3321065.96	-49007.18	999.54

SAMPLING LOCATIONS							
Site Name	Y	X	Z	Site Name	Y	X	Z
Huis Vaalputs	-3331243.03	-49600.11	974.37	Wolfkraal dam - s	-3321006.17	-49146.48	1002.56
Kamiebees 2	-3324383.56	-50477.46	943.84	Vaalputs W Station	-3335597.66	-40775.62	979.99
Kamiebees 4	-3326324.64	-41799.74	990.58	BH3C2	-3324205.45	-27155.32	971.07
Lepel 1	-3337941.32	-25198.77	976.01	BH4C1	-3332963.49	-36455.84	989.67
Lepel tank s	-3337933.48	-25214.78	977.23	BH5C2	-3335375.48	-35498.95	989.17
MON1	-3334877.86	-41546.83	1004.29	BH5C4	-3335882.08	-31397.12	980.18
MON2	-3335089.78	-41680.15	1003.07	BH14C5	-3330490.00	-48740.00	996.84
MON3	-3335299.70	-41814.64	1003.88	BH16C3	-3325118.42	-42918.92	990.67
MON4	-3335511.94	-41948.53	1006.43	BH9B1	-3338653.33	-41290.02	1005.07
MON5	-3335851.71	-41799.72	1005.21	BH12C1	-3341041.67	-52647.12	1044.00
MON6	-3336012.84	-41549.56	1003.24	BH13C7	-3335824.88	-54376.24	952.29
				BH13C5	-3335149.74	-51703.57	952.29

Table 20: Summary of hydrocensus information

Site ID	X-coord	Y-coord	Site Type	AquaRead Tag	Collar Height (m)	BH Depth (m)	BH Use	GWL (mbch)	Comments
Huis Vaalputs	18.48543	-30.09939	B						
Platbakkies 1	18.56557	-30.29799	B	1184	0.15	107	Animal watering		Closed windmill, Sand dune - Quartz vein to the west
Platbakkies 2	18.48695	-30.31206	B	1185-1207		82	Drinking water	11.62	Pipes down to 36.5m, 90 gallon per hr, open windmill, east to west granite structure with 80-90% quartz, very young and acidic granite, 120 ft pipe. Layered structure (quartz vein).
Kap kap 1	18.44267	-30.25140	B				Animal watering		Closed windmill, Windpomp - closed no profiling or chemistry.
Kap kap 2	18.44146	-30.22419	B	1208			Animal watering		Closed windmill
Boesmanplaat 5	18.40916	-30.10826	B	1209			Animal watering		Closed windmill
Boesmanplaat 4	18.40910	-30.10830	B	1210	0.2	6.37	Open BH	5.37	Open BH next to windmill, not in use, Open borehole. Weathered granite basin. Next to WM
Boesmanplaat 3	18.40782	-30.08379	B	1211-1243	0.25	100+	Open BH	5.8	Located on quartz vein next to stream bed (alluvium), close to animal kraal, Open bh. Drilled on a quartz vein. Next to stream
Dikmatjie 1	18.39826	-30.07105	B	1244-1275	0.5	100+	windmill	5	Located on east west structure, valley, close to river
Boesmanplaat 1	18.40028	-30.07551	B				Animal watering		
Kamiebees 2	18.47665	-30.03748	B	1276	0.25		Animal watering	7.92	Two boreholes next to each other
Kamiebees 3	18.47695	-30.03884	B				Animal watering		
Kamiebees 5	18.56654	-30.05532	B				Animal watering		

Kamiebees 1	18.47665	-30.03739	B				Animal		

Site ID	X-coord	Y-coord	Site Type	AquaRead Tag	Collar Height (m)	BH Depth (m)	BH Use	GWL (mbch)	Comments
							watering		
Wolfkraal 1	18.47537	-30.01665	B	1			Animal watering		Quartz vein
Wolfkraal 2	18.47620	-30.00639	B				Animal watering		
Wolfkraal 4	18.49205	-30.00761	B		0.3	37.1	Animal watering		Collapsed or dry BH (no water level), calcretes
Wolfkraal 3	18.49207	-30.00757	B		0.3		Animal watering	41.39	Calcretes
Wolfkraal Dam	18.49061	-30.00707	B	2			Animal watering		Calcretes
Goubees Krip Sample	18.61975	-30.02442	B	3			Animal watering		Calcretes
Goubees 1	18.61936	-30.02452	B				Animal watering		
Norabees 1	18.62039	-30.11838	B				Animal watering		Calcretes
Norabees Dam Sample	18.61205	-30.11481	B	4			Animal watering		Calcretes
Norabees 2	18.64463	-30.11275	B		0.25		Animal watering	29.92	
Frommelbakkies 1	18.68888	-30.05284	B	13-20	0.25	100+	Animal watering	26.84	5-12 AquaRead data bad data
Frommelbakkies 2	18.68723	-30.05292	B				Animal watering		
Frommelbakkies 3	18.68702	-30.05330	B				Animal watering		
Frommelbakkies 4	18.68006	-30.05223	B				Animal		

Site ID	X-coord	Y-coord	Site Type	AquaRead Tag	Collar Height (m)	BH Depth (m)	BH Use	GWL (mbch)	Comments
							watering		
Hartbeesbank Dam Sample	18.67212	-30.14309	B	21			Animal watering		Sample taken out of dam
Hartbeesbank 1	18.67218	-30.14308	B				Animal watering		
Lepel tank sample	18.73825	-30.16049	B	22			Animal watering		
Lepel 1	18.73841	-30.16056	B		0.4		Animal watering	45.03	
Groenvlei 1	18.70609	-30.25530	B	23	0.5		Animal watering	20.6	
Dasdap 1	18.60492	-30.32448	B	24			Animal watering	60.67	
Dasdap 2	18.60497	-30.32449	B				Open BH		
Dasdap 3	18.60559	-30.32490	B				Animal watering		windmill dry
Ons 1	18.64210	-30.26051	B	25			Animal watering		
Kamiebees 4	18.56532	-30.04717	B	27			Animal watering		
Platbakkies 3	18.58693	-30.29127	B	26			Animal watering		
Garing 1	18.48958	-30.10067	B	1 to 31	0.27	100+	Monitoring	4.81	
FW 28	18.48422	-30.10501	B	32-65	0.27	100+	Monitoring	3.46	
FW 26	18.48446	-30.10502	B	66-96	0.27	100+	Monitoring	4.62	
FW 27	18.48459	-30.10506	B	97-102	0.27	11.42	Monitoring	5.36	Possible collapse of BH, discard AquaRead reading 103

Site ID	X-coord	Y-coord	Site Type	AquaRead Tag	Collar Height (m)	BH Depth (m)	BH Use	GWL (mbch)	Comments
FW 14	18.49694	-30.13576	B	104	0.26		Monitoring	34.5	
MON 9	18.57545	-30.13890	B	105	0.22		Monitoring	33.77	
MON 10	18.57684	-30.13698	B		0.16		Monitoring	51.62	
GWB 3	18.57669	-30.13464	B		0.17		Monitoring	50.6	
GWB 8	18.57654	-30.13456	B		0.15		Monitoring	50.63	
MON 11	18.57509	-30.13420	B		0.3		Monitoring	53.18	
MON 12	18.57249	-30.13274	B		0.19		Monitoring	56.33	
PBH 8	18.56961	-30.12923	B		0.19		Monitoring	54.68	
MON 19	18.57023	-30.12991	B		0.26		Monitoring	50.84	
MON 1	18.56884	-30.13249	B		0.25		Monitoring	52.49	
MON 2	18.56744	-30.13439	B		0.31		Monitoring	53.87	
MON 3	18.56603	-30.13628	B		0.16		Monitoring	54.06	
MON 4	18.56464	-30.13819	B		0.33		Monitoring	54.76	
MON 5	18.56617	-30.14126	B		0.28		Monitoring	59.86	
MON 6	18.56876	-30.14272	B		0.38		Monitoring	55.03	
PBH 17	18.56975	-30.14368	B		0.15		Monitoring	57.05	
MON 7	18.57263	-30.14267	B		0.24		Monitoring	57.95	
MON 8	18.57404	-30.14076	B		0.35		Monitoring		BH is dry
GWB 4	18.56675	-30.13232	B		0.08		Monitoring	51.74	
GWB 5	18.56397	-30.13605	B		0.15		Monitoring	53.51	

GWB 7	18.56404	-30.13594	B		0.2		Monitoring	53.53	

Site ID	X-coord	Y-coord	Site Type	AquaRead Tag	Collar Height (m)	BH Depth (m)	BH Use	GWL (mbch)	Comments
GWB 1	18.56137	-30.14320	B		0.24		Monitoring	57.47	
PBH 16	18.56553	-30.14373	B		0.35		Monitoring	58.18	
GWB 9	18.56569	-30.14370	B		0.16		Monitoring	57.91	
FW 3	18.51646	-30.11886	B		0.15		Monitoring	38.16	
FW 34	18.52367	-30.12295	B		0.2		Monitoring	37.58	
FW 19	18.52115	-30.12112	B		0.19		Monitoring	36	
FW 35	18.51887	-30.12062	B				Monitoring		Monitoring BH, closed, tap for sampling
519	18.51908	-30.12031	B		0.25		Monitoring	36	
FW 17	18.51920	-30.12014	B		0.23		Monitoring	35.6	
FW 31	18.52233	-30.11988	B		0.25		Monitoring	35.68	
FW 32	18.52191	-30.11837	B		0.22		Monitoring	34.84	
FW 7	18.51891	-30.11757	B	106	0.24		Monitoring	34.4	
FW 1	18.51370	-30.11068	B	107	0.29		Monitoring	33.89	
FW 4	18.50686	-30.10318	B		0.31		Monitoring	34.7	
FW 12	18.52073	-30.10505	B	108-111	0.27		Monitoring	30.41	
FW 5	18.51920	-30.10850	B	112-114	0.16		Monitoring	32.03	
PBH 21	18.54318	-30.11564	B		0.21		Monitoring	35.45	
MON 17	18.57905	-30.13489	B		0.22		Monitoring	51.6	
MON 16	18.57757	-30.13882	B		0.27		Monitoring	52.99	
MON 15	18.57473	-30.14250	B		0.24		Monitoring	57.06	

GWB 6	18.56486	-30.13983	B		0.28		Monitoring	54.92	

Site ID	X-coord	Y-coord	Site Type	AquaRead Tag	Collar Height (m)	BH Depth (m)	BH Use	GWL (mbch)	Comments
FW 24	18.48766	-30.14080	B				Monitoring		

Table 21: Groundwater levels 1986 to 2014 for the VRWS and selected farms (Necsa database)

GROUNDWATER LEVELS (MBGL)								
Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level
FW1	1987/11/01	34.84	FW1	2011/03/01	32	FW14	2007/10/01	35.09
FW1	1989/02/01	34.37	FW1	2011/06/01	33.79	FW14	2008/05/01	34.8
FW1	1989/11/01	35.1	FW1	2013/07/01	34.27	FW14	2008/06/01	35.78
FW1	1990/02/01	35.2	FW1	2013/11/01	33.78	FW14	2009/06/01	34.73
FW1	1990/11/01	35.26	FW1	2014/01/01	34.21	FW14	2010/12/01	35.6
FW1	1991/02/01	35.14	FW14	1987/11/01	34.87	FW14	2011/03/01	34.51
FW1	1991/11/01	35.13	FW14	1989/02/01	34.06	FW14	2011/06/01	34.5
FW1	1992/02/01	35.1	FW14	1989/11/01	35	FW14	2013/07/01	34.7
FW1	1992/11/01	35.1	FW14	1990/02/01	34.99	FW14	2013/11/01	34.55
FW1	1993/05/01	35.2	FW14	1990/11/01	35.29	FW14	2014/01/01	34.8
FW1	1994/02/01	34.7	FW14	1991/02/01	34.98	FW24	1987/11/01	3.04
FW1	1994/11/01	34.3	FW14	1991/11/01	35.08	FW24	1988/02/01	3.19
FW1	1995/02/01	34.5	FW14	1992/02/01	35.01	FW24	1988/11/01	4.25
FW1	1995/11/01	34.5	FW14	1992/11/01	35.25	FW24	1989/02/01	3.71
FW1	1996/08/01	32.3	FW14	1993/02/01	35.36	FW24	1989/11/01	2.6
FW1	1996/11/02	31.7	FW14	1993/08/01	35.07	FW24	1990/02/01	3.03
FW1	1997/02/01	31.89	FW14	1994/02/01	35.8	FW24	1990/11/01	2.57
FW1	1997/11/01	31.71	FW14	1994/11/01	35.4	FW24	1991/02/01	2.46
FW1	1998/02/01	32.11	FW14	1995/02/01	35.7	FW24	1991/11/01	2.68
FW1	1998/11/01	31.13	FW14	1995/11/01	35	FW24	1992/02/01	2.62
FW1	1999/02/01	31.26	FW14	1996/08/01	35.5	FW24	1992/11/01	3.86
FW1	1999/11/01	31.23	FW14	1996/11/02	34.85	FW24	1993/02/01	2.46
FW1	2000/02/01	31.23	FW14	1997/02/01	34.49	FW24	1993/08/01	4.01
FW1	2003/05/01	32.3	FW14	1997/11/01	34.02	FW24	1994/02/01	3.2
FW1	2003/11/01	32.58	FW14	1998/02/01	34.07	FW24	1994/11/01	4
FW1	2004/05/01	32.5	FW14	1998/11/01	32.87	FW24	1995/02/01	2.85
FW1	2004/12/01	32.6	FW14	1999/02/01	32.45	FW24	1995/11/01	4.4
FW1	2005/05/01	32.6	FW14	1999/11/01	32.67	FW24	1996/08/01	1.64
FW1	2005/11/01	32.7	FW14	2000/02/01	32.46	FW24	1996/11/02	1.57
FW1	2006/05/01	32.83	FW14	2003/05/01	33.89	FW24	1997/02/01	2.27
FW1	2006/11/01	32.88	FW14	2003/11/01	34.6	FW24	1997/11/01	1.8
FW1	2007/05/01	33.04	FW14	2004/05/01	33.73	FW24	1998/02/01	1.97
FW1	2007/10/01	33.18	FW14	2004/12/01	34.34	FW24	1998/11/01	1.28
FW1	2008/05/01	33.22	FW14	2005/02/01	34.12	FW24	1999/02/01	2.39
FW1	2008/09/01	52.67	FW14	2005/11/01	34.5	FW24	1999/11/01	2.88
FW1	2009/06/01	33.4	FW14	2006/05/01	34.6	FW24	2000/02/01	3.01
FW1	2010/06/01	32.8	FW14	2006/11/01	34.7	FW24	2003/05/01	4.06
FW1	2010/12/01	31.97	FW14	2007/05/01	34.58	FW24	2003/11/01	6.37

GROUNDWATER LEVELS (MBGL)								
Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level
FW24	2004/02/01	4.66	FW27	1993/02/01	9.77	FW28	2009/06/01	3.85
FW24	2004/12/01	5.19	FW28	1987/05/01	6.72	FW28	2010/06/01	3.96
FW24	2005/02/01	5.18	FW28	1987/11/01	7.3	FW28	2010/12/01	4.01
FW24	2005/11/01	2.3	FW28	1988/02/01	6.71	FW28	2011/03/01	3.6
FW24	2006/05/01	2.02	FW28	1988/11/01	7.24	FW28	2011/06/01	3.6
FW24	2006/11/01	2.25	FW28	1989/02/01	6.8	FW28	2012/04/01	3.57
FW24	2007/05/01	3	FW28	1989/11/01	6.92	FW28	2012/10/01	3.95
FW24	2007/10/01	1.96	FW28	1990/02/01	7.01	FW28	2013/07/01	3.7
FW24	2008/02/01	2.8	FW28	1990/11/01	6.87	FW28	2013/11/01	4.01
FW24	2008/09/01	1.96	FW28	1991/02/01	6.67	FW28	2014/01/01	4.05
FW24	2009/06/01	2.55	FW28	1991/11/01	6.85	FW29	1987/03/01	5.4
FW24	2010/06/01	2.73	FW28	1992/02/01	7.07	FW29	1987/11/01	5.1
FW24	2010/12/01	4	FW28	1992/11/01	7.78	FW29	1988/05/01	4.57
FW24	2011/03/01	4.01	FW28	1993/02/01	7.3	FW29	1988/11/01	5.49
FW24	2011/06/01	4.03	FW28	1993/05/01	7.78	FW29	1989/02/01	5.16
FW24	2012/04/01	2.07	FW28	1994/02/01	5.9	FW29	1989/11/01	5.2
FW24	2012/11/01	2.07	FW28	1994/11/01	6.2	FW29	1990/02/01	5.27
FW24	2013/04/01	3.66	FW28	1995/02/01	5.14	FW29	1990/11/01	5.25
FW24	2013/10/01	2.24	FW28	1995/11/01	6.7	FW29	1991/02/01	5.21
FW24	2014/01/01	2.25	FW28	1996/08/01	3.16	FW29	1991/11/01	5.13
FW26	1987/11/01	8.45	FW28	1996/11/02	2.83	FW29	1992/02/01	5.2
FW26	1989/02/01	8	FW28	1997/02/01	3.27	FW29	1992/11/01	5.78
FW26	1989/11/01	8.1	FW28	1997/11/01	2.39	FW29	1993/02/01	5.47
FW26	1990/02/01	8.2	FW28	1998/02/01	2.35	FW29	1993/05/01	5.78
FW26	1990/11/01	8.05	FW28	1998/11/01	2.06	FW29	1994/02/01	5
FW26	1991/02/01	7.91	FW28	1999/02/01	2.64	FW29	1994/11/01	5.4
FW26	1991/11/01	8.03	FW28	1999/11/01	2.95	FW29	1995/02/01	4.8
FW26	1992/02/01	8.24	FW28	2000/02/01	2.91	FW29	1995/11/01	5.5
FW26	1992/11/01	8.67	FW28	2003/11/01	5.86	FW29	1996/08/01	2.94
FW26	1993/02/01	8.9	FW28	2004/02/01	4.9	FW29	1996/11/02	2.04
FW26	1993/02/02	9.53	FW28	2004/12/01	5.17	FW29	1997/02/01	2.48
FW27	1988/11/01	9.09	FW28	2005/02/01	4.6	FW29	1997/11/01	0.89
FW27	1989/02/01	9.09	FW28	2005/11/01	4.01	FW29	1998/02/01	1.22
FW27	1989/11/01	9.19	FW28	2006/05/01	3.79	FW29	1998/11/01	1.11
FW27	1990/02/01	9.06	FW28	2006/11/01	4.4	FW29	1999/02/01	1.54
FW27	1990/11/01	9	FW28	2007/05/01	4.54	FW29	1999/11/01	1.88
FW27	1991/02/01	9.09	FW28	2007/10/01	4.7	FW29	2000/02/01	1.54
FW27	1991/11/01	9.24	FW28	2008/05/01	4.04	FW29	2003/05/01	3.27
FW27	1992/02/01	9.68	FW28	2008/09/01	3.67	FW29	2003/11/01	3.13

GROUNDWATER LEVELS (MBGL)								
Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level
FW29	2004/02/01	3.1	FW31	1991/11/01	36.87	FW34	1987/11/01	38.56
FW29	2004/12/01	3.5	FW31	1992/02/01	36.4	FW34	1987/11/01	38.76
FW29	2005/03/01	3.26	FW31	1992/11/01	36.3	FW34	1988/05/01	38.56
FW29	2005/11/01	2.83	FW31	1993/02/01	36.5	FW34	1988/11/01	38.58
FW29	2006/05/01	2.64	FW31	1993/05/01	36.5	FW34	1989/02/01	38.13
FW29	2006/11/01	2.7	FW31	1994/02/01	34.2	FW34	1989/11/01	38.7
FW29	2007/05/01	2.86	FW31	1994/11/01	33.62	FW34	1990/02/01	38.92
FW29	2007/10/01	3.17	FW31	1995/02/01	33.7	FW34	1990/11/01	38.89
FW29	2008/05/01	2.7	FW31	1995/11/01	33.67	FW34	1991/02/01	38.64
FW29	2008/09/01	1.91	FW31	1996/08/01	34.03	FW34	1991/11/01	38.56
FW29	2009/06/01	2.5	FW31	1996/11/02	32.92	FW34	1992/02/01	38.6
FW29	2010/06/01	2.46	FW31	1997/02/01	33.1	FW34	1992/11/01	38.42
FW29	2010/12/01	3.23	FW31	1997/11/01	33.02	FW34	1993/02/01	38.45
FW29	2011/03/01	3.23	FW31	1998/02/01	32.92	FW34	1993/05/01	38.45
FW29	2011/06/01	3.24	FW32	1987/03/01	35.81	FW34	1994/02/01	38.3
FW29	2012/04/01	2.24	FW32	1988/11/01	35.34	FW34	1994/11/01	38
FW29	2012/11/01	2.86	FW32	1989/02/01	36.04	FW34	1995/02/01	38.3
FW29	2013/07/01	3.43	FW32	1989/11/01	36.28	FW34	1995/11/01	38
FW29	2013/11/01	2.49	FW32	1990/02/01	36.21	FW34	1996/08/01	36.5
FW29	2014/01/01	2.33	FW32	1990/11/01	36.12	FW34	1996/11/02	35.85
FW30	1987/03/01	5.23	FW32	1991/02/01	36.04	FW34	1997/02/01	36
FW30	1988/11/01	5.28	FW32	1991/11/01	36.11	FW34	1997/11/01	36.15
FW30	1989/02/01	5.31	FW32	1992/02/01	36.01	FW34	1998/02/01	36.42
FW30	1989/11/01	5.38	FW32	1993/02/01	36.11	FW34	1998/11/01	35.29
FW30	1990/02/01	5.26	FW32	1987/03/01	35.5	FW34	1999/02/01	35.22
FW30	1990/11/01	5.21	FW32	1987/11/01	35.6	FW34	1999/11/01	35.06
FW30	1991/02/01	5.17	FW32	1988/05/01	35.8	FW34	2000/02/01	34.95
FW30	1991/11/01	5.13	FW32	1988/11/01	35	FW34	2003/05/01	35.86
FW30	1992/02/01	5.68	FW32	1989/02/01	33.4	FW34	2003/11/01	35.85
FW30	1993/02/01	5.71	FW32	1989/11/01	32.78	FW34	2004/05/01	36.02
FW31	1987/03/01	36.66	FW32	1990/02/01	32.82	FW34	2004/12/01	36.26
FW31	1987/11/01	36.19	FW32	1990/11/01	32.78	MON1	1986/02/01	53.42
FW31	1988/05/01	36.88	FW32	1991/02/01	33.1	MON1	1986/11/01	53.21
FW31	1988/11/01	37.13	FW32	1991/11/01	32.06	MON1	1987/02/01	53.45
FW31	1989/02/01	37.05	FW32	1992/02/01	32.2	MON1	1987/11/01	53.05
FW31	1989/11/01	36.94	FW32	1992/11/01	32.12	MON1	1988/02/01	53.09
FW31	1990/02/01	36.88	FW32	1993/02/01	32.07	MON1	1988/11/01	52.9
FW31	1990/11/01	36.99	FW34	1987/02/01	38.75	MON1	1989/02/01	52.63
FW31	1991/02/01	36.86	FW34	1987/05/01	38.75	MON1	1989/11/01	53.34

GROUNDWATER LEVELS (MBGL)								
Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level
MON1	1990/02/01	53.5	MON1	2010/12/01	52.6	MON4	1990/02/01	56.54
MON1	1990/11/01	53.31	MON1	2011/03/01	52.55	MON4	1990/11/01	55.6
MON1	1991/02/01	53.37	MON1	2011/06/01	52.58	MON4	1991/02/01	55.7
MON1	1991/11/01	53.42	MON1	2012/05/01	52.77	MON4	1991/11/01	55.69
MON1	1992/02/01	53.44	MON1	2012/10/01	52.34	MON4	1992/02/01	55.74
MON1	1992/11/01	53.53	MON1	2013/07/01	52.49	MON4	1992/11/01	55.82
MON1	1993/02/01	53.65	MON1	2013/11/01	52.47	MON4	1993/02/01	55.76
MON1	1993/05/01	53.58	MON1	2014/01/01	52.52	MON4	1993/05/01	55.73
MON1	1994/02/01	53.6	MON2	1985/09/01	54.3	MON4	1994/11/01	55.82
MON1	1994/11/01	54	MON2	1985/12/01	54.85	MON4	1995/02/01	56.5
MON1	1995/02/01	54.24	MON2	1986/02/01	54.75	MON4	1995/11/01	56.5
MON1	1995/11/01	54.3	MON2	1986/11/01	54.53	MON4	1996/08/01	56.5
MON1	1996/08/01	54.2	MON2	1987/02/01	54.94	MON4	1996/11/02	55.9
MON1	1996/11/02	53.54	MON2	1987/11/01	54.42	MON4	1997/02/01	55.85
MON1	1997/02/01	53.54	MON2	1988/02/01	54.44	MON4	1997/11/01	55.33
MON1	1997/11/01	55.03	MON2	1988/11/01	54.25	MON4	1998/02/01	55.62
MON1	1998/02/01	53.26	MON2	1989/02/01	53.93	MON4	1998/11/01	50.47
MON1	1998/11/01	52.22	MON2	1989/11/01	54.73	MON4	1999/02/01	55.39
MON1	1999/02/01	53.03	MON2	1990/02/01	54.82	MON4	1999/11/01	54.25
MON1	1999/11/01	51.98	MON2	1990/11/01	54.65	MON4	2000/02/01	54.23
MON1	2000/02/01	51.93	MON2	1991/02/01	54.73	MON4	2000/11/01	55.15
MON1	2001/11/01	52.72	MON2	1991/11/01	54.77	MON4	2001/05/01	55.09
MON1	2002/05/01	52.52	MON2	1992/02/01	54.78	MON4	2001/11/01	54.93
MON1	2002/11/01	52.45	MON2	1992/11/01	54.85	MON4	2002/05/01	54.89
MON1	2003/05/01	52.23	MON2	1993/02/01	54.95	MON4	2002/11/01	54.93
MON1	2003/11/01	52.34	MON2	1993/05/01	54.99	MON4	2003/05/01	54.6
MON1	2004/05/01	52.1	MON2	1998/02/01	54.23	MON4	2003/11/01	53.1
MON1	2004/12/01	52.18	MON2	1998/11/01	54.56	MON4	2004/05/01	54.5
MON1	2005/05/01	52.1	MON2	1999/02/01	54.4	MON4	2004/12/01	54.52
MON1	2005/11/01	52.28	MON4	1985/09/01	55.25	MON4	2005/05/01	54.44
MON1	2006/05/01	52.36	MON4	1985/12/01	55.91	MON4	2005/11/01	54.6
MON1	2006/11/01	52.4	MON4	1986/02/01	55.66	MON4	2006/05/01	54.37
MON1	2007/05/01	52.42	MON4	1986/11/01	52.22	MON4	2006/11/01	54.7
MON1	2007/10/01	52.67	MON4	1987/05/01	55.48	MON4	2007/05/01	54.83
MON1	2008/05/01	52.7	MON4	1987/11/01	55.39	MON4	2007/10/01	54.94
MON1	2008/09/01	52.67	MON4	1988/02/01	53.35	MON4	2008/05/01	55
MON1	2009/03/01	52.76	MON4	1988/11/01	55.88	MON4	2008/09/01	55.01
MON1	2009/06/01	52.8	MON4	1989/02/01	55.19	MON4	2009/03/01	55.07
MON1	2010/06/01	52.78	MON4	1989/11/01	56.35	MON4	2009/06/02	55.12

GROUNDWATER LEVELS (MBGL)								
Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level
MON4	2010/06/01	55.15	MON5	2000/02/01	68.67	MON8	1991/11/01	74
MON4	2010/12/01	55.83	MON5	2001/05/01	67.95	MON8	1992/02/01	71.92
MON4	2011/03/01	55.76	MON5	2002/11/01	66.45	MON8	1992/11/01	69.77
MON4	2011/06/01	55.77	MON5	2003/05/01	66.15	MON8	1993/02/01	68.09
MON4	2012/05/01	54.9	MON5	2003/11/01	66.04	MON8	1993/05/01	69.46
MON4	2012/10/01	55.32	MON5	2004/05/01	65.06	MON8	1994/02/01	68
MON4	2013/07/01	54.76	MON5	2004/12/01	64.7	MON8	1994/11/01	67
MON4	2013/11/01	54.72	MON5	2005/05/01	64.36	MON8	1995/02/01	65.5
MON4	2014/01/01	54.8	MON5	2005/11/01	63.97	MON8	1995/11/01	65.9
MON5	1985/02/01	100	MON5	2006/05/01	63.54	MON8	1996/08/01	64.23
MON5	1985/11/01	99.36	MON5	2006/11/01	63.2	MON8	1996/11/02	63.69
MON5	1986/02/01	99.29	MON5	2007/05/01	62.95	MON8	1997/02/01	63.18
MON5	1986/11/01	65.75	MON5	2007/10/01	62.64	MON8	1997/11/01	61.53
MON5	1987/02/01	65.3	MON5	2008/05/01	62.2	MON8	1998/02/01	63.91
MON5	1987/11/01	87.64	MON5	2008/09/01	62.04	MON8	1998/11/01	61.87
MON5	1988/02/01	87.4	MON5	2009/03/01	61.8	MON8	1999/02/01	64.64
MON5	1988/11/01	85.32	MON5	2009/06/01	61.65	MON8	1999/11/01	64.15
MON5	1989/02/01	82.05	MON5	2010/06/01	61.6	MON8	2000/02/01	64.64
MON5	1989/11/01	81.92	MON5	2010/12/01	64.7	MON8	2001/05/01	63.41
MON5	1990/02/01	81.43	MON5	2011/03/01	64.8	MON8	2001/11/01	62.64
MON5	1990/11/01	80.16	MON5	2011/06/01	64.88	MON8	2002/05/01	62.03
MON5	1991/02/01	79.51	MON5	2012/04/01	60.72	MON8	2002/11/01	62.13
MON5	1991/11/01	78.85	MON5	2012/10/01	60.8	MON8	2003/05/01	62.04
MON5	1992/02/01	77.47	MON5	2013/07/01	59.86	MON8	2003/11/01	62.02
MON5	1992/11/01	76.16	MON5	2013/11/01	59.77	MON8	2004/05/01	60.02
MON5	1993/02/01	74.79	MON5	2014/01/01	59.79	MON8	2004/12/01	60
MON5	1993/05/01	75.87	MON8	1985/02/01	100	MON8	2005/05/01	58.5
MON5	1994/02/01	73.7	MON8	1985/11/01	99.03	MON8	2005/11/01	58.89
MON5	1994/11/01	73.8	MON8	1986/02/01	98.69	MON8	2006/05/01	58.36
MON5	1995/02/01	72.8	MON8	1986/11/01	68.11	MON8	2006/11/01	57.93
MON5	1995/11/01	73	MON8	1987/02/01	66.82	MON8	2007/05/01	57.72
MON5	1996/08/01	73.72	MON8	1987/11/01	85.06	MON8	2007/10/01	57.36
MON5	1996/11/02	72.6	MON8	1988/02/01	84.53	MON8	2008/05/01	56.8
MON5	1997/02/01	72.2	MON8	1988/11/01	85.05	MON9	1985/02/01	96.4
MON5	1997/11/01	71.93	MON8	1989/02/01	80.97	MON9	1985/11/01	87.38
MON5	1998/02/01	72.21	MON8	1989/11/01	79.66	MON9	1986/02/01	85.26
MON5	1998/11/01	70.57	MON8	1990/02/01	78.87	MON9	1986/11/01	70.84
MON5	1999/02/01	70.42	MON8	1990/11/01	77.04	MON9	1987/02/01	65.82
MON5	1999/11/01	69	MON8	1991/02/01	75.19	MON9	1987/11/01	68.05

GROUNDWATER LEVELS (MBGL)								
Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level
MON9	1988/02/01	65	MON10	1998/02/01	52.1	MON11	2012/10/01	50.6
MON9	1988/11/01	72.72	MON10	1998/11/01	51.28	MON11	2013/07/01	53.18
MON9	1989/02/01	60.24	MON10	1999/02/01	52.03	MON12	1991/02/01	57.42
MON9	1989/11/01	59.22	MON10	1999/11/01	51.01	MON12	1991/11/01	57.29
MON9	1990/02/01	57.76	MON10	2000/02/01	50.98	MON12	1992/02/01	57.4
MON9	1990/11/01	55.93	MON10	2001/05/01	52.68	MON12	1992/11/01	57.57
MON9	1991/02/01	55.05	MON10	2001/11/01	51.58	MON12	1993/02/01	57.55
MON9	1991/11/01	60.56	MON10	2002/05/01	51.52	MON12	1993/05/01	57.69
MON9	1992/02/01	55.15	MON10	2002/11/01	51.46	MON12	1999/02/01	56.76
MON9	1992/11/01	53.33	MON10	2003/05/01	51.09	MON12	2000/07/01	56.58
MON9	1993/02/01	52.33	MON10	2003/11/01	51.2	MON12	2000/02/01	56.45
MON9	1997/11/01	53.54	MON10	2004/05/01	51.02	MON12	2001/05/01	56.39
MON9	1998/02/01	50.71	MON10	2004/12/01	51.2	MON12	2001/11/02	56.27
MON9	1997/11/01	53.74	MON10	2005/05/01	50.77	MON12	2002/05/06	56.2
MON9	2014/01/10	50.8	MON10	2005/11/01	51.33	MON12	2002/11/07	56.12
MON10	1985/02/01	52.35	MON10	2006/05/01	51.44	MON12	2003/05/01	56.05
MON10	1985/11/01	52.72	MON10	2006/11/01	51.47	MON12	2003/11/01	55.96
MON10	1986/02/01	52.53	MON10	2007/05/01	51.55	MON12	2004/05/01	55.9
MON10	1986/11/01	52.27	MON10	2007/10/01	51.64	MON12	2004/11/01	55.93
MON10	1987/05/01	52.24	MON10	2008/05/01	51.74	MON12	2005/05/01	56
MON10	1987/11/01	52.32	MON10	2008/09/01	51.77	MON12	2005/10/01	56
MON10	1988/02/01	52.25	MON10	2009/03/01	53.83	MON12	2006/11/01	56.2
MON10	1988/11/01	52.9	MON10	2009/06/01	51.88	MON12	2007/05/01	56.3
MON10	1989/02/01	54.3	MON10	2010/06/01	51.5	MON12	2007/10/01	56.35
MON10	1989/11/01	52.87	MON10	2010/12/01	51.11	MON12	2008/05/01	56.45
MON10	1990/02/01	52.87	MON10	2011/03/01	51.1	MON12	2008/10/01	56.5
MON10	1990/11/01	52.49	MON11	2000/02/01	53.86	MON12	2009/11/01	56.52
MON10	1991/02/01	53.08	MON11	2003/05/01	50.92	MON12	2010/04/01	56.92
MON10	1991/11/01	52.72	MON11	2003/11/01	51.4	MON12	2011/05/01	56.5
MON10	1992/02/01	53.51	MON11	2004/05/01	53.78	MON12	2012/05/01	56.35
MON10	1992/11/01	52.96	MON11	2004/12/01	53.9	MON12	2013/05/01	56.3
MON10	1993/02/01	53.05	MON11	2007/10/01	52.64	MON12	2014/01/01	56.45
MON10	1993/05/01	53.54	MON11	2008/05/01	52.26	MON14	1985/10/01	56.45
MON10	1994/02/01	53.59	MON11	2008/09/01	53.26	MON14	1985/11/01	57.07
MON10	1994/11/01	52.78	MON11	2009/03/01	53.3	MON14	1986/02/01	57.11
MON10	1996/08/01	53.2	MON11	2009/06/01	53.43	MON14	1986/11/01	57.01
MON10	1996/11/02	52.58	MON11	2011/03/01	54.53	MON14	1987/02/01	57.82
MON10	1997/02/01	52.64	MON11	2011/06/01	54.55	MON14	1987/11/01	56.87
MON10	1997/11/01	51.93	MON11	2012/04/01	50.34	MON14	1988/02/01	56.9

GROUNDWATER LEVELS (MBGL)								
Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level
MON14	1988/11/01	56.88	MON15	1996/08/01	58.02	MON16	1986/02/01	58.01
MON14	1989/02/01	56.1	MON15	1996/11/02	58	MON16	1986/11/01	57.78
MON14	1989/11/01	57.12	MON15	1997/02/01	57.42	MON16	1987/02/01	58.02
MON14	1990/02/01	57.29	MON15	1997/11/01	57.6	MON16	1987/11/01	57.64
MON14	1990/11/01	57.11	MON15	1998/02/01	56.65	MON16	1988/02/01	57.75
MON14	1991/02/01	57.15	MON15	1998/11/01	57.54	MON16	1988/11/01	57.48
MON14	1991/11/01	57.25	MON15	1999/02/01	56.51	MON16	1989/02/01	57.26
MON14	1992/02/01	57.24	MON15	1999/11/01	56.5	MON16	1989/11/01	58
MON14	1992/11/01	57.33	MON15	2000/03/01	56.22	MON16	1990/02/01	58.14
MON14	1993/02/01	57.33	MON15	2000/11/02	57.31	MON16	1990/11/01	57.9
MON14	1993/05/01	57.41	MON15	2001/05/01	57.21	MON16	1991/02/01	57.97
MON14	1997/06/01	57.21	MON15	2001/11/01	57.1	MON16	1991/11/01	58.06
MON14	1998/02/01	56.05	MON15	2002/05/01	57.02	MON16	1992/02/01	58.13
MON14	1998/11/01	56.91	MON15	2002/11/01	56.92	MON16	1992/11/01	58.15
MON14	1999/02/01	56.8	MON15	2003/05/01	56.54	MON16	1993/02/01	58.23
MON14	1999/05/01	56.8	MON15	2003/11/01	56.71	MON16	1993/05/01	58.29
MON14	2000/11/01	56.59	MON15	2004/05/01	56.56	MON16	1994/02/01	58
MON15	1985/02/01	58.05	MON15	2004/12/01	56.72	MON16	1994/11/01	58.7
MON15	1985/11/01	58.01	MON15	2005/05/01	56.28	MON16	1995/02/01	59.1
MON15	1986/02/01	57.78	MON15	2005/11/01	56.85	MON16	1995/11/01	59
MON15	1986/11/01	58.02	MON15	2006/05/01	56.95	MON16	1996/08/01	58.7
MON15	1987/02/01	57.64	MON15	2006/11/01	56.95	MON16	1996/11/02	58.02
MON15	1987/11/01	57.75	MON15	2007/05/01	57.04	MON16	1997/02/01	58
MON15	1988/02/01	57.48	MON15	2007/10/01	57.22	MON16	1997/11/01	57.42
MON15	1988/11/01	57.26	MON15	2008/05/01	57.28	MON16	1998/02/01	57.6
MON15	1989/02/01	58	MON15	2008/09/01	57.27	MON16	1998/11/01	56.65
MON15	1989/11/01	58.14	MON15	2009/03/01	57.33	MON16	1999/02/01	57.54
MON15	1990/02/01	57.9	MON15	2009/06/01	57.38	MON16	1999/11/01	56.51
MON15	1990/11/01	57.97	MON15	2010/06/01	57.38	MON16	2000/02/01	56.5
MON15	1991/02/01	58.06	MON15	2010/12/01	57.49	MON16	2003/05/01	52.58
MON15	1991/11/01	58.13	MON15	2011/03/01	57.24	MON16	2003/11/01	52.84
MON15	1992/02/01	58.15	MON15	2011/06/01	57.25	MON16	2004/05/01	52.34
MON15	1992/11/01	58.23	MON15	2012/05/01	57.15	MON16	2004/12/01	52.56
MON15	1993/02/01	58.29	MON15	2012/10/01	57.28	MON16	2005/05/01	52.62
MON15	1993/05/01	58	MON15	2013/07/01	57.06	MON16	2005/11/01	52.63
MON15	1994/02/01	58.7	MON15	2013/11/01	57.09	MON16	2006/05/01	52.77
MON15	1994/11/01	59.1	MON15	2014/01/01	57.3	MON16	2006/11/01	52.85
MON15	1995/02/01	59	MON16	1985/02/01	126.16	MON16	2007/05/01	52.92
MON15	1995/11/01	58.7	MON16	1985/11/01	58.05	MON16	2007/10/01	53.12

GROUNDWATER LEVELS (MBGL)								
Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level
MON16	2008/05/01	53.1	MON17	1998/02/01	51.27	MON19	1991/02/01	62.59
MON16	2008/09/01	53.2	MON17	1998/11/01	50.77	MON19	1991/11/01	59.99
MON16	2009/03/01	50.19	MON17	1999/02/01	51	MON19	1992/02/01	58.74
MON16	2009/06/01	53.25	MON17	1999/11/01	51.02	MON19	1992/11/01	56.8
MON16	2010/06/01	53.2	MON17	2000/02/01	52.11	MON19	1993/02/01	58
MON16	2010/12/01	54.43	MON17	2003/05/01	51.82	MON19	1993/05/01	56.5
MON16	2011/03/01	54.41	MON17	2003/11/01	51.22	MON19	1994/02/01	56.1
MON16	2011/06/01	54.4	MON17	2004/05/01	51.04	MON19	1994/11/01	54.9
MON16	2012/04/01	53.09	MON17	2004/12/01	51.2	MON19	1995/02/01	55.5
MON16	2012/10/01	53.26	MON17	2005/05/01	50.66	MON19	1995/11/01	54.27
MON16	2013/07/01	52.99	MON17	2005/11/01	51.32	MON19	1996/08/01	53.6
MON16	2013/11/01	53.98	MON17	2006/05/01	51.35	MON19	1996/11/02	53.45
MON16	2014/01/01	52.9	MON17	2006/11/01	51.47	MON19	1997/02/01	52.85
MON17	1985/02/01	52.72	MON17	2007/05/01	51.58	MON19	1997/11/01	53.03
MON17	1985/11/01	52.5	MON17	2007/10/01	51.69	MON19	1998/02/01	51.84
MON17	1986/02/01	52.36	MON17	2008/05/01	51.72	MON19	1998/12/01	51.41
MON17	1986/11/01	53.16	MON17	2008/09/01	51.76	MON19	1999/02/01	51.4
MON17	1987/02/01	52.14	MON17	2009/06/01	51.82	MON19	1999/11/01	51.33
MON17	1987/11/01	52.15	MON17	2010/06/01	51.87	MON19	2000/02/01	50.99
MON17	1988/02/01	52.19	MON17	2010/12/01	51.83	MON19	2003/05/01	51.3
MON17	1988/11/01	53.37	MON17	2011/03/01	51.67	MON19	2003/11/01	51.1
MON17	1989/02/01	52.85	MON17	2011/06/01	51.6	MON19	2004/05/01	51.08
MON17	1989/11/01	52.88	MON17	2012/05/01	51.55	MON19	2004/12/01	51.02
MON17	1990/02/01	52.48	MON17	2012/10/01	51.93	MON19	2005/05/01	50.92
MON17	1990/11/01	53.02	MON17	2013/10/01	51.88	MON19	2005/11/01	50.89
MON17	1991/02/01	52.74	MON17	2013/11/01	51.7	MON19	2006/05/01	50.82
MON17	1991/11/01	53.32	MON17	2014/01/01	51.64	MON19	2006/11/01	50.8
MON17	1992/02/01	52.91	MON19	1985/02/01	143.33	MON19	2007/05/01	50.74
MON17	1992/11/01	53	MON19	1985/11/01	143	MON19	2007/10/01	50.87
MON17	1993/02/01	53.23	MON19	1986/02/01	103.71	MON19	2008/05/01	50.77
MON17	1993/05/01	53	MON19	1986/07/01	103.71	MON19	2008/09/01	50.76
MON17	1994/02/01	53.5	MON19	1987/02/01	84.5	MON19	2009/03/01	50.78
MON17	1994/11/01	53.5	MON19	1987/11/01	83.03	MON19	2009/06/01	50.8
MON17	1995/02/01	53.8	MON19	1988/02/01	77.95	MON19	2010/06/01	50.77
MON17	1995/11/01	53.2	MON19	1988/11/01	71.97	MON19	2010/12/01	51
MON17	1996/08/01	52.55	MON19	1989/02/01	68.86	MON19	2011/03/01	50.89
MON17	1996/11/02	52.64	MON19	1989/11/01	68.66	MON19	2011/06/01	50.91
MON17	1997/02/01	51.92	MON19	1990/02/01	65.31	MON19	2012/04/01	50.94
MON17	1997/11/01	52.09	MON19	1990/11/01	63.17	MON19	2012/10/01	51

GROUNDWATER LEVELS (MBGL)								
Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level	Site Name	Date	Groundwater Level
MON19	2013/07/01	50.84	MON19	2013/11/01	50.84	MON19	2014/01/01	50.97

Table 22: Groundwater level recorded since 1986 to 2014 for the VRWS and selected farms (Necsa database

Site Name	Date	Water Level	Site Name	Date	Water Level	Site Name	Date	Water Level
MON21	1985/12/01	51.67	PBH17	1999/02/01	67.1	Garing1	1987/11/01	8.61
MON21	1985/11/01	51.67	PBH17	1999/11/01	66.52	Garing1	1988/02/01	8.51
MON21	1986/02/01	51.52	PBH17	2000/02/01	66.95	Garing1	1988/11/01	8.55
MON21	1986/11/01	51.4	PBH17	2001/05/01	65.59	Garing1	1989/02/01	8.68
MON21	1987/02/01	51.6	PBH17	2001/11/01	64.84	Garing1	1989/11/01	8.42
MON21	1987/11/01	51.09	PBH17	2002/05/01	64.42	Garing1	1990/02/01	7.95
MON21	1988/02/01	51.14	PBH17	2002/11/01	64.08	Garing1	1990/11/01	8.2
MON21	1988/11/01	50.98	PBH17	2003/05/01	63.45	Garing1	1991/02/01	8.15
MON21	1989/02/01	51.01	PBH17	2003/11/01	62.77	Garing1	1991/11/01	8.88
MON21	1989/11/01	51.54	PBH17	2004/05/01	62	Garing1	1992/02/01	8.99
MON21	1990/02/01	51.6	PBH17	2004/12/01	61.74	Garing1	1992/11/01	6.9
MON21	1990/11/01	51.38	PBH17	2005/05/01	61.2	Garing1	1993/02/01	7.6
MON21	1991/02/01	51.76	PBH17	2005/11/01	60.6	Garing1	1993/05/01	6.41
MON21	1991/11/01	51.74	PBH17	2006/05/01	60.21	Garing1	1994/02/01	8.1
MON21	1992/02/01	51.68	PBH17	2006/11/01	59.85	Garing1	1994/11/01	4.26
MON21	1992/11/01	51.67	PBH17	2007/05/01	59.67	Garing1	1995/02/01	4.02
MON21	1993/02/01	51.87	PBH17	2007/10/01	59.31	Garing1	1995/11/01	4.65
MON21	1993/05/01	51.85	PBH17	2008/05/01	58.88	Garing1	1996/08/01	3.11
MON21	1994/02/01	57.93	PBH17	2008/09/01	58.66	Garing1	1996/11/02	1.99
MON21	1998/06/01	50.38	PBH17	2009/06/01	58.43	Garing1	1997/02/01	2.83
MON21	1998/11/01	51.31	PBH17	2010/06/01	58.32	Garing1	1997/11/01	3.61
MON21	2000/05/01	51.05	PBH17	2010/12/01	58.22	Garing1	1998/02/01	4.05
MON21	2000/07/02	50.94	PBH17	2011/03/01	58.12	Garing1	1998/11/01	4.15

Site Name	Date	Water Level	Site Name	Date	Water Level	Site Name	Date	Water Level
GWB1	1985/10/01	58.1	PBH17	2011/06/01	58.13	Garing1	1999/05/01	3.61
GWB1	1985/11/01	58.31	PBH17	2012/05/01	58.15	Garing1	1999/11/01	4.18
GWB1	1986/05/01	57.89	PBH17	2012/10/01	57.8	Garing1	2000/02/01	4.29
GWB1	1986/11/01	58.01	PBH17	2013/07/01	57.3	Garing1	2003/05/01	5.82
GWB1	1987/05/01	58.13	PBH17	2013/11/01	57.3	Garing1	2003/11/01	8.78
GWB1	1987/11/01	57.69	PBH17	2014/01/01	56.98	Garing1	2004/05/01	6.4
GWB1	1988/02/01	57.93	PBH21	1985/11/01	44.89	Garing1	2004/12/01	6.78
GWB1	1988/11/01	57.47	PBH21	1985/12/01	45.08	Garing1	2005/05/01	6.24
GWB1	1989/05/01	57.14	PBH21	1986/05/01	42.9	Garing1	2005/11/01	5.65
GWB1	1989/11/01	56.87	PBH21	1986/11/01	41.54	Garing1	2006/05/01	5.56
GWB1	1990/02/01	58.12	PBH21	1987/05/01	39.79	Garing1	2006/11/01	6.22
GWB1	1990/11/01	58.23	PBH21	1987/11/01	39.13	Garing1	2007/05/01	6.18
GWB1	1991/02/01	58.16	PBH21	1988/05/01	38.38	Garing1	2007/10/01	6.7
GWB1	1991/11/01	58.16	PBH21	1988/11/01	38.17	Garing1	2008/05/01	6
GWB1	1992/02/01	58.17	PBH21	1989/02/01	36.97	Garing1	2008/09/01	5.6
GWB1	1992/11/01	58.15	PBH21	1989/11/01	37.25	Garing1	2009/06/01	5.65
GWB1	1993/02/01	58.36	PBH21	1990/02/01	37.3	Garing1	2010/06/01	5.94
GWB1	1993/05/01	58.31	PBH21	1990/11/01	36.98	Garing1	2010/12/01	5.95
GWB1	1994/02/01	58.38	PBH21	1991/02/01	36.85	Garing1	2011/03/01	5.99
GWB1	1994/11/01	58.2	PBH21	1991/11/01	36.77	Garing1	2011/06/01	5.94
GWB1	1995/02/01	58.8	PBH21	1992/02/01	36.64	Garing1	2012/04/01	4.94
GWB1	1995/11/01	59	PBH21	1992/11/01	36.55	Garing1	2012/10/01	5.33
GWB1	1996/08/01	59.1	PBH21	1993/02/01	36.47	Garing1	2013/07/01	4.81
GWB1	1996/11/02	59.14	PBH21	1993/05/01	36.52	Garing1	2013/11/01	5.14

Site Name	Date	Water Level	Site Name	Date	Water Level	Site Name	Date	Water Level
GWB1	1997/02/01	58.46	PBH21	1994/02/01	36	Garing1	2014/01/01	5.7
GWB1	1997/11/01	58.43	PBH21	1994/11/01	36.5	GWB4	1985/10/01	52.7
GWB1	1998/02/01	58.03	PBH21	1995/02/01	36.8	GWB4	1985/11/01	52.62
GWB1	1998/11/01	58.24	PBH21	1995/11/01	36.6	GWB4	1986/05/01	52.45
GWB1	1999/02/01	57.14	PBH21	1996/08/01	36.65	GWB4	1986/11/01	52.86
GWB1	2003/05/01	57.1	PBH21	1996/11/02	36.15	GWB4	1987/05/01	52.47
GWB1	2003/11/01	57.14	PBH21	1997/02/01	36.17	GWB4	1987/11/01	52.33
GWB1	2004/05/01	57.1	PBH21	1997/11/01	34.75	GWB4	1988/05/01	52.04
GWB1	2004/12/01	57.13	PBH21	1998/02/01	36.04	GWB4	1988/11/01	52.46
GWB1	2005/05/01	57.08	PBH21	1998/11/01	35.14	GWB4	1989/02/01	51.89
GWB1	2005/11/01	57.18	PBH21	1999/02/01	35.19	GWB4	1989/11/01	52.61
GWB1	2006/05/01	57.28	PBH21	1999/11/01	35.22	GWB4	1990/02/01	52.83
GWB1	2006/11/01	57.3	PBH21	2000/02/01	35.23	GWB4	1990/11/01	52.65
GWB1	2007/05/01	57.46	PBH21	2002/11/01	36.68	GWB4	1991/02/01	52.63
GWB1	2007/10/01	57.55	PBH21	2003/05/01	37.36	GWB4	1991/11/01	52.71
GWB1	2008/05/01	57.61	PBH21	2003/11/01	37.68	GWB4	1992/02/01	52.71
GWB1	2008/09/01	57.61	PBH21	2004/05/01	35.6	GWB4	1992/11/01	52.8
GWB1	2009/06/01	57.72	PBH21	2004/12/01	33.24	GWB4	1993/02/01	52.91
GWB1	2010/06/01	57.71	PBH21	2005/05/01	56.8	GWB4	1993/05/01	52.86
GWB1	2010/12/01	57.82	PBH21	2005/11/01	47.55	GWB4	1994/02/01	54.1
GWB1	2011/03/01	57.8	PBH21	2006/05/01	43.7	GWB4	1994/11/01	52.3
GWB1	2011/06/01	57.8	PBH21	2006/11/01	43.48	GWB4	1995/02/01	53.5
GWB1	2012/04/01	57.81	PBH21	2007/05/01	41.45	GWB4	1995/11/01	53.5
GWB1	2012/10/01	57.91	PBH21	2007/10/01	38.46	GWB4	1996/08/01	53.36

Site Name	Date	Water Level	Site Name	Date	Water Level	Site Name	Date	Water Level
GWB1	2013/07/01	57.48	PBH21	2008/05/01	37.88	GWB4	1996/11/02	51.8
GWB1	2013/11/01	57.3	PBH21	2008/09/01	58.48	GWB4	1997/02/01	52.78
GWB1	2014/01/01	57.66	PBH21	2009/06/01	37.05	GWB4	1997/11/01	52.42
GWB5	1985/11/01	54.49	PBH21	2010/06/01	58.55	GWB4	1998/02/01	52.51
GWB5	1985/12/01	54.56	PBH21	2010/12/01	38.8	GWB4	1998/11/01	51.59
GWB5	1986/05/01	54.18	PBH21	2011/03/01	38.83	GWB4	1999/02/01	51.34
GWB5	1986/11/01	54.4	PBH21	2011/06/01	38.8	GWB4	1999/11/01	51.34
GWB5	1987/05/01	54.3	PBH21	2012/07/01	36.97	GWB4	2000/02/01	51.35
GWB5	1987/11/01	54.13	PBH21	2012/10/01	36.1	GWB4	2003/05/01	51.52
GWB5	1988/02/01	53.96	PBH21	2013/07/01	35	GWB4	2003/11/01	52
GWB5	1988/11/01	53.98	PBH21	2013/11/01	35.38	GWB4	2004/05/01	51.3
GWB5	1989/02/01	53.2	PBH21	2014/01/01	35.06	GWB4	2004/12/01	51.5
GWB5	1989/11/01	54.3	PBH22	1987/11/01	44.07	GWB4	2005/05/01	51.16
GWB5	1990/02/01	54.42	PBH22	1989/02/01	43.4	GWB4	2005/11/01	51.53
GWB5	1990/11/01	54.34	PBH22	1989/11/01	44.3	GWB4	2006/05/01	51.64
GWB5	1991/02/01	54.34	PBH22	1990/02/01	44.4	GWB4	2006/11/01	51.54
GWB5	1991/11/01	54.37	PBH22	1990/11/01	44.37	GWB4	2007/05/01	51.72
GWB5	1992/02/01	54.35	PBH22	1991/02/01	44.4	GWB4	2007/10/01	51.87
GWB5	1992/11/01	54.48	PBH22	1991/11/01	44.4	GWB4	2008/05/01	51.92
GWB5	1993/02/01	54.59	PBH22	1992/02/01	44.44	GWB4	2008/09/01	51.94
GWB5	1993/05/01	54.56	PBH22	1992/11/01	44.61	GWB4	2009/03/01	52.05
GWB5	1994/02/01	54	PBH22	1993/02/01	44.74	GWB4	2009/06/01	52.05
GWB5	1994/11/01	55	PBH22	1993/05/01	44.64	GWB4	2010/06/01	52.01
GWB5	1995/02/01	55.4	EM8	1987/11/01	37.99	GWB4	2010/12/01	52

Site Name	Date	Water Level	Site Name	Date	Water Level	Site Name	Date	Water Level
GWB5	1995/11/01	53	EM8	1989/02/01	37.34	GWB4	2011/03/01	52.05
GWB5	1996/08/01	55.32	EM8	1989/11/01	37.9	GWB4	2011/06/01	52.1
GWB5	1996/11/02	53.6	EM8	1990/02/01	38.14	GWB4	2012/05/01	52.04
GWB5	1997/02/01	54.58	EM8	1990/11/01	38.17	GWB4	2012/10/01	52.36
GWB5	1997/11/01	54.25	EM8	1991/02/01	37.8	GWB4	2013/07/01	51.74
GWB5	1998/02/01	54.37	EM8	1991/11/01	37.77	GWB4	2013/11/01	51.7
GWB5	1998/11/01	53.39	EM8	1992/02/01	37.79	GWB4	2014/01/01	51.79
GWB5	1999/02/01	53.27	EM8	1992/11/01	38.59	FW35	1986/05/01	36.86
GWB5	1999/11/01	53.2	EM8	1993/02/01	37.6	FW35	1987/05/01	36.86
GWB5	2000/02/01	53.16	EM8	1993/05/01	38.6	FW35	1987/11/01	36.88
GWB5	2003/05/01	54.44	Dasdap	2013/06/10	60.67	FW35	1988/05/01	36.86
GWB5	2003/11/01	54.48	Dikmatjie	2013/06/10	5	FW35	1988/11/01	36.88
GWB5	2004/05/01	54.64	Groenvlei	2013/06/10	20.6	FW35	1989/02/01	36.37
GWB5	2004/12/01	54.81	Kamiebees2	2013/06/10	7.92	FW35	1989/11/01	37.07
GWB5	2005/05/01	54.85	Lepel1	2013/06/10	45.03	FW35	1990/02/01	37.63
GWB5	2005/11/01	54.52	Norabees1	2013/06/10	29.92	FW35	1990/11/01	37.4
GWB5	2006/06/01	53.4	Platbakkies2	2013/06/10	7.92	FW35	1991/02/01	37.02
GWB5	2006/11/01	54.56	Walfkraal3	2013/06/10	41.39	FW35	1991/11/01	37
GWB5	2007/05/01	54.5	GWB8	2005/05/01	50.24	FW35	1992/02/01	37.1
GWB5	2007/10/01	53.76	GWB8	2005/08/01	50.4	FW35	1992/11/01	36.9
GWB5	2008/05/01	53.72	GWB8	2006/06/01	50.35	FW35	1993/02/01	36.83
GWB5	2008/09/01	53.75	GWB8	2006/11/01	50.4	FW35	1993/05/01	36.99
GWB5	2009/03/01	53.82	GWB8	2007/05/01	50.5	MON1	1985/09/01	53.1
GWB5	2009/06/01	53.86	GWB8	2007/10/01	50.69	MON1	1985/12/01	53.56

Site Name	Date	Water Level	Site Name	Date	Water Level	Site Name	Date	Water Level
GWB5	2010/06/01	53.82	GWB8	2008/05/01	50.63	MON12	1985/02/01	56.9
GWB5	2010/12/01	53.48	GWB8	2008/09/01	50.69	MON12	1985/10/01	57.13
GWB5	2011/03/01	53.6	GWB8	2009/03/01	50.76	MON12	1986/02/01	57.07
GWB5	2011/06/01	53.63	GWB8	2009/06/01	50.8	MON12	1986/11/01	56.7
GWB5	2012/04/01	53.77	GWB8	2010/06/01	50.88	MON12	1987/04/01	56.9
GWB5	2012/10/01	53.89	GWB8	2010/12/01	51.01	MON12	1987/11/01	56.73
GWB5	2013/07/01	53.51	GWB8	2011/03/01	51.03	MON12	1988/02/01	56.76
GWB5	2013/11/01	53.44	GWB8	2011/06/01	51.07	MON12	1988/11/01	56.58
GWB5	2014/01/01	53.52	GWB8	2012/04/01	50.44	MON12	1989/02/01	57.69
GWB6	1985/12/01	83.14	GWB8	2012/10/01	50.46	MON12	1989/11/01	57.19
GWB6	1986/05/01	79.18	GWB8	2013/07/01	50.63	MON12	1990/11/01	57.12
GWB6	1986/11/01	76.24	GWB8	2013/11/01	50.5	MON11	2010/06/01	53.48
GWB6	1987/05/01	72.74	GWB8	2014/01/01	50.64	MON11	2010/12/01	54.52
GWB6	1987/11/01	70.36	PBH16	1985/10/01	59	MON11	2005/05/01	53.91
GWB6	1988/05/01	67.77	PBH16	1985/12/01	59.12	MON11	1985/02/01	53.85
GWB6	1988/11/01	66.05	PBH16	1986/05/01	58.69	MON11	1985/11/01	54.29
GWB6	1989/02/01	64.41	PBH16	1986/11/01	58.83	MON11	1986/02/01	54.17
GWB6	1989/11/01	63.87	PBH16	1987/05/01	58.5	MON11	1986/11/01	54.06
GWB6	1990/02/01	63.48	PBH16	1987/11/01	58.77	MON11	1987/05/01	54.04
GWB6	1990/11/01	62.38	PBH16	1988/05/01	58.29	MON11	1987/11/01	54.09
GWB6	1991/02/01	61.54	PBH16	1988/11/01	58.23	MON11	1988/02/01	54.02
GWB6	1991/11/01	61.14	PBH16	1989/02/01	57.75	MON11	1988/11/01	53.83
GWB6	1992/02/01	60.24	PBH16	1989/11/01	58.99	MON11	1989/02/01	56.17
GWB6	1992/11/01	59.54	PBH16	1990/02/01	59.08	MON11	1989/11/01	54.71

Site Name	Date	Water Level	Site Name	Date	Water Level	Site Name	Date	Water Level
GWB6	1993/02/01	58.9	PBH16	1990/11/01	59	MON11	1990/02/01	54.62
GWB6	1993/05/01	59.59	PBH16	1991/02/01	59.06	MON11	1990/11/01	54.12
GWB6	1994/02/01	58.5	PBH16	1991/11/01	59.01	MON11	1991/02/01	56.87
GWB6	1994/11/01	58.2	PBH16	1992/02/01	59.09	MON11	1991/11/01	56.56
GWB6	1995/02/01	57.9	PBH16	1992/11/01	59.12	MON11	1992/02/01	55.42
GWB6	1995/11/01	57.62	PBH16	1993/05/01	58.78	MON11	1992/11/01	55.48
GWB6	1996/08/01	57.76	PBH16	1993/05/01	59.22	MON11	1993/02/01	58.24
GWB6	1996/11/02	57.1	PBH16	1994/02/01	59	MON11	1993/05/01	55.48
GWB6	1997/04/01	56.72	PBH16	1994/11/01	59.6	MON11	1994/02/01	56.68
GWB6	1997/11/01	56.59	PBH16	1995/02/01	60	MON11	1994/11/01	55.55
GWB6	1998/02/01	56.85	PBH16	1995/11/01	60.1	MON11	1995/01/01	55.02
GWB6	1998/11/01	55.74	PBH16	1996/08/01	59.96	MON11	1997/07/01	53.62
GWB6	1999/02/01	55.69	PBH16	1996/11/02	59.3	MON11	1997/11/01	53.42
GWB6	1999/11/01	55.48	PBH16	1997/02/01	59.25	MON11	1998/02/01	53.68
GWB6	2000/02/01	55.43	PBH16	1997/11/01	58.74	MON11	1998/11/01	55.65
GWB6	2003/05/01	54.58	PBH16	1998/02/01	59.05	MON11	1999/06/01	53.3
GWB6	2003/11/01	54.88	PBH16	1998/11/01	57.86	MON11	2005/11/01	53.62
GWB6	2004/05/01	55.28	PBH16	1999/02/01	57.73	MON11	2006/11/01	53.04
GWB6	2004/12/01	55.42	PBH16	1999/11/01	57.64	MON11	2007/05/01	53.1
GWB6	2005/05/01	55	PBH16	2000/02/01	57.68	MON11	2013/11/01	53.21
GWB6	2005/11/01	55.33	PBH16	2003/05/01	58.01	FW34	2005/05/01	36.48
GWB6	2006/05/01	55.39	PBH16	2003/11/01	58	FW34	2005/11/01	36.53
GWB6	2006/11/01	55.26	PBH16	2004/05/01	57.9	FW34	2006/05/01	36.65
GWB6	2007/05/01	55.22	PBH16	2004/12/01	57.9	FW34	2006/11/01	36.78

Site Name	Date	Water Level	Site Name	Date	Water Level	Site Name	Date	Water Level
GWB6	2007/10/01	55.23	PBH16	2005/05/01	57.34	FW34	2007/05/01	36.92
GWB6	2008/05/01	55.2	PBH16	2005/11/01	58.02	FW34	2007/10/01	37.07
GWB6	2008/09/01	55.16	PBH16	2006/05/01	58.1	FW34	2008/05/01	37.2
GWB6	2009/03/01	55.15	PBH16	2006/11/01	58.12	FW34	2008/09/01	37.01
GWB6	2009/06/01	55.16	PBH16	2007/05/01	58.22	FW34	2009/06/01	37.5
GWB6	2010/06/01	55.11	PBH16	2007/10/01	57.4	FW34	2010/06/01	37.7
GWB6	2010/12/01	55.07	PBH16	2008/05/01	58.41	FW34	2010/12/01	37.81
GWB6	2011/03/01	55.09	PBH16	2008/09/01	58.42	FW34	2011/03/01	37.84
GWB6	2011/06/01	55.08	PBH16	2009/06/01	58.48	FW34	2011/06/01	38.31
GWB6	2012/04/01	55.7	PBH16	2010/06/01	58.53	FW34	2012/04/01	37.57
GWB6	2012/10/01	55.92	PBH16	2010/12/01	58.55	FW34	2012/10/01	37.66
GWB6	2013/07/01	54.92	PBH16	2011/03/01	58.59	FW34	2013/07/01	37.58
GWB6	2013/10/01	51.9	PBH16	2011/06/01	58.59	FW34	2013/11/01	37.47
GWB6	2014/01/01	51.86	PBH16	2012/05/01	58.6	FW34	2014/01/01	37.9
GWB8	1985/10/01	52.91	PBH16	2012/10/01	58.94	MON10	2011/06/01	51.1
GWB8	1985/12/01	52.22	PBH16	2013/07/01	58.01	MON10	2012/05/01	51.57
GWB8	1986/05/01	51.11	PBH16	2013/10/01	58	MON10	2012/10/01	51.9
GWB8	1986/11/01	51.07	PBH16	2014/01/01	58.03	MON10	2013/07/01	51.62
GWB8	1987/05/01	51.07	PBH17	1985/10/01	92.45	MON10	2013/11/01	51.65
GWB8	1987/11/01	51.05	PBH17	1985/11/01	98.95	MON10	2014/01/01	51.95
GWB8	1988/05/01	50.74	PBH17	1986/05/01	91.62	PBH17	1991/02/01	76.77
GWB8	1988/11/01	52.72	PBH17	1986/11/01	90.34	PBH17	1991/11/01	76.1
GWB8	1989/02/01	52.44	PBH17	1987/05/01	88.02	PBH17	1992/02/01	74.15
GWB8	1989/11/01	51.9	PBH17	1987/11/01	86.4	PBH17	1992/11/01	72.32

Site Name	Date	Water Level	Site Name	Date	Water Level	Site Name	Date	Water Level
GWB8	1990/02/01	51.83	PBH17	1988/05/01	84.68	PBH17	1993/02/01	70.49
GWB8	1990/11/01	51.44	PBH17	1988/11/01	82.41	PBH17	1993/05/01	71.77
GWB8	1991/02/01	52.06	PBH17	1989/02/01	80.67	PBH17	1994/02/01	70
GWB8	1991/11/01	51.7	PBH17	1989/11/01	80.17	PBH17	1994/11/01	69.3
GWB8	1992/02/01	52.34	PBH17	1990/02/01	79.59	PBH17	1995/02/01	67.8
GWB8	1992/11/01	51.88	PBH17	1990/11/01	78.14	PBH17	1995/11/01	68
GWB8	1993/02/01	52	GWB8	1998/11/01	50.16	PBH17	1996/08/01	66.53
GWB8	1993/05/01	52.32	GWB8	1999/02/01	53.99	PBH17	1996/11/02	68.3
GWB8	1994/02/01	52	GWB8	1999/11/01	49.61	PBH17	1997/02/01	67.82
GWB8	1994/11/01	52.6	GWB8	2000/02/01	49.88	PBH17	1997/11/01	66.4
GWB8	1995/02/01	52	GWB8	2001/05/01	50.74	PBH17	1998/02/01	67.91
GWB8	1995/11/01	51.73	GWB8	2001/11/01	50.7	PBH17	1998/11/01	66.27
GWB8	1996/08/01	52.16	GWB8	2002/05/01	50.5	GWB8	2003/11/01	51.36
GWB8	1996/11/02	51.54	GWB8	2002/11/01	50.42	GWB8	2004/05/01	50.36
GWB8	1997/02/01	51.57	GWB8	2003/05/01	51.27	GWB8	2004/12/01	50.43

APPENDIX C

WATER CHEMISTRY RESULTS

Table 23: Groundwater average chemistry results for the VRWS and surrounding farms from 1985 to 2013 (Necsa database)

Site Name	pH	EC mS/m	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	MALK mg/l	Cl mg/l	SO4 mg/l	NO3-N mg/l	F mg/l	Al mg/l	Fe mg/l	Mn mg/l	U
BH13C5	7.3	1071	456.11	232.1	1381.3	11.34	104.75	3250.89	613.54	0.55	1.88		3.97	0.77	0.36
Platbakkies 2	8.51	1932	209.9	46	5624.9	167.92	222	9458	272.8	-2.5	1.17	0.4	0.2	0.1	
Group A (average values)	7.91	1501.50	333.01	139.05	3503.10	89.63	163.38	6354.45	443.17	-0.98	1.53	0.40	2.09	0.44	0.36
GWB3	7.58	539.56	132.94	96.98	937.5	27.23	288.1	1554.51	339.13	8.96	2.9		3.86		0.78
MON10	7.66	576.61	124.53	96.06	990.25	25.14	32.3	1569	344.93	19.61	2.74		0.26	0.15	0.87
MON15	7.74	595.22	143.33	107.88	1032.29	24.94	322.3	1709.14	325.93	13.1	2.62		0.15	0.15	0.94
Lepel 1	7.3	665	317.9	130.7	965.5	37.32	28	1975	542.9	18.8	1.5	0.1	0.2	0.1	
Platbakkies 1	8.3	578	97.3	98.2	1021.3	29.28	235	1707	416.2	-0.5	1.4	0.2	0.4	0.1	
MON2	7.74	496.82	89.53	69.81	887.09	23.14	334.53	1254.47	291.4	26.17	3.1	0.14	0.18	0.18	0.89
MON4	7.76	419.39	59.14	52.76	784.96	25.79	317.83	1088.4	229.21	1.57	2.58	0.18	0.5	0.59	0.9
Frommelbakkies 4	7.5	404	86.7	41.8	783.1	28.69	32	946	331.6	32.25	1.9	0.04	0.3	0.1	
Goubees 1	7.8	578	242.9	152	811.9	26.87	197	1708	380	12.96	0.6	0.2	0.2	0.1	
Goubees 2	7.5	728	215.1	141.9	1202.3	73.59	214	2110	580	21.82	1.8	0.12	0.11	0.1	
Groenvlei 1	7.4	596	203.2	138.1	1005.1	25.38	312	1503	630	38.9	0.2	0.21	0.47	0.11	
Norabees1	7.5	519	223.4	136.9	671.5	25.49	189	1508	375.2	17.7	-0.1	0.1	0.9	0.8	
Norabees2	7.8	516	242.6	124.9	656.6	29.92	156	1490	375.2	24.4	0.14	0.1	0.1	0.1	
Group B (average values)	7.66	554.74	167.58	106.77	903.80	30.98	204.47	1547.89	397.05	18.13	1.64	0.14	0.59	0.22	0.88
BH3C2	7.75	351.17	206.48	77.7	416.91	18.48	123.07	866.06	253.14	82.34	1.18		28.21	0.16	0.28
BH4C1	7.58	529.71	248.61	128.73	691.3	29.53	19.9	1467.37	348.9	16.07	1.49		0.3	0.15	
BH16C3	7.6	463.93	273.41	121.28	485.48	28.98	184	1229.06	260.19	11.53	1.5		0.47	0.18	0.56
BH13C7	7.49	503.4	203.25	137.45	650.53	8.47	227	1343.22	380.13	1.95	2.26	0.1	0.51		0.18
BH 519	7.4	412	165.2	110.1	578.3	15.7	231	1022	530.3	0.64	0.14	0.02	0.2	0.1	
Dasdap 1	7.23	304	266.7	99.4	221.1	16.48	144	924	112.3	0.5	-0.1	0.01	0.29	0.86	

Group C (average	7.51	427.37	227.28	112.44	507.27	19.61	154.83	1141.95	314.16	18.84	1.08	0.04	5.00	0.29	0.34

Site Name	pH	EC mS/m	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	MALK mg/l	Cl mg/l	SO4 mg/l	NO3-N mg/l	F mg/l	Al mg/l	Fe mg/l	Mn mg/l	U
values)															
Wolfkraal 3	8.5	229	28.2	35.7	395.2	19.27	22	570	170.2	-0.5	0.2	0.6	0.5	0.2	
Dikmatjie 1	7.68	177.1	84.1	76.9	245.2	2	232	465	156.4	2.63	0.53	0.02	0.15	0.6	
Wolfkraal 1	8.1	108	43.7	27.3	139.9	4.7	248	173	62	3.24	0.5	0.2	0.2	0.1	
Kamiebees 2	7.6	262	99.9	61.8	398.5	6.2	286	548	284	9.14	2.5	0.2	0.14	0.15	
Group D (average values)	7.97	194.03	63.98	50.43	294.70	8.04	197.00	439.00	168.15	3.63	0.93	0.26	0.25	0.26	

Table 24: Calculated ion balance groundwater chemical borehole for the VRWS and surrounding farms

Site Name	Date Time Meas	pH	EC mS/m	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	MALK mg/l	Cl mg/l	SO4 mg/l	NO3-N mg/l	F mg/l	Al mg/l	Fe mg/l	Mn mg/l	U
Dasdap 1	2013/11/11	7.23	304.00	266.70	99.40	221.10	16.48	144.00	924.00	112.30	0.50	-0.10	0.01	0.29	0.86	-1.00
BH3C2	2011/05/01	7.40	359.00	190.00	83.80	358.00	16.90	150.20	821.31	251.84	26.70	1.23	-1.00	0.10	0.10	0.30
BH16C3	2008/05/01	7.20	502.00	291.00	146.00	469.00	89.00	156.00	1397.00	313.00	14.20	0.90	-1.00	-1.00	-1.00	-1.00
Norabees 2	2013/11/11	7.80	516.00	242.60	124.90	656.60	29.92	156.00	1490.00	375.20	24.40	0.14	0.10	0.10	0.10	-1.00
BH4C1	2008/05/01	7.20	539.00	218.00	138.00	690.00	56.00	160.00	1457.00	367.00	4.41	0.90	-1.00	-1.00	-1.00	-1.00
BH3C2	2009/11/01	7.70	365.00	218.00	95.00	414.00	8.00	179.80	960.30	251.00	34.60	1.20	-1.00	0.11	0.20	-1.00
BH13C5	2008/05/01	7.00	1280.00	504.00	310.00	1810.00	24.00	182.00	4003.00	899.00	0.11	1.00	-1.00	-1.00	-1.00	-1.00
Norabees 1	2013/11/11	7.50	519.00	223.40	136.90	671.50	25.49	189.00	1508.00	375.20	17.70	0.10	0.10	0.90	0.80	-1.00
Goubees 1	2013/11/11	7.80	578.00	242.90	152.00	811.90	26.87	197.00	1708.00	380.00	12.96	0.60	0.20	0.20	0.10	-1.00
Wolfkraal 3	2013/11/11	8.50	229.00	28.20	35.70	395.20	19.27	202.00	570.00	170.20	-0.50	0.20	0.60	0.50	0.20	-1.00
Lepel 1	2013/11/11	7.30	665.00	317.90	130.70	965.50	37.32	208.00	1975.00	542.90	18.80	1.50	0.10	0.20	0.10	-1.00
Goubees 2	2013/11/11	7.50	728.00	215.10	141.90	1202.30	73.59	214.00	2110.00	580.00	21.82	1.80	0.12	0.11	0.10	-1.00
Platbakkies 2	2013/11/11	8.50	1932.00	209.90	46.00	5624.90	167.92	222.00	9458.00	272.80	-2.50	1.17	0.40	0.20	0.10	-1.00
BH13C7	2001/11/01	7.20	512.00	230.00	185.00	576.00	4.30	227.00	1441.17	433.49	0.55	2.37	-1.00	0.10	0.10	0.10
BH 519	2013/11/11	7.40	412.00	165.20	110.10	578.30	15.70	231.00	1022.00	530.30	0.64	0.14	0.02	0.20	0.10	-1.00
Dikmatjie 1	2013/11/11	7.68	177.10	84.10	76.90	245.20	2.00	232.00	465.00	156.40	2.63	0.53	0.02	0.15	0.60	-1.00

Platbakkies 1	2013/11/11	8.30	578.00	97.30	98.20	1021.30	29.28	235.00	1707.00	416.20	-0.50	1.40	0.20	0.40	0.10	-1.00
Wolfkraal 1	2013/11/11	8.10	108.00	43.70	27.30	139.90	4.70	248.00	173.00	62.00	3.24	0.50	0.20	0.20	0.10	-1.00
GWB3	2008/07/01	7.30	572.00	117.00	93.00	913.00	61.00	282.00	1460.00	341.00	2.96	1.20	-1.00	-1.00	-1.00	-1.00
Kamiebees 2	2013/11/11	7.60	262.00	99.90	61.80	398.50	6.20	286.00	548.00	284.00	9.14	2.50	0.20	0.14	0.15	-1.00
MON15	2013/11/11	7.60	695.00	166.60	151.70	1173.10	27.96	298.00	2234.00	432.10	4.88	1.80	-1.00	0.10	0.10	-1.00
MON10	2013/11/11	7.70	551.00	111.80	96.10	997.30	22.11	301.00	1548.00	351.70	9.67	2.10	-1.00	0.10	0.10	-1.00
Frommelbakkies 4	2013/11/11	7.50	404.00	86.70	41.80	783.10	28.69	302.00	946.00	331.60	32.25	1.90	0.04	0.30	0.10	-1.00
MON10	2008/05/01	7.60	576.00	108.00	92.00	1035.00	57.00	303.00	1478.00	352.00	92.00	0.80	-1.00	-1.00	-1.00	-1.00
MON4	2009/11/01	7.60	424.00	60.00	43.00	697.00	17.00	311.00	1046.00	233.00	0.50	1.30	-1.00	-1.00	-1.00	-1.00
Groenvlei 1	2013/11/11	7.40	596.00	203.20	138.10	1005.10	25.38	312.00	1503.00	630.00	38.90	0.20	0.21	0.47	0.11	-1.00
MON2	2013/07/02	7.60	486.00	87.80	73.90	919.20	21.30	325.00	1530.00	289.10	1.91	2.50	0.16	0.10	0.10	-1.00
MON4	2013/11/04	7.70	480.00	60.20	48.90	812.90	18.57	392.80	1070.00	250.70	-0.50	2.30	0.14	0.59	0.23	-1.00

APPENDIX D

RADIOISOTOPE DATA

Table 25: Radioisotope data for the VRWS and surrounding farms for year 2014

Sample Identification	Y-coord	X-coord	d D (‰)	d^{18}O (‰)	Tritium (T.U.)		Carbon-14 (pMC)		d^{13}C (‰)	Crystalline Rock Conv.C-14
Mon 2	-30.134388	18.567438	-30.4	-3.62	0.0	±0.2	26.0	±1.8	-7.10	11135.77638
FW 14	-30.135756	18.496944	-31.0	-4.24	0.0	±0.2	64.4	±4.3	-7.35	3637.79024
Mon 12	-30.13274	18.572489	-30.4	-3.43	0.6	±0.2	28.0	±1.8	-7.69	10523.15226
FW 35	-30.120617	18.518874	-32.2	-4.38	0.0	±0.2	27.9	±1.8	-7.51	10552.72883
Mon 10	-30.136979	18.576836	-30.1	-3.57	0.2	±0.2	27.6	±1.8	-7.25	10642.09881
EM 8			-31.9	-4.30	0.2	±0.2	23.3	±1.8	-7.98	12042.15734
FW 28	-30.105006	18.484219	-27.8	-3.95	0.0	±0.2	81.2	±2.4	-12.14	1721.569146
PBH 21	-30.115641	18.543184	-29.0	-3.40	0.7	±0.2	87.5	±2.4	-9.67	1103.856297
PBH 16	-30.143734	18.565531	-28.0	-3.58	0.7	±0.2	60.8	±2.2	-9.64	4113.319299
Platbakkies (1)	-30.297987	18.565567	-31.8	-4.84	0.2	±0.2	83.3	±2.4	-9.91	1510.494464
Dasdap	-30.324493	18.604974	-34.6	-5.44	0.3	±0.2	56.5	±2.1	-5.54	4719.670513
Frummelbakkies	-30.052837	18.688883	-28.3	-3.14	0.0	±0.2	59.5	±2.2	-5.65	4291.990184
Norabees (2)	-30.112752	18.644626	-29.1	-3.74	0.5	±0.2	61.9	±2.2	-5.91	3965.095168
Platbakkies (PB2T)	-30.31206	18.486946	-29.7	-4.88	1.2	±0.3	10.5	±1.6	-6.62	18631.31713
Goubees (1)	-30.024523	18.619362	-28.1	-3.48	0.1	±0.2	25.9	±1.8	-7.38	11167.63246
Boesmanplaat	-30.075511	18.400277	-29.9	-4.84	0.6	±0.2	79.0	±2.4	-9.84	1948.63228
Wolwekraal	-30.007567	18.492068	-25.6	-3.28	0.0	±0.2	19.3	±1.7	-8.40	13599.16513
Dikmatjie	-30.071053	18.398264	-34.5	-5.24	0.4	±0.2	84.1	±2.4	-8.89	1431.481747
Kamiebees	-30.03739	18.476651	-30.0	-4.61	0.3	±0.2	45.9	±2.0	-9.47	6437.276483
Goubees (2)	-30.024523	18.619362	-29.3	-4.11	0.0	±0.2	52.6	±2.1	-8.66	5310.938142
Groenvlei	-30.2553	18.706085	-28.0	-3.29	0.4	±0.2	67.8	±2.3	-4.56	3212.483367
PB 2 (m)			-30.0	-4.94	0.8	±0.2				

Lepel	-30.160563	18.738414	-29.1	-4.08	1.0	±0.2	33.7	±1.9	-6.85	8991.398555

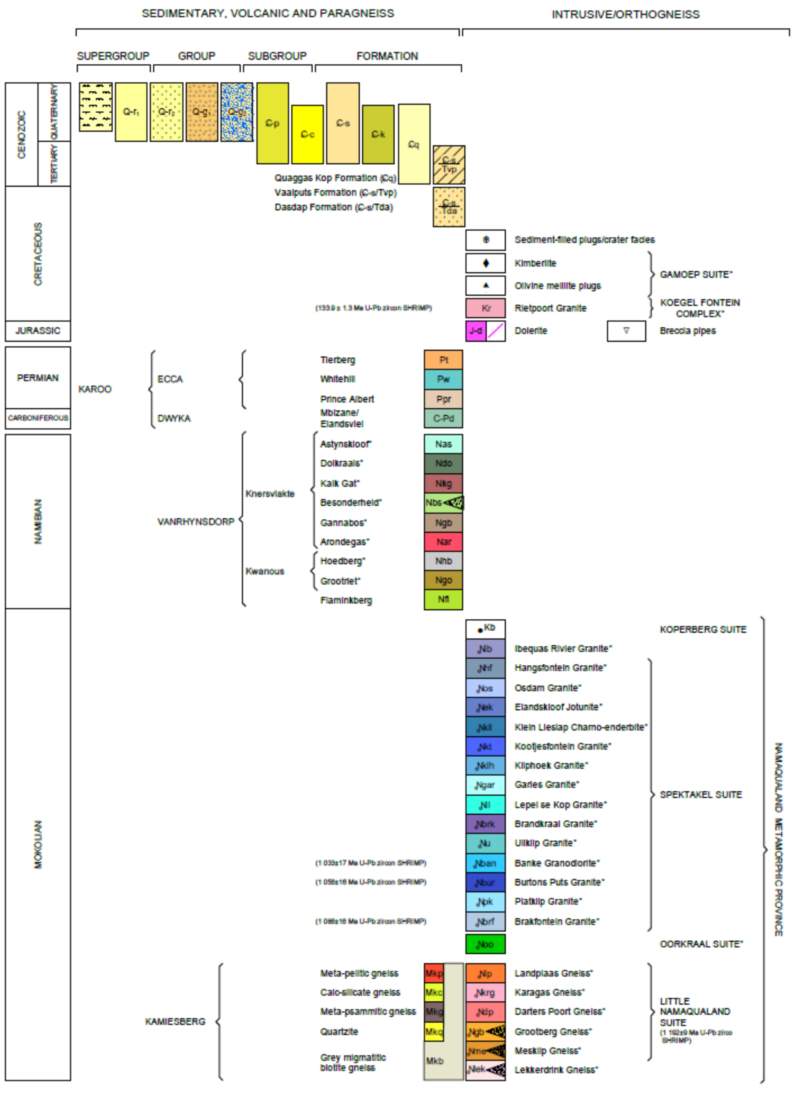
Table 26: groundwater chloride results for the calculation for recharge in the VRWS and surrounding farms (Necsa database)

Site Name	Cl mg/l	Site Name	Cl mg/l	Site Name	Cl mg/l	Site Name	Cl mg/l
Dasdap 1	924.00	BH13C7	1441.17	Norabees 1	1508.00	MON15	2234.00
BH3C2	821.31	BH 519	1022.00	Goubees 1	1708.00	MON10	1548.00
BH16C3	1397.00	Dikmatjie 1	465.00	Wolfkraal 3	570.00	Frommelbakkies 4	946.00
Norabees 2	1490.00	Platbakkies 1	1707.00	Lepel 1	1975.00	MON10	1478.00
BH4C1	1457.00	Wolfkraal 1	173.00	Goubees 2	2110.00	MON4	1046.00
BH3C2	960.30	GWB3	1460.00	Platbakkies 2	9458.00	Groenvlei 1	1503.00
BH13C5	4003.00	Kamiebees 2	548.00	MON4	1070.00	MON2	1530.00

APPENDIX E

GEOLOGICAL LEGEND

GEOLOGICAL LEGEND



* Not yet approved by SACS