DESERT LiON ENERGY

WINDHEOK NAMIBIA

HYDROGEOLOGICAL BASELINE STATUS ASSESSMENT AND GROUNDWATER EXPLORATION IN EPL 5439, KARIBIB AREA

FINAL REPORT

Project: NHN-203

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Executive Summary

Desert Lion Energy plans to apply for a mining licence on Exclusive Prospecting License (EPL) 5439 to mine lithium ore at part of Farm Okongava Ost, near Karibib in the Erongo Region of Namibia. To apply for a mining license, hydrogeological baseline assessments and groundwater monitoring data are needed to complete the required environmental impact assessment. In addition, groundwater exploration and development in the EPL for supply to the future mine and local community is needed. The estimated water demand for a fully operational mine (Phase 2) is expected to be 36 m^3/h or 864 m^3/day.

Exploration targets were selected based on aerial photos, satellite imagery and airborne magnetic data interpretation as well as local ground inspections. The final drilling sites were selected on the basis of geophysical surveys (horizontal loop electromagnetic profiling).

Selected sites were drilled using the rotary air-percussion method to depths ranging from 90 to 150 m. Water was struck in faulted marble and in marble in contact with calcsilicate and pegmatite. Initial blowout yields from yielding boreholes ranged from 5 to 40 m^3/h. The boreholes were test pumped and recommended pumping rates were estimated from the data. Four boreholes are recommended for production pumping (WW204831, WW204832, WW204833, and WW204838). The boreholes WW204831, WW204832, WW204833 are recommended for use for mine operations exclusively. Borehole WW204838 is recommended to supply local community and also to complement the mine water supply when needed. The very low yielding boreholes are to be used for groundwater level monitoring and sampling purposes only. The recommended total yield from the four boreholes is 334 m^3/day which represents about 40% of the projected Phase 2 water demand. The groundwater quality of boreholes recommended for pumping meets Group C standards (Water with low health risk) thus suitable for human consumption.

An application for an abstraction permit for the four boreholes was made by the consultant to the Department of Water Affairs and Forestry (DWAF). Abstraction permit granted by the DWAF require that production records and water levels are submitted on a quarterly basis. The monitoring data from the production and monitoring boreholes should be assessed for sustainability. Daily rainfall is to be recorded in the project area in the absence of an operating meteorological station close to the area. Sampling and analyses of groundwater quality of production boreholes is to be carried out once every three months as recommended by the Water Act (Act 54 of 1956).

Table of Contents

List of Tables

List of Figures

1 Introduction

Substantial lithium deposits have been found in Exclusive Prospecting License (EPL) 5439 located south of Karibib (Figure 1). Desert Lion Energy intends to apply for a mining licence on the EPL. To ensure that the hydrogeological environmental requirements are met and to have sufficient data to complete environmental impact assessments, a prerequisite to apply for mining licenses, hydrogeological baseline assessments and groundwater monitoring are needed.

In addition, groundwater exploration and development in the EPL for supply to the future mine and local community was required. The estimated water demand for Phase 2 is 36 m^3/h (10 lps). This report summarises work carried out to date on the baseline hydrogeology study and groundwater exploration. The hydrogeology of the area is presented based on existing data and results of Phase 1 groundwater exploration work. Groundwater sources developed were evaluated for sustainable supply and groundwater monitoring requirements for the future are addressed.

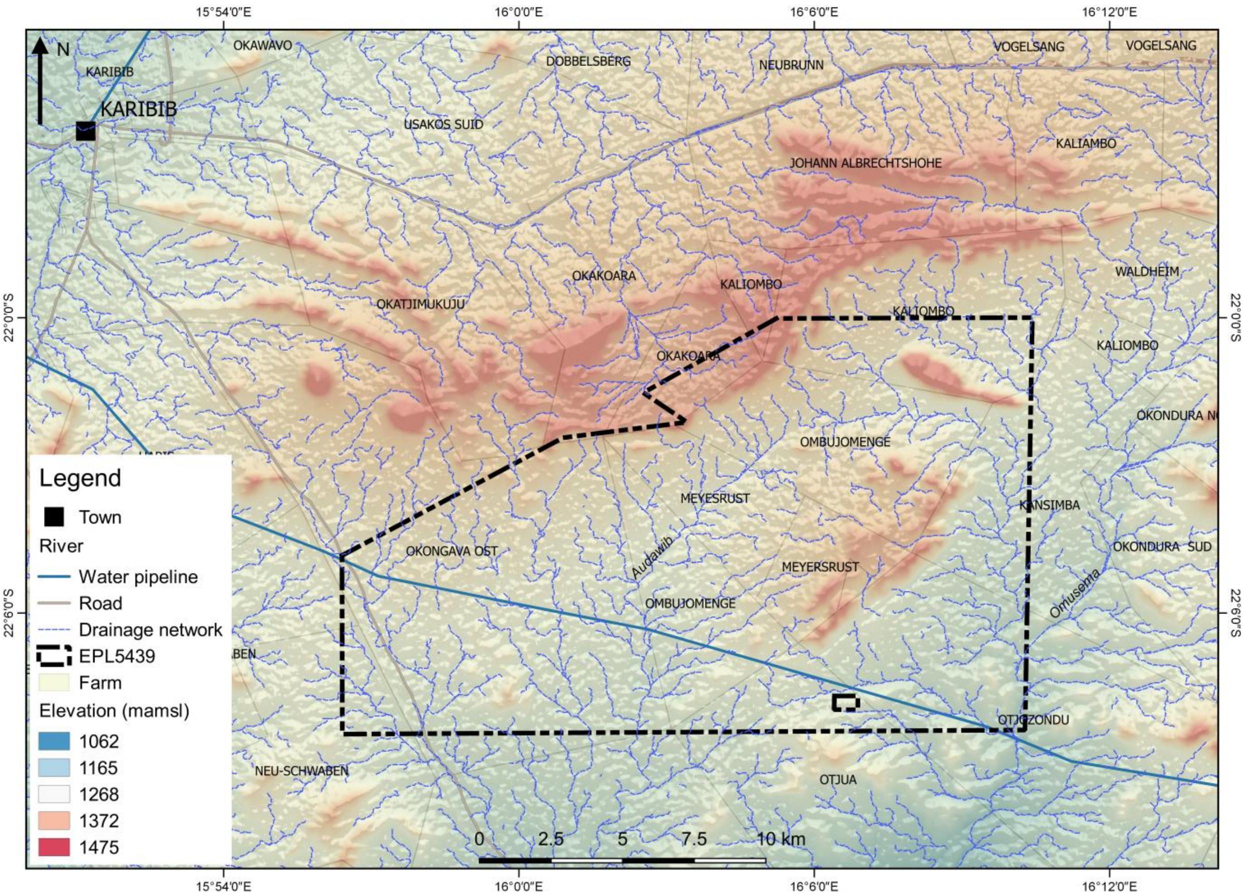


Figure 1: Location of the project area - exclusive prospecting license (EPL) 5439

2 Baseline hydrogeological study

2.1 Rainfall

The area experiences semi-arid climatic conditions (of 211 mm average rainfall per annum in the period 1945-2000). Annual average potential evaporation rate far exceeds average annual rainfall and net water deficit conditions prevail.

Historical rainfall data from the Karibib station[1] (Figure 2) were used to evaluate recurrence of larger rainfall events that are responsible for the replenishment of groundwater and surface water bodies. The probability of an arbitrary 300 mm rainfall event is given in Table 1. Supply potential of aquifers that are dependent on local rainfall for replenishment is low in the study area. Any water resource evaluation and abstraction plan has to be designed for supply from storage for long periods without replenishment.

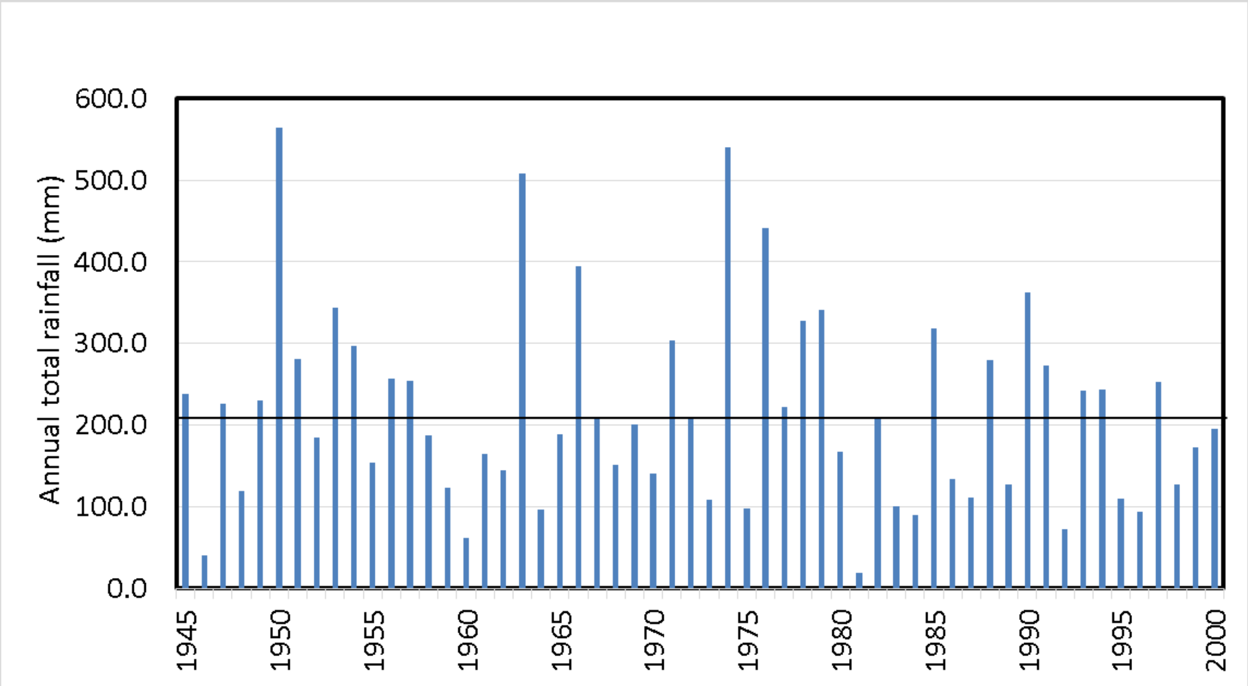


Figure 2: Annual total rainfall in Karibib for the period 1945-2000. Black solid line indicates long term average rainfall

Table 1: Recurrence statistics of rainfall in three stations in the study area

Station	Data record	Mean annual rainfall (mm)	Probability of a 300 mm event
Karibib	1945-2000	210.9	21 % (return period 4.8 year)

2.2 Surface drainage

[1] No recent rainfall data is available for the Karibib meteorological station.

The study area lies within the Swakop River catchment, a large west flowing ephemeral river of the country. Southwards flowing ephemeral tributaries of the Swakop River, namely the Audawib and the Omusema, drain the study area. A channel network derived from a digital elevation model (Aster satellite data) is shown in Figure 1. Elevated areas to the north with exposed basement rocks form a surface water divide. Arid Region Rivers typically show extreme variability with extended dry periods followed by runoff that is rapidly initiated in response to summer rain. Groundwater recharge occurs during these flow events. The safeguarding of the ephemeral drainage system is therefore important for groundwater recharge.

There are no natural permanent surface water bodies in the project area. The only large water body in the vicinity is the Swakoppoort Dam built on the Swakop River and is situated 80 km southeast of Karibib. The Dam supplies Windhoek, Karibib Town, Otjimbingwe Town and the Navachab Gold Mine through a pipeline that cross EPL 5439 (Figure 1). The potential of the Dam is given in Table 2. Completed in 1978, the dam is part of the three-dam system that supply to the Central Region of Namibia. During recent drought years (2015-2017), the Dam ran dry and it is doubtful that any extra capacity exists to supply. Additionally, pollution in the Swakop River catchment that includes urban areas from Windhoek to Okahandja has resulted in algal growth and eutrophication in the Dam.

Table 2: Details of Swakoppoort Dam

Storage capacity	67.1 MCM
Catchment area	5 480 Mm^2
Yield (95% assured)	4.7 MCM/annum

2.3 Project area hydrogeology

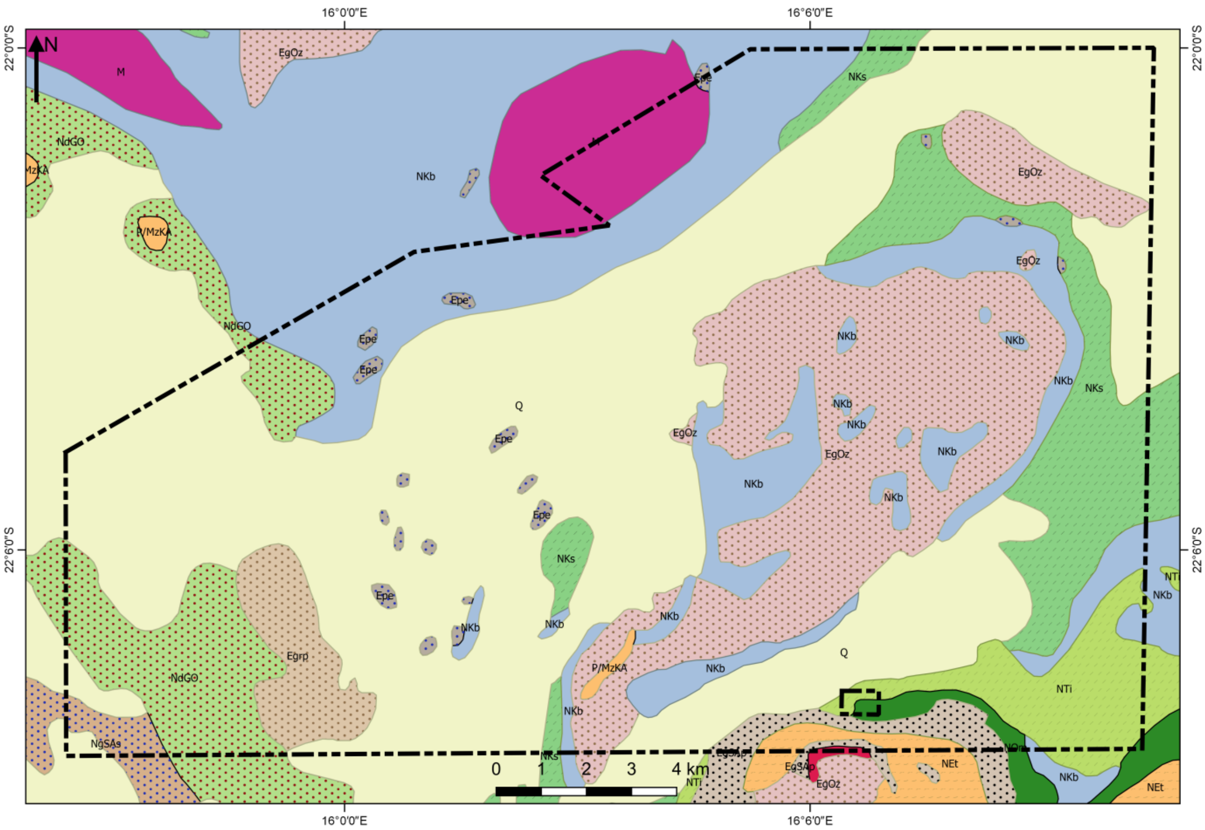
The area is underlain by meta-sedimentary rocks of the Damara Supergroup (Figure 3). The study area falls in the Northern and Southern Central Zone of the Damara Orogenic Belt (Miller 2008). The meta-sedimentary sequence have been folded into dome and basin structures and intruded by granitic plutons. Older basement are present at the core of the domes. The dominant structural fabric of the folded strata is oriented northeast. The lithology and orogenic events are discussed in detail in Miller (2008).

Groundwater levels were available from project boreholes only. The points are not sufficient for interpolation and contouring in a fractured rock aquifer. The water level elevations are shown in Figure 4. The groundwater flow direction appears to follow the topography and surface drainage.

The Damara Supergroup rocks form fractured rock aquifers and has negligible primary porosity. Secondary porosity is developed through faulting and karstification. The main faults are usually parallel to strike. Past records of borehole blowout yield provide an approximate measure of groundwater potential although it does not take into account the sustainability of the yield. The GROWAS database maintained by the Department of Water Affairs and Forestry (DWAF) was used and higher yields are seen to be associated with rocks affected by faulting particularly along contact zones of carbonate units with other rock types (granite, schists, calcsilicate). A second lithology associated with higher yields is quartzite. A histogram of blowout yields from the GROWAS database is shown in Figure 5 and distribution of borehole yield in the area is shown in Figure 6 overlaid on a satellite image that highlights carbonate lithology (the Karibib Formation marble unit in grey colour). Within EPL 5439 higher yields are associated with the folded Karibib Formation marble.

2.4 Groundwater quality assessment from historical data

Groundwater quality in the study area is variable with total dissolved solids varying from 119 mg/l to 4,778 mg/l in the records found in the GROWAS database. Boreholes close to the ephemeral river channels have lowest dissolved solids (dissolved inorganic content). Away from the drainage, higher total dissolved solids, sulphate, chloride and sodium are found. The increase of dissolved constituents is attributed to the long residence time and loss of water through evapotranspiration. Figure 7 shows total dissolved solids (TDS, in mg/l units) in groundwater as a measure of salinity in the study area.



LITHCODE	MAIN LITHOLOGY	AGE	FORMATION	SUITE	GROUP	SUPERGROUP
Q	sand;gravel;calcrete	Cenozoic				
P/MzKA	sandstone;shale;mudstone;tillite	Carboniferous to Cretaceous				Karoo
Epe	pegmatite	Cambrian				
EgOz	granite (red;post-tectonic)	Cambrian				
Egrp	granite (red;post-tectonic)	Cambrian				
EgSAp	biotite granite (syntectonic to post-tectonic; porphyritic)	Cambrian		Salem		
NgSAs	biotite granite (porphyritic;syntectonic)	Namibian		Salem		
NdGO	diorite (early syntectonic)	Namibian		Goas		
NOm	amphibolite	Namibian	Omusema		Swakop	Damara
NKs	mica schist;greywacke	Namibian	Kuiseb		Swakop	Damara
NKb	marble	Namibian	Karibib		Swakop	Damara
NTi	calc-silicate rock	Namibian	Tinkas		Swakop	Damara

Figure 3: Simplified geology of the project area after Miller (1983)

Few occurrences of elevated fluoride exceeding 3 mg/l have been reported in groundwater in the southwestern part of EPL 5439. Figure 8 indicates fluoride level in groundwater in the study area to be mostly within Group A level (1.5 mg/l) or acceptable for drinking water when compared to the highest acceptable level of fluoride in drinking water(3 mg/L, Group C) according to the Namibian Water Quality Guidelines – refer to Appendix B. The higher fluoride levels recorded in certain boreholes in the area is probably related to granitic and pegmatite intrusions in the Damara Supergroup rocks. Elevated fluoride causes dental and skeletal fluorosis. Elevated Nitrate in groundwater was recorded in several boreholes (Figure 9). Nitrate in groundwater originates from mobilisation of waste (human and animal) and from nitrogen fixed in the soil by vegetation. Nitrate contamination levels can vary during the time of year, with higher levels being recorded after rain when surface water infiltrates and recharges groundwater. Elevated Nitrate can cause methemoglobinemia, a blood disorder. The Group C and D limit of nitrate in groundwater are 20 and 40 mg/l (as N) respectively and boreholes where the limits are exceeded are highlighted in Figure 9.

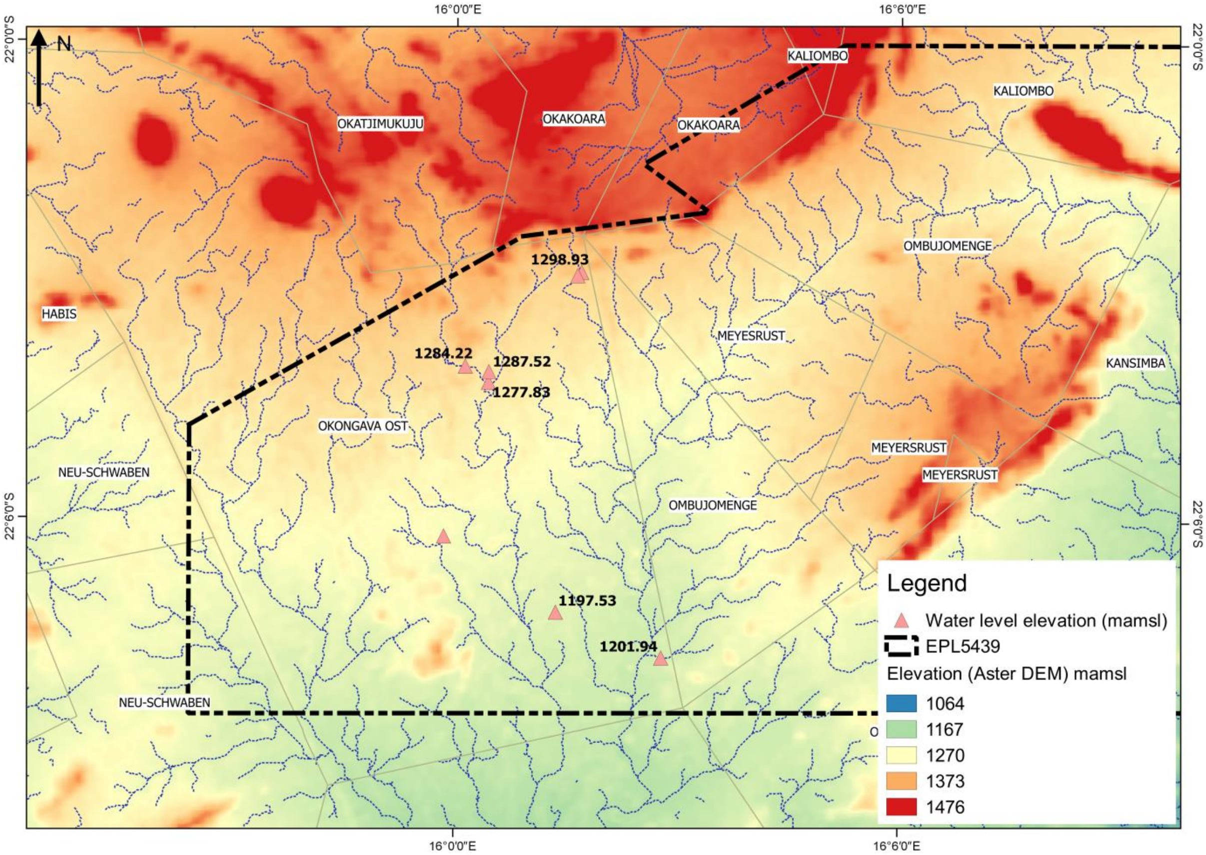


Figure 4: Groundwater elevation measured in boreholes in the project area

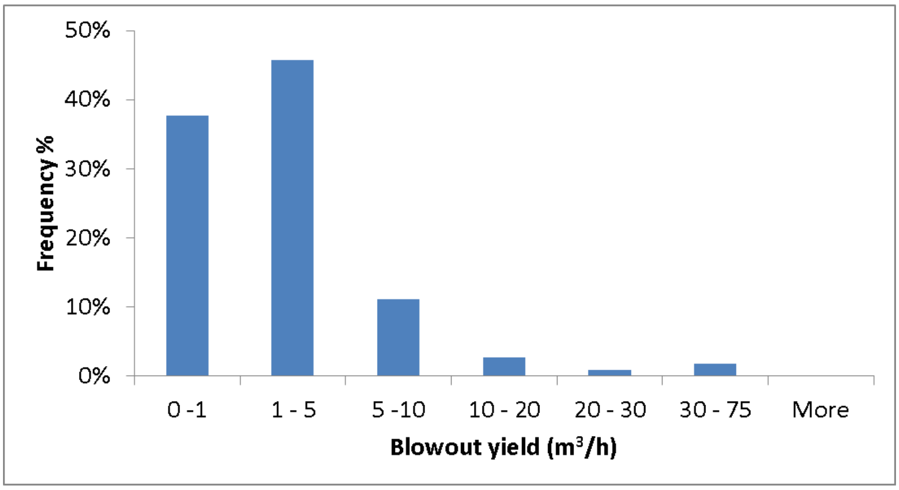


Figure 5: Histogram of blowout yield values from the project area (GROWAS database)

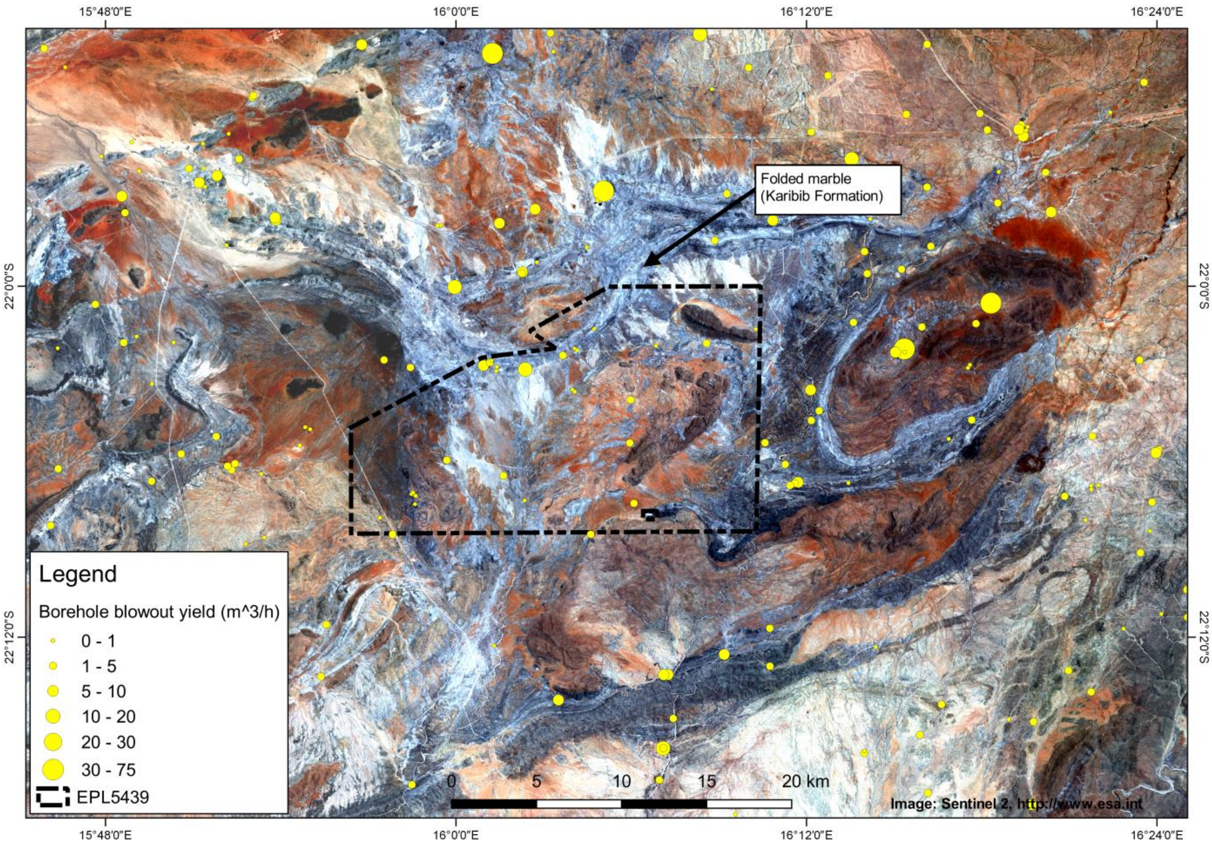


Figure 6: Borehole yield in relation to lithology in the project area

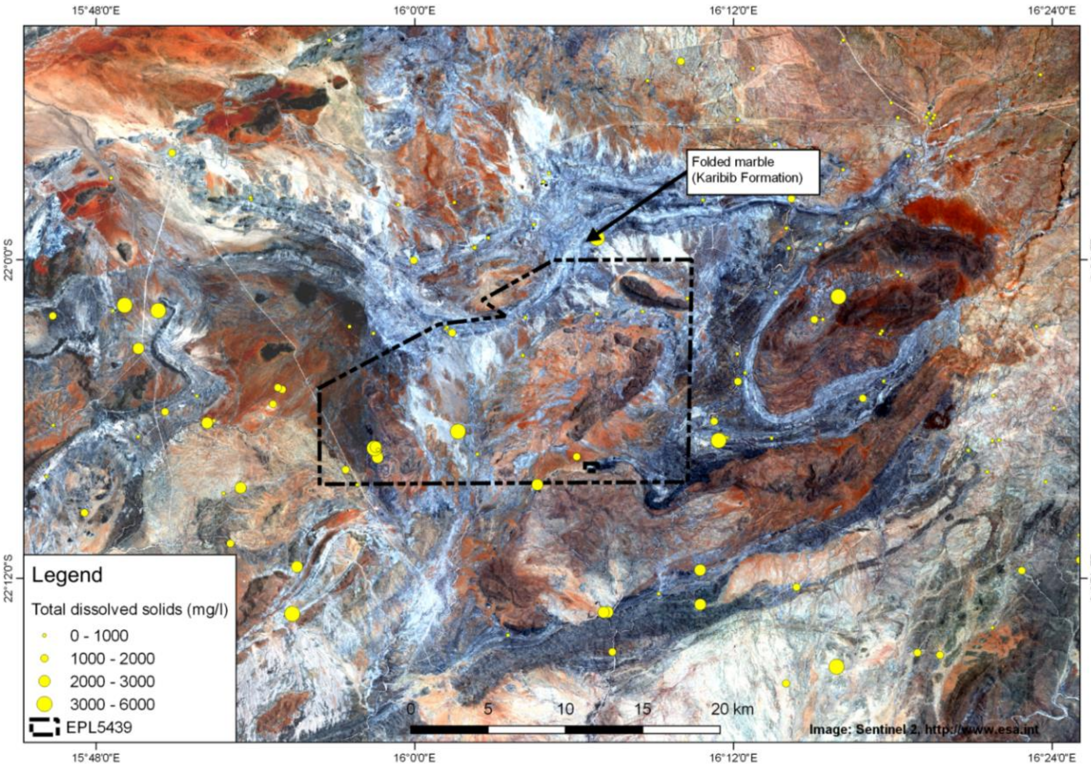


Figure 7: Total dissolved solids in groundwater in the project area

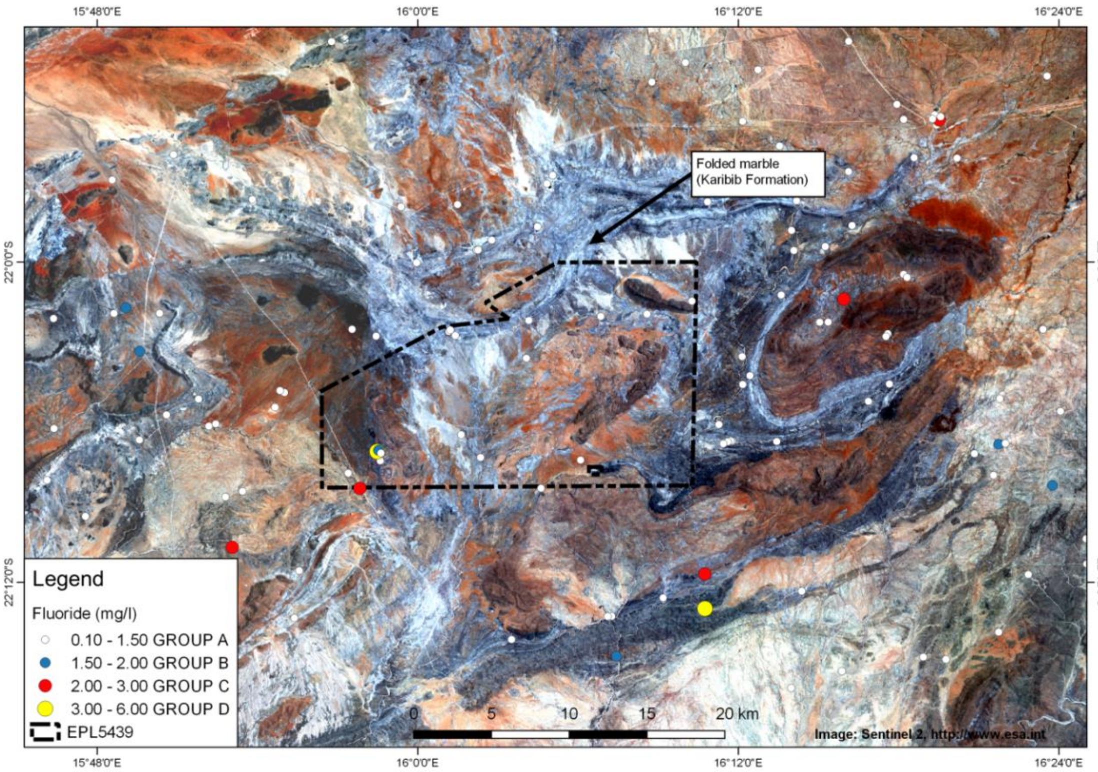


Figure 8: Fluoride levels in groundwater in the project area

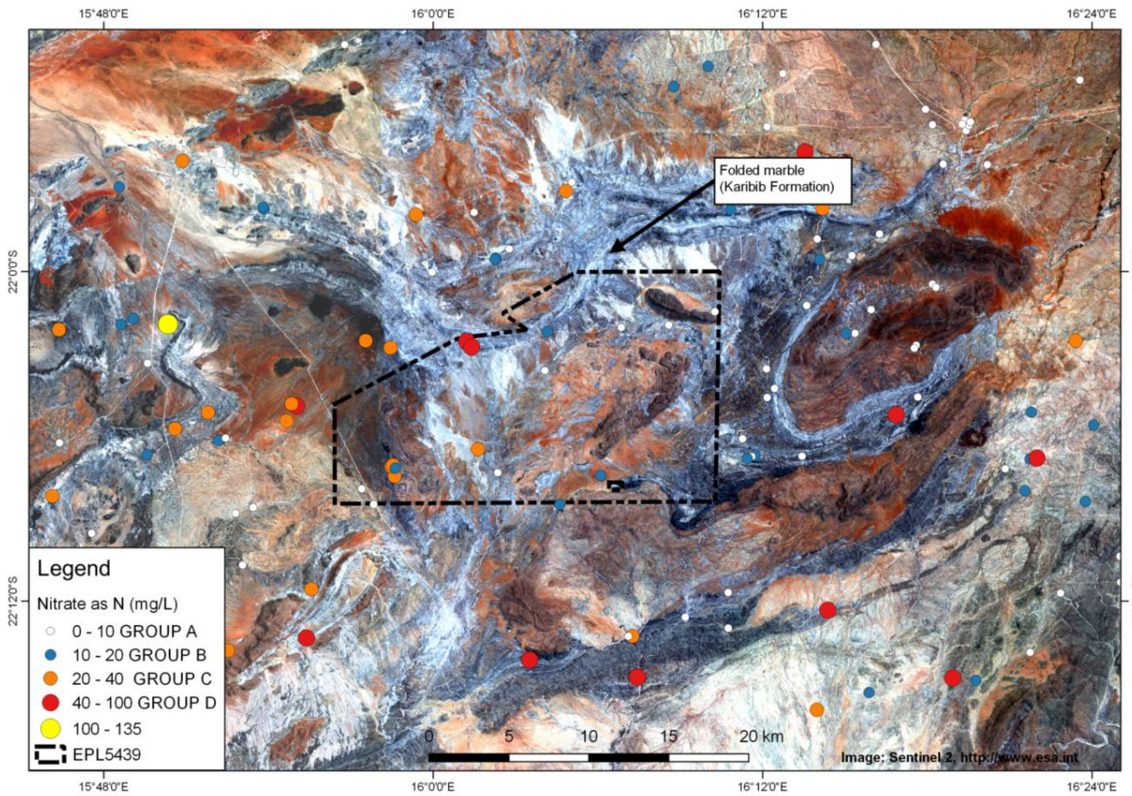


Figure 9: Nitrate levels in groundwater in the project area

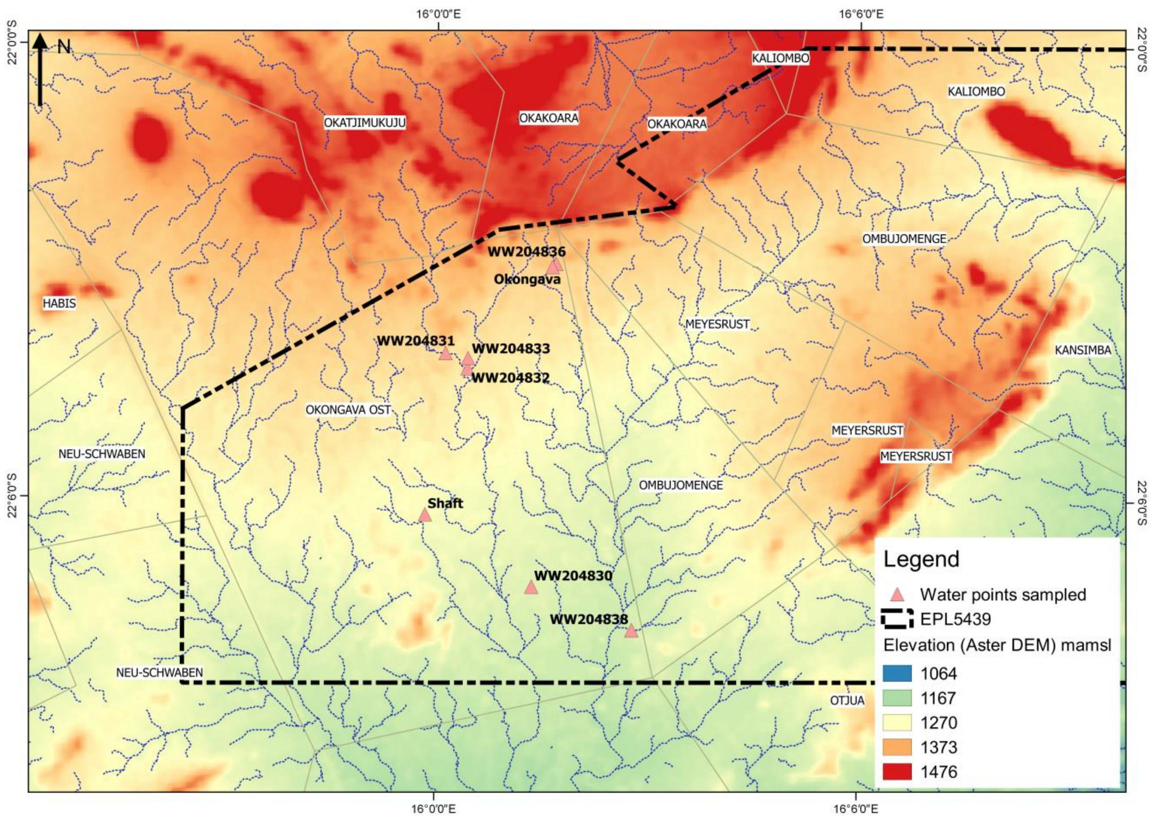


Figure 10: Location of groundwater sampling for water quality analyses

2.5 Water quality sampling in the project area

Water sampling for recording the baseline quality of groundwater was undertaken with the assistance of the appointed drilling contractor. The western part of the EPL5439 (Farm Okongava Ost) was accessible for groundwater sampling and sample locations are restricted to this part. Other than the project boreholes, two other locations – borehole Okongava and an old mine shaft was sampled. Other boreholes found in the field were blocked. Boreholes sampled are shown in Figure 10. Sampled boreholes were purged (2x stored volume) and well head parameters were recorded before sampling (Table 3). A Chain of Custody of collected samples was maintained for the sampling program. Samples were analysed by Analytical Laboratory Services in Windhoek. and results are given in Appendix B2-B4. Comparison of the water analysed parameters were made with the guidelines given in the Water Act, 1956 (Act 54 of 1956). The guideline values are given in Appendix B-1 and the findings from the analyses are listed below. The cation and anions (in percentage meq/l) are plotted in a Piper Diagram (Figure 11). The water is of magnesium-calcium bicarbonate type with the exception of WW204838 and WW204830. In these two boreholes sulphate is seen to be higher than other anions possibly through dissolution of pyrite. Calcium and magnesium are the dominant cations and the relative content vary according to the host rock type.

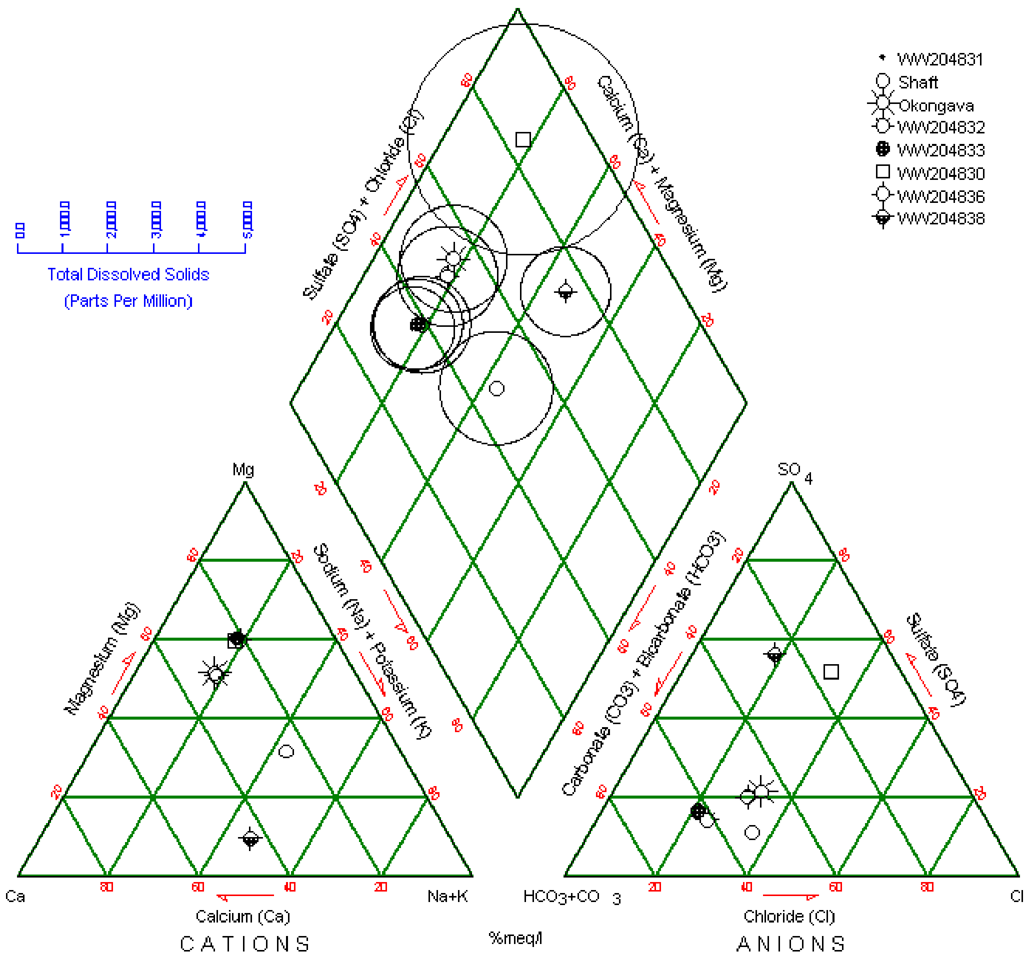


Figure 11: Trilinear representation of major ion chemistry of groundwater in the project area

Comparison with the applicable guidelines of the Water Act, 1956 (Act 54 of 1956)

1. The groundwater is hard with elevated magnesium and calcium hardness. This is mainly due to dissolved magnesium and to a lesser degree dissolved calcium in the water. The magnesium and calcium is probably derived from dissolution of dolomitic lithology.
2. Elevated uranium and barium has been noted in all samples. The uranium and barium levels are acceptable in terms of the current guidelines (Water Act 54, 1956) but exceed the water quality standards and guidelines for potable water in the draft Regulations of the Water Resources Management Act of 2013.
3. Borehole WW204830 has water quality that exceeds group D standards (Magnesium) and group C (sulphate, nitrate) and is not suitable for human or livestock watering.

3 Groundwater targets and geophysical profiling

The carbonate rock (mainly marble) fractured and karstified aquifers of the Karibib Formation have higher groundwater potential in the area. Other lithologies in the area are quartzite, pegmatite and granites units that can form groundwater targets if affected by large scale faulting. In the carbonate units fault zones of interest are mostly strike parallel. The dipping carbonate rock fractured aquifers can extend along the strike and form important supply sources. Weathering and karstification occurs along contact zones with the country rock - usually syn-tectonic granite and schistose rocks (Kuiseb Schist).

Three target areas were selected on Karibib Formation marble units. These are shown in Figure 12. The targets were selected based on an initial desktop study included aerial photo and satellite imagery interpretation, interpretation of airborne magnetic data and ground inspection of the targets. The final drilling sites were selected based on horizontal loop electromagnetic profiling using an EM34-3 instrument. The profiling data is given in Appendix A.

Selected sites were drilled using rotary air-percussion method to depths ranging from 92 to 150 m. Water was struck in faulted marble – calcsilicate or marble – pegmatite contact. Initial blowout yield ranged from 5 to 100 m^3/h. The boreholes were test pumped and recommended pumping rates were estimated from the data. The lower yielding boreholes are to be used for groundwater level monitoring and sampling purposes.

Table 3: Well head parameters measured at groundwater sampling points

Site	Date	Time	Electrical Conductivity (µS/cm)	Temp (˚C)	Dissolved oxygen (mg/l)	pH	Total Alkalinity (mg/l)
WW204830	28/03/17	13:02	3280	29.9	3.93	7.41	360
WW204833	31/03/17	11:00	1388	25.0	2.83	7.05	545
		11:15	1345	25.6	3.12	7.08	506
WW204832	03/04/17	14:00	1513	33.1	2.35	7.11	583
		14:05	1440	30.3	2.84	6.96	509
Okongava	04/04/17	10:45	1985	31.1	2.69	6.96	499

borehole		10:50	1716	29.9	2.49	7.00	478
Shaft	04/04/17	16:20	1694	23.7	5.03	7.92	541
		16:25	1687	22.8	5.13	7.95	510
WW204831	08/04/17	16:16	1293	27.8	1.99	7.02	458
		16:33	1283	27.3	3.27	7.13	459
WW204838	07/05/17	16:20	1225	26.0	5.32	6.52	239
		16:40	1181	26.6	5.00	6.93	192
WW204836	19/05/17	12:20	1483	27.6	7.27	7.46	393
		13:10	1515	29.2	6.08	7.29	429

4 Drilling and test pumping of boreholes

4.1 Application for permission to drill and abstract

An application for permission to drill 10 sites was submitted to the Geohydrology Division, Department of Water Affairs and Forestry (DWAF) on 10 March 2017. Approved borehole numbers (WW numbers) were received from the DWAF. An application for abstraction of groundwater will be submitted on completion of the project and acceptance of this final report.

4.2 Drilling results

Seven sites are selected for drilling and summary information is given in Table 4. In addition, two observation boreholes were drilled 15 meters south and west of Line 9/295 m (WW204831) for recording water levels during test pumping. Borehole locations are shown in Figure 12. Individual boreholes are discussed below and borehole logs are given in Figure 13 to Figure 21. The drilling sites are marked at the targeted anomalies on the geophysical profiles in Appendix A.

All boreholes were drilled with a nominal diameter of 203 mm and productive boreholes were cased with uPVC casing and perforated casing of nominal 165 mm diameter. The positon of borehole perforated sections are shown in the borehole logs (Figure 13 to Figure 21).

4.2.1 Site Line 3 /120 m – WW204830

The borehole was drilled to 150 m depth on a broad electromagnetic (EM) profile anomaly. The target was a prominent lineament visible on aerial photographs with evidence of faulting on the ground. Intercepted lithology included calcsilicate with pegmatite intrusions. A water strike was encountered at 45 m but yield was low (0.4 m^3/h blowout yield). The electrical conductivity (EC) measured was 3,280 microS/cm, that is higher than other groundwater EC measured in the project area. The borehole can be used for monitoring of water level and water quality.

Table 4: Summary information on boreholes drilled

Borehole	Drilled depth (m)	Water strike (m)	Blowout yield (m^3/h)	Water level (m)	Electrical conductivity (microS/cm)
WW204830	150	45	0.4	37.97	3280
WW204831	105	34, 45, 91	40	20.28	1293

WW204832	120	21	20	15.67	1513
WW204833	150	16	5	13.98	1388
WW204836	150	27	3	27.37	1515
WW204837	150	None	-	-	-
WW204838	150	83, 122	8	15.46	1225
WW204834*	99	28	-	18.73	-
WW204835*	91	32	-	19.20	-

* Observation boreholes drilled 15 m south and west of WW204831

4.2.2 Site Line 9 /295 m – WW204831, WW204834 and WW204835

Borehole WW204831 was drilled on a north-south trending, marble unit. The site was selected on a prominent and broad EM anomaly on an east west traverse. Three distinct water strikes were encountered at 34, 45 and 91 m in white and grey marble. Blowout yield from the borehole was approximately 40 m^3/h. The water is fresh with electrical conductivity of 1,293 microS/cm.

To estimate storage co-efficient of the aquifer and to better understand the heterogeneous nature of the aquifer, two observation boreholes (WW204834 and WW204835) were drilled. The boreholes WW204834 and WW204835 were positioned along strike and across strike of the structure tapped by borehole WW204830 respectively. Both boreholes were drilled penetrated predominantly white and grey marble.

4.2.3 Site Line 4 /790 m – WW204832

Borehole WW204832 was drilled on a dipping EM anomaly encountered the first water strike at 21 meters at the contact zone between calcsilicate and pegmatite. The blow out yield was 20 m^3/h. Water strikes at a depth of 75 m in a pegmatite and marble contact did not significantly increase the yield of the borehole. The water is fresh as judged from the electrical conductivity of 1,513 µS/cm.

4.2.4 Site Line 4 /530 m – WW204833

Borehole WW204833 was drilled on a similar dipping conductor to Line 4/530 m mapped by EM profiling on a marble unit. Water was struck at 16 m at a marble-pegmatite contact and gradual increase of yield was recorded with depth as more fractures were encountered. The blow out yield of the borehole was moderate (5 m^3/h). The onsite measured quality of the water is fresh (1,388 µS/cm).

4.2.5 Site Line 7 /230 m – WW204836

Borehole WW204836 was drilled as the possible supply source to the local community. A water strike was encountered at shallow depth (28 m) in calc-silicate rock. The targeted contact between calc-silicate and marble was penetrated at 132 m but no additional yield was noted. A step drawdown test was carried out on the borehole to assess the potential of the water strike at 28 m. The water strike dewatered at a yield of 3 m^3/h. Considering the low borehole yield and shallow depth to water strike, the borehole was not cased and left as a water level and water quality monitoring point.

4.2.6 Site Line 4 /770 m – WW204837

Borehole WW204837 was drilled to target the calc-silicate and marble contact at a deeper level to increase the available drawdown and sustainability of the source. The borehole penetrated calc-silicate and pegmatite units till 150 m depth. No water strikes were encountered. The borehole was terminated at 150 m.

4.2.7 Site Line 1 /430 m – WW204838

The borehole (WW204838) was drilled to 150 m targeting an electromagnetic anomaly. Water was struck in contact zones of quartz biotite schist and weathered pegmatite (potassium feldspar and quartz rich lithology). Depths to water strikes were at 83 m and 122 m and the final blow out yield was 8 m^3/h. The onsite measured quality of the water is fresh (1,225 µS/cm).

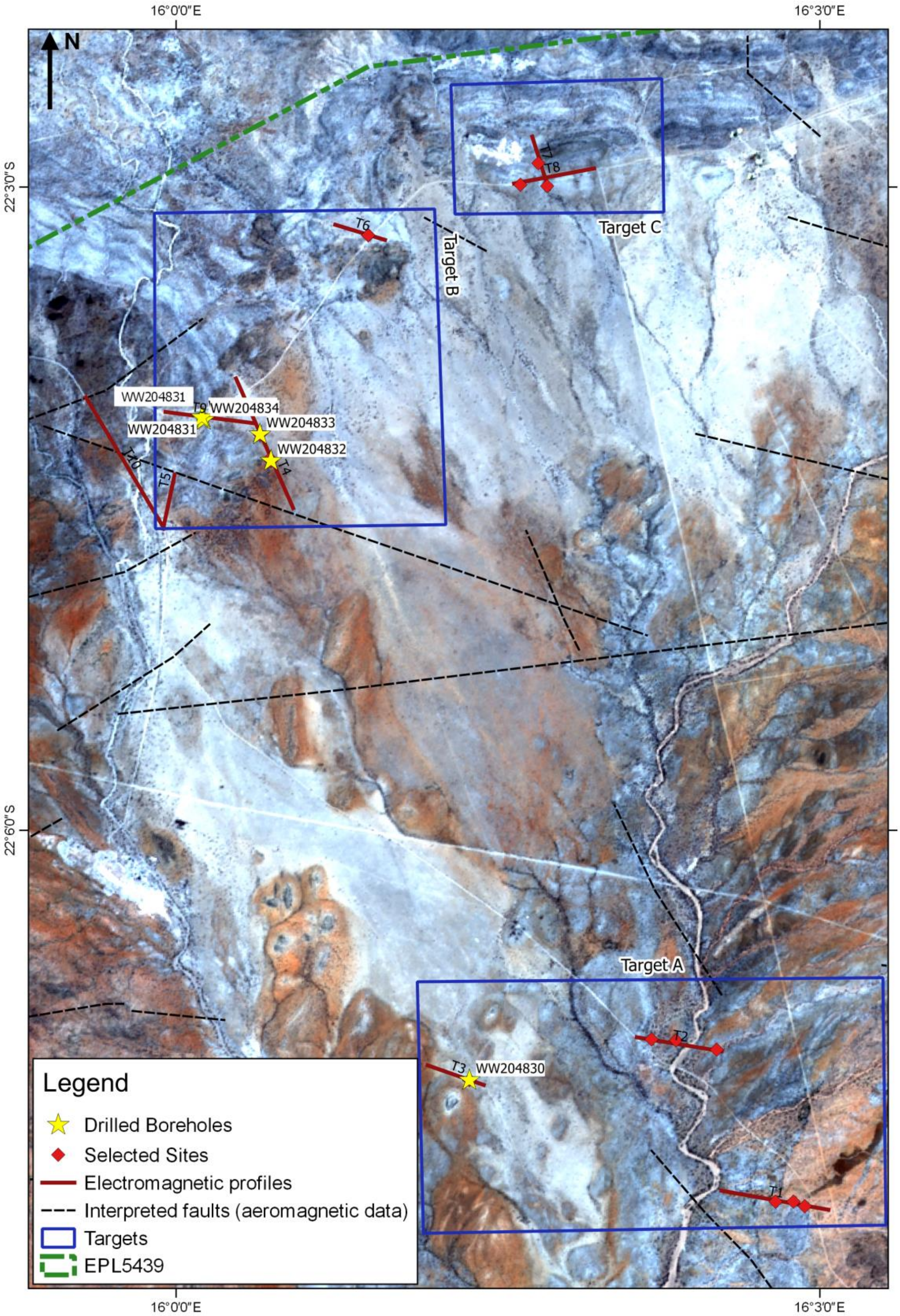


Figure 12: Location of drilled sites

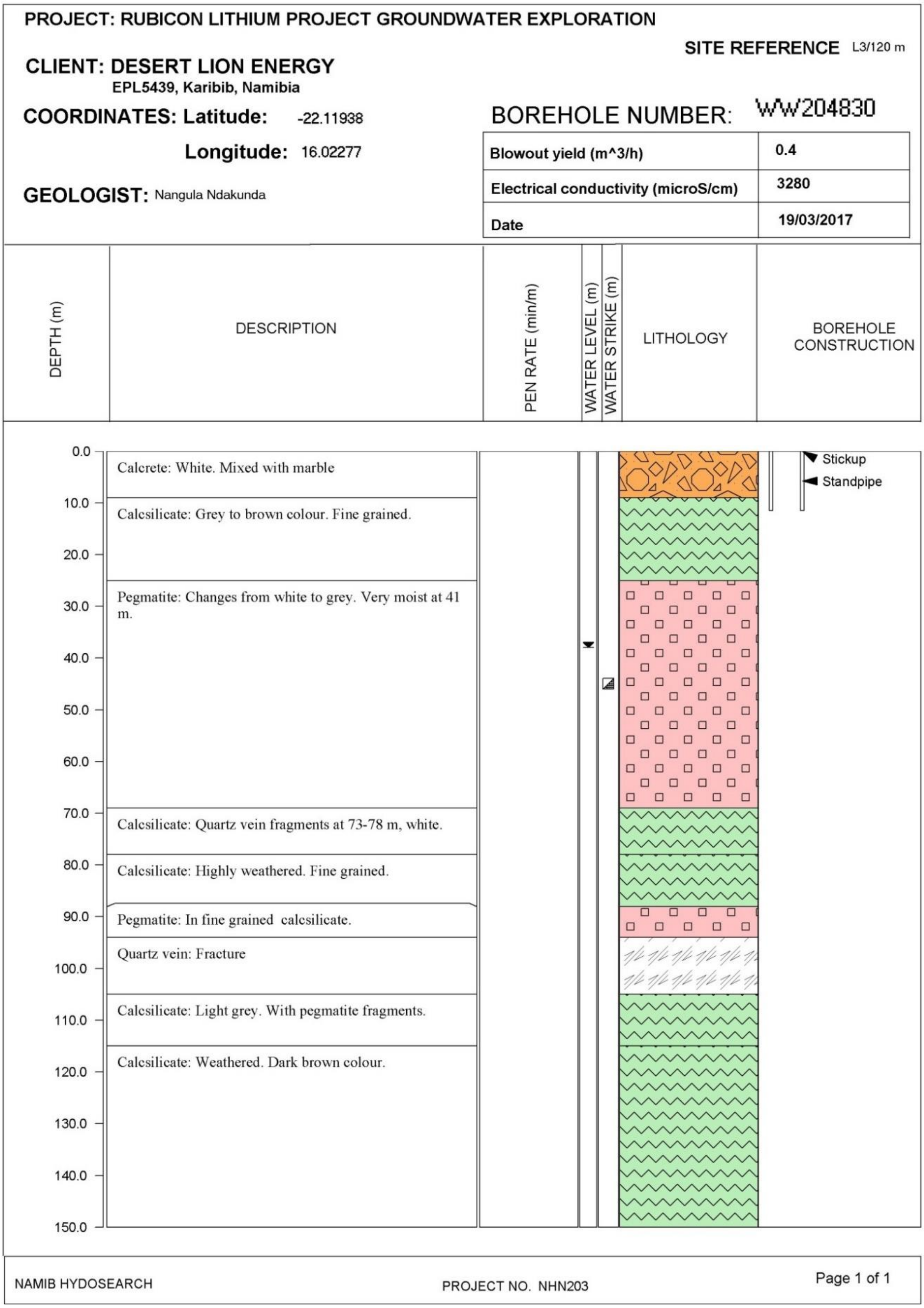


Figure 13: Borehole log, WW204830

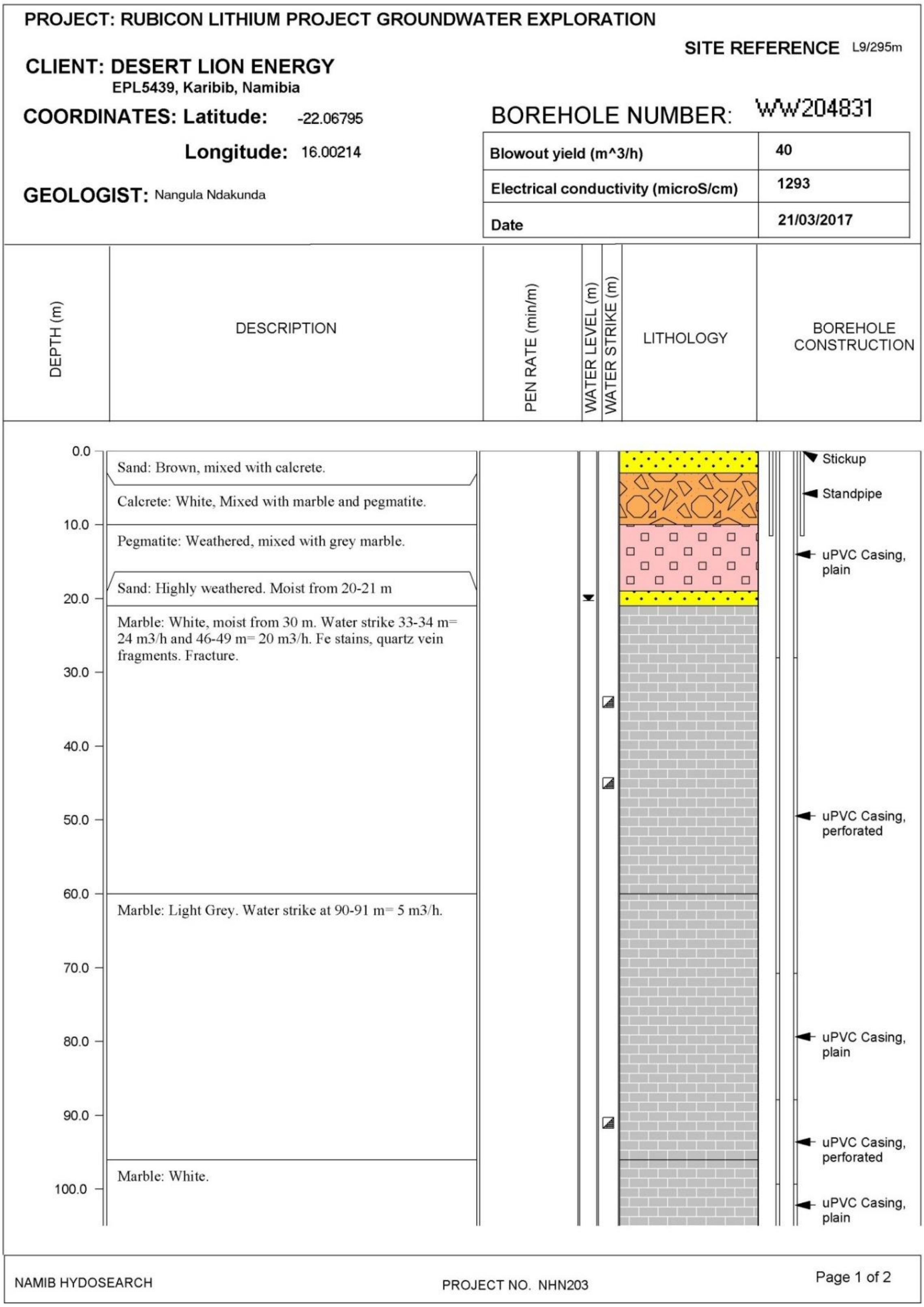


Figure 14: Borehole log, WW204831

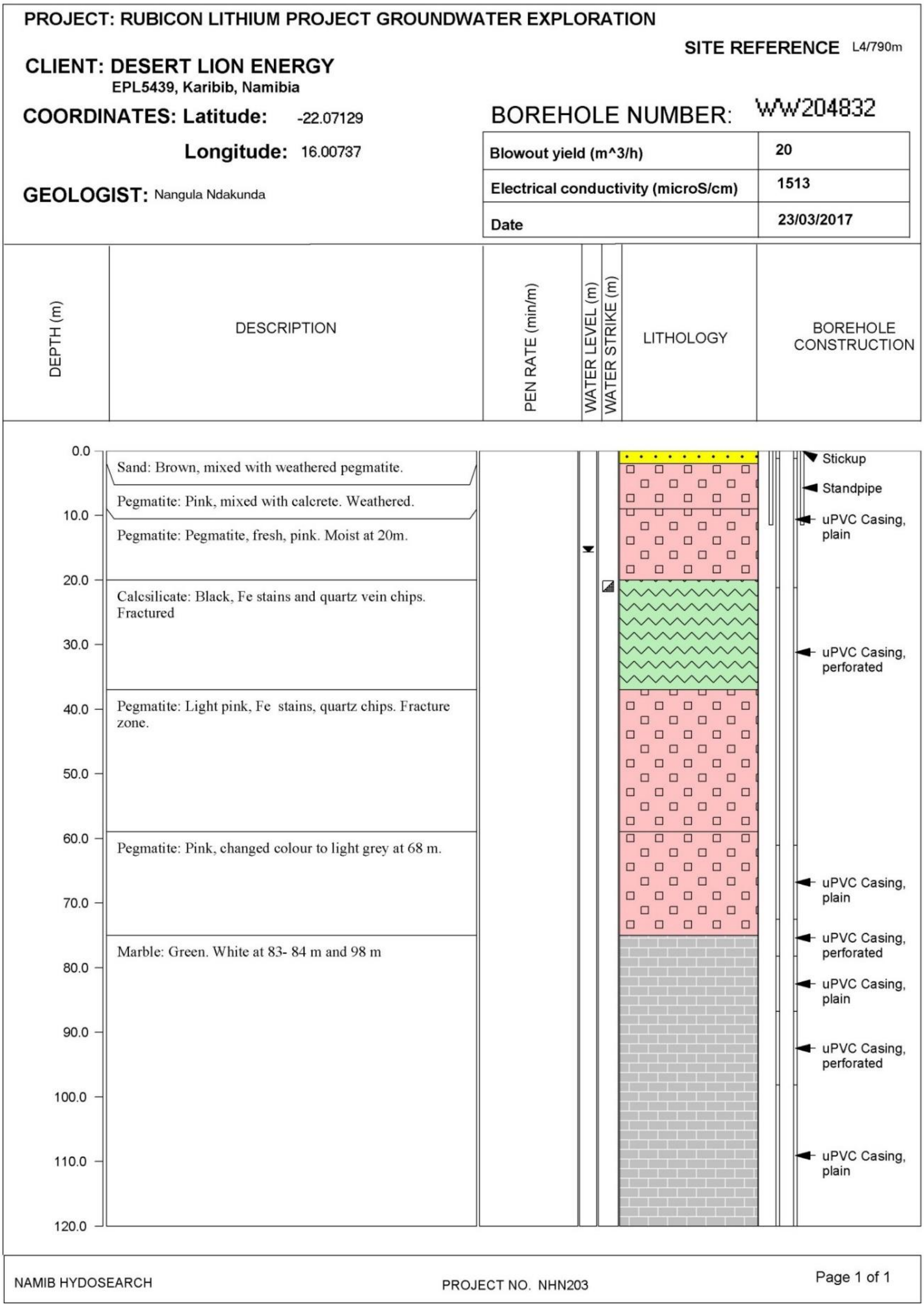


Figure 15: Borehole log, WW204832

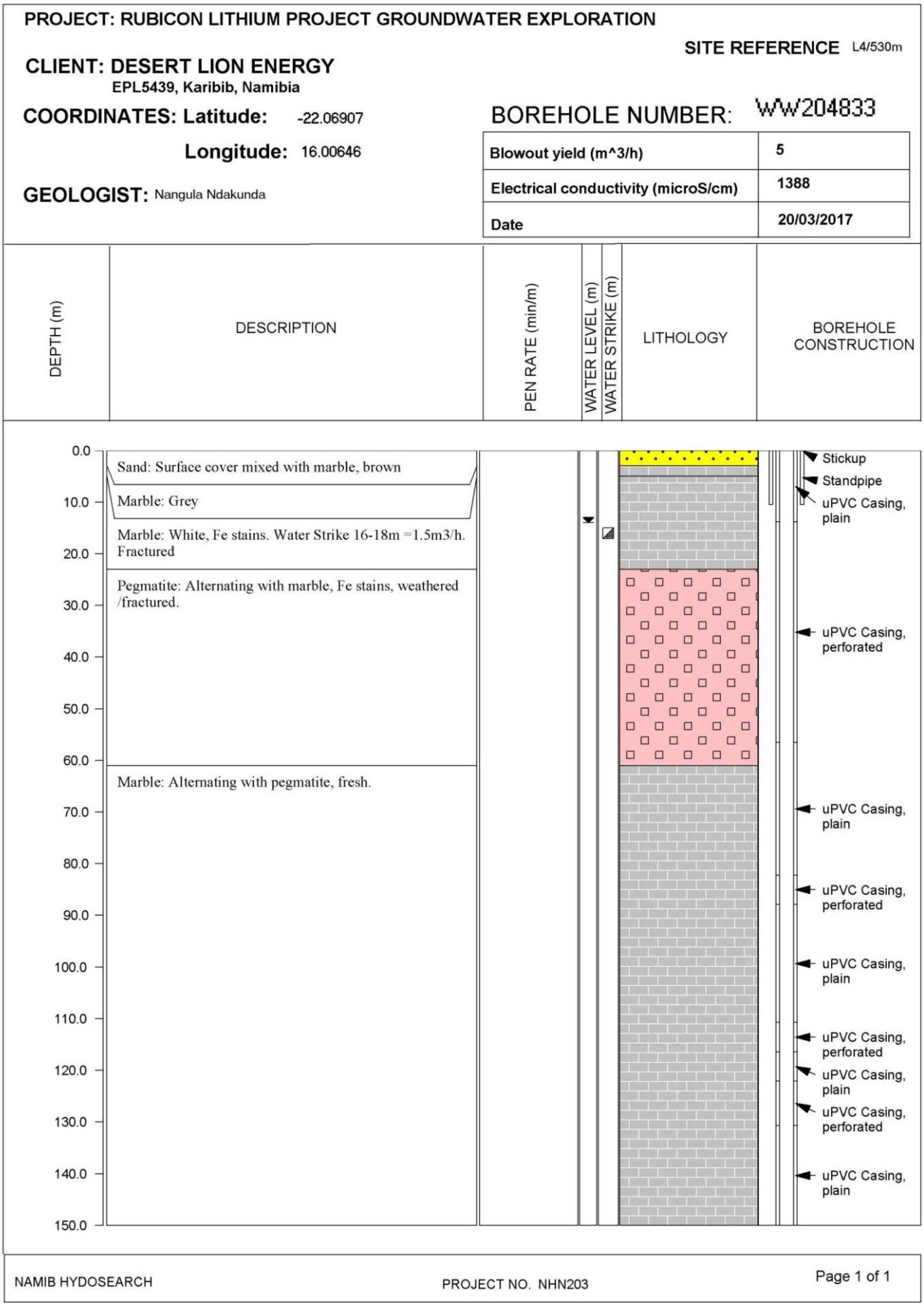


Figure 16: Borehole log, WW204833

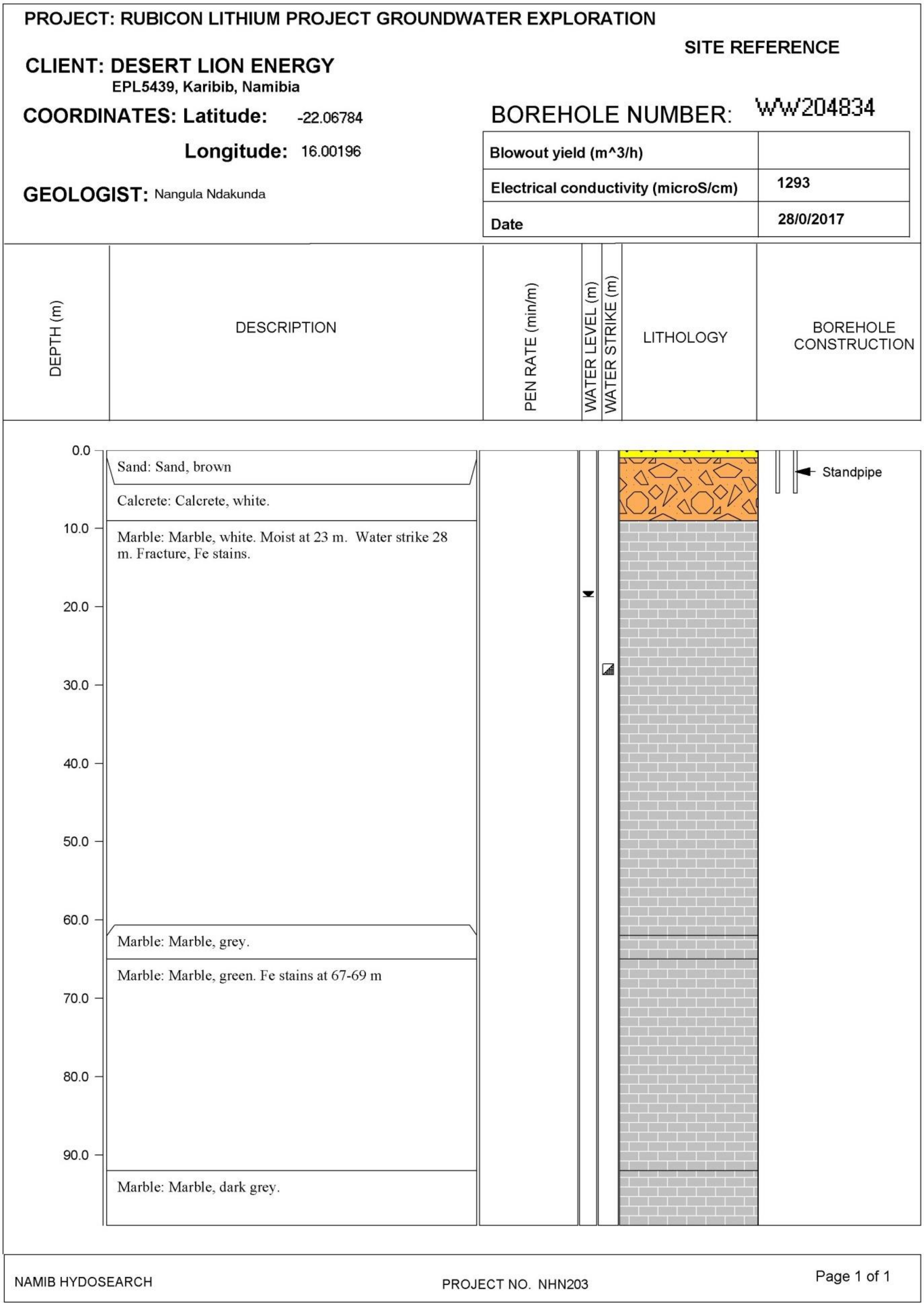


Figure 17: Borehole log, WW204834

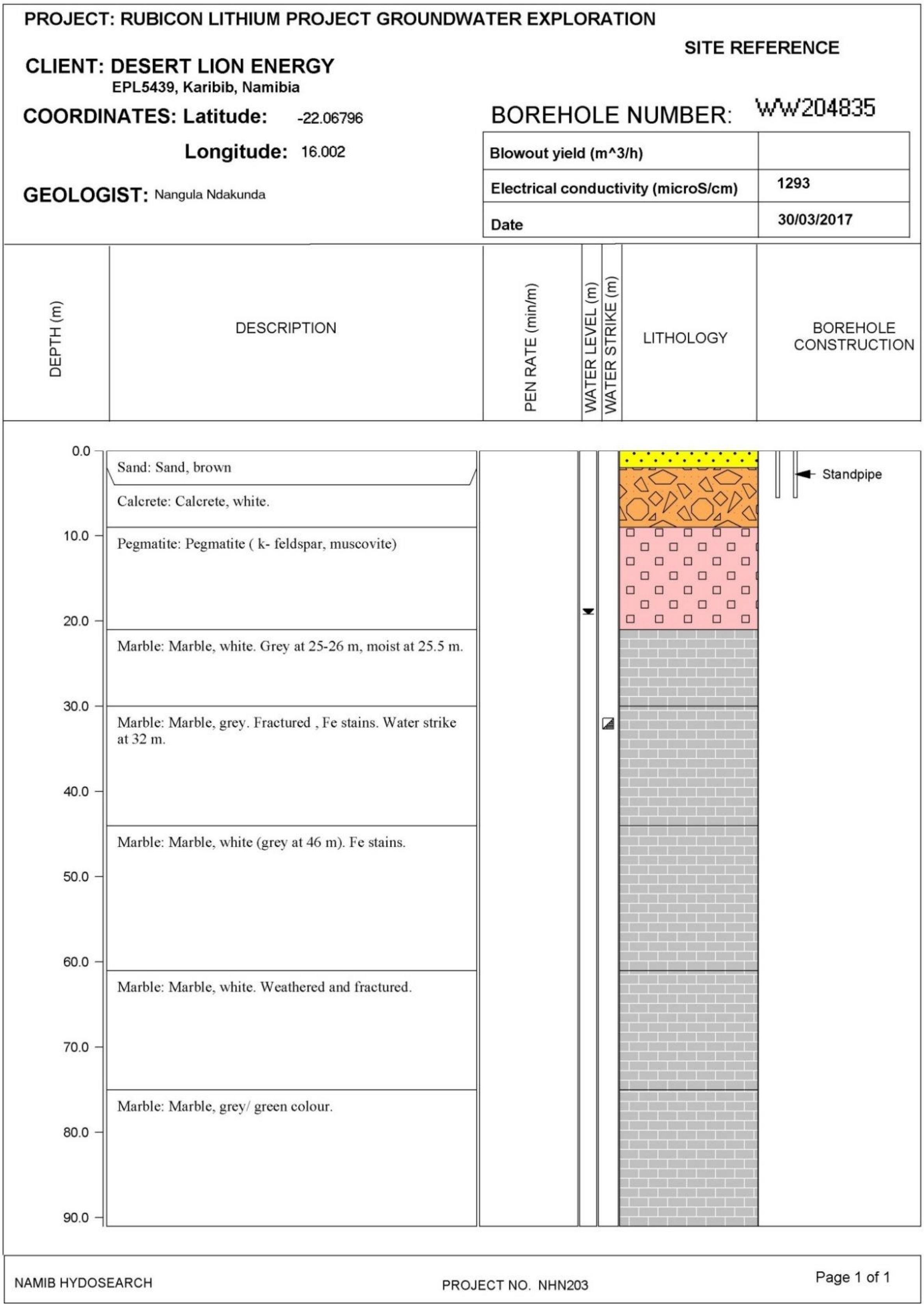


Figure 18: Borehole log, WW204835

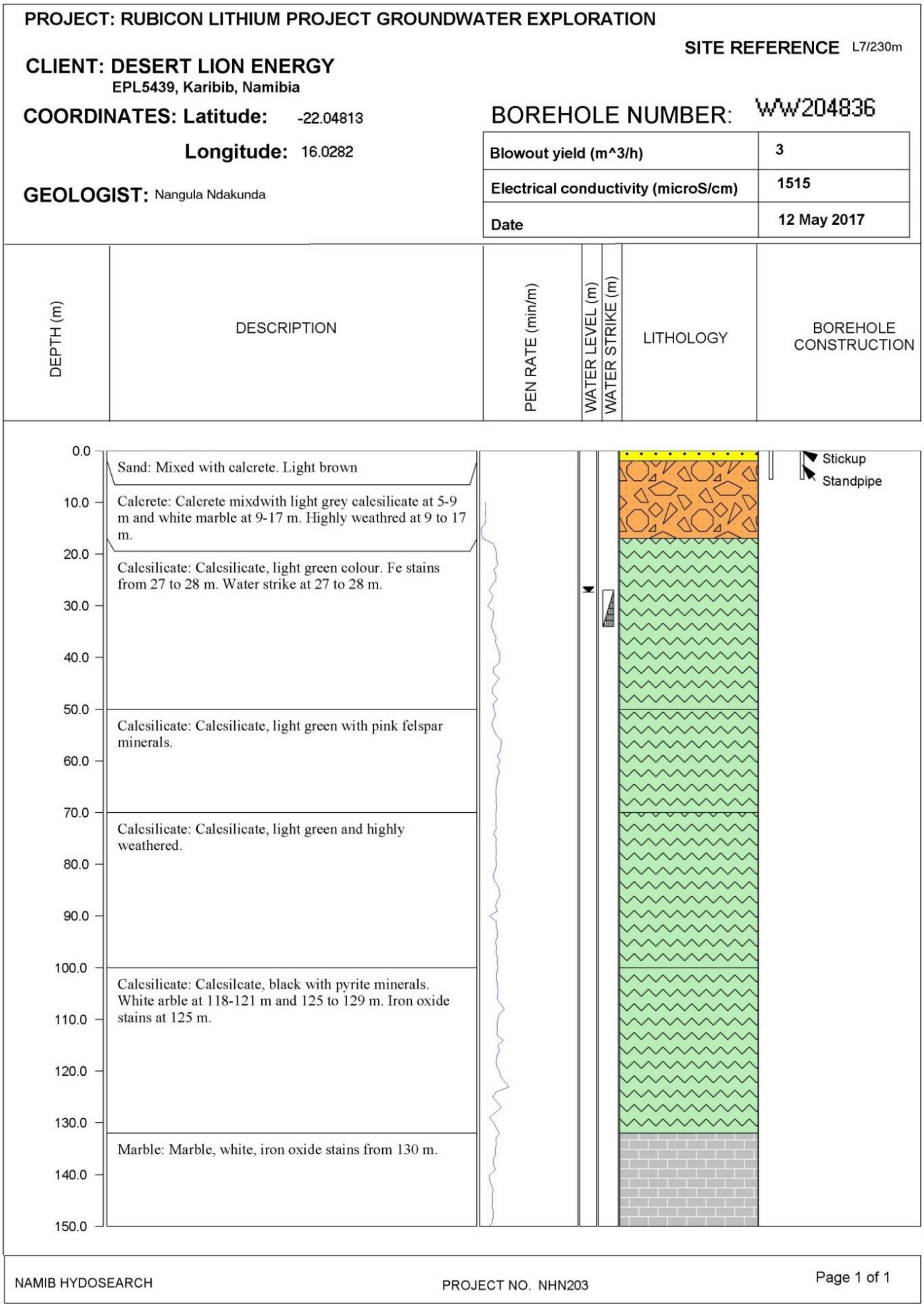


Figure 19: Borehole log, WW204836

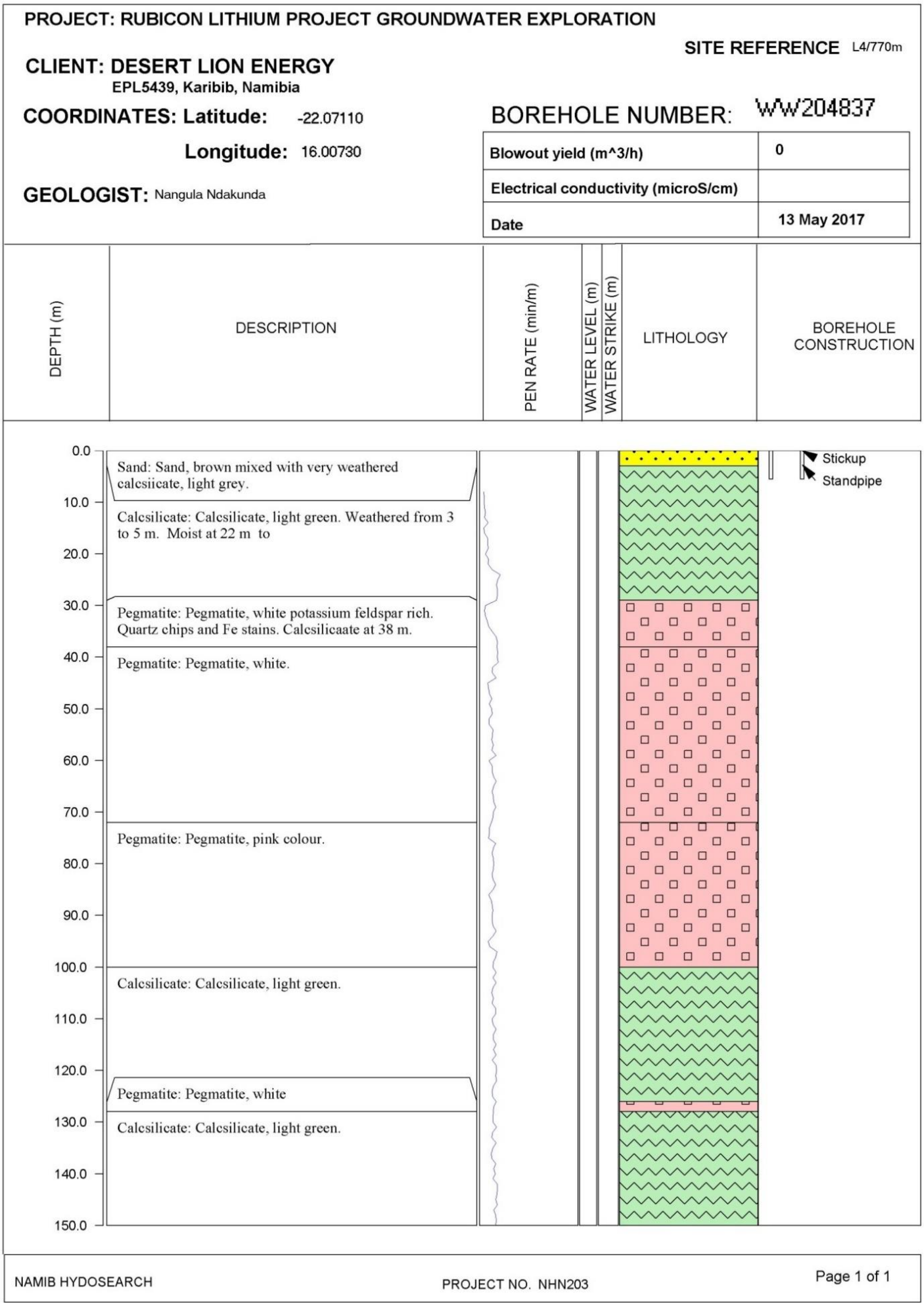


Figure 20: Borehole log, WW204837

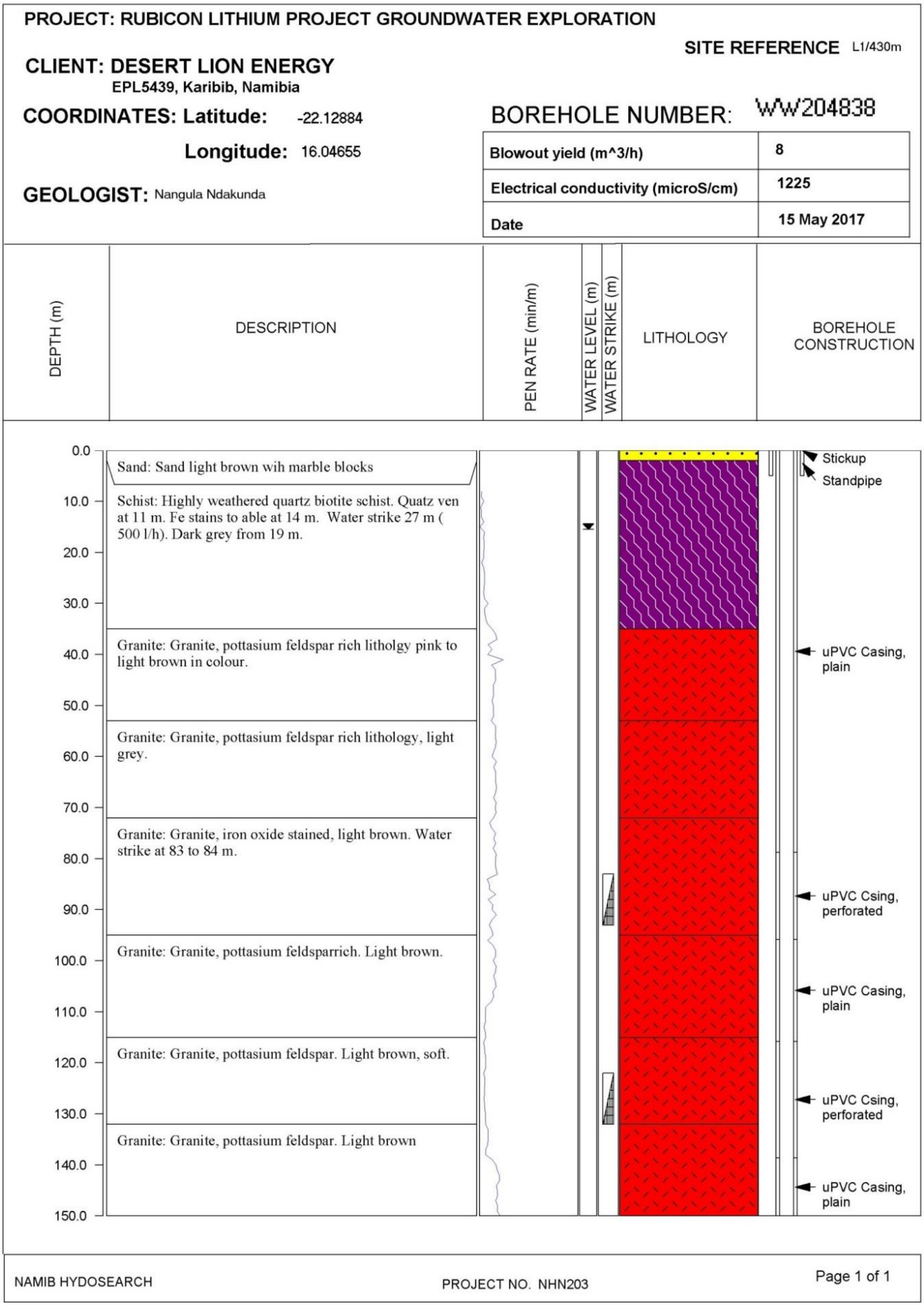


Figure 21: Borehole log, WW204838

5 Groundwater Resource Assessment

Productive boreholes were test pumped and based on the interpretation recommended yield has been calculated. The available resource and borehole installation details are given below.

5.1 Interpretation of test pumping data

Data obtained through pumping test reflect lowering of the water table due to pumping. This generally creates what's referred to as a "cone of depression". Depending on the type of aquifer and its hydraulic parameters, radius of influence around the pumped borehole differs.

Interpretation of data obtained from the pumped borehole through the duration of the test provides insight on the type of aquifer and hydraulic parameters, e.g. hydraulic conductivity. Certain parameters, like storativity, can only be deduced in the presence of an additional borehole (monitoring borehole) at close proximity to the pumped borehole such that impact of pumping can generate change in water level in the monitoring borehole.

Monitoring boreholes are needed for estimation of storativity values. Two observation boreholes were drilled (WW204834 and WW204835) for the borehole with high blowout yield (WW204831). Time versus drawdown data from the pumping borehole was compared in various diagnostic flow plots and characterised. "Barrier boundaries" are present within the radius of influence and these were taken into consideration when estimating production pumping rates.

Interpretation is done by modelled curve fitting. The model applied to generate the curves depends on the aquifer type. Recommendations are made based on forward modelling of the modelled curve projected to 5 years of continues pumping at a set rate. During this period, it is assumed that there are no recharge events to the aquifer, such that pumping is only from the stored volumes within the aquifer as a closed system. Step drawdown test (SDT) and constant rate test (CRT) pumping were carried out on the boreholes.

5.1.1 Diagnostics

Diagnostic plots serve to identify the aquifer characteristics and applicable models (solutions). The following characteristics have been identified from the step drawdown and constant rate test time drawdown data.

- Wellbore storage effect is identified at early time in log-log radial flow plots. Time when wellbore storage effect ceases is estimated from the plots.
- Aquifer response is identified where the drawdown derivative stabilises at intermediate time of pumping. Curve fitting with the Theis solution at intermediate time after wellbore storage gave preliminary estimate of the aquifer transmissivity.
- Effect of barrier boundaries was seen in WW204831. The drawdown curve and drawdown derivative increase in slope at late time. Two parallel barrier boundaries were interpreted.
- Dougherty-Babu's (1984) solution and parallel barrier boundaries were used to model the overall response that is appropriate for the physical setting.

– A single barrier boundary was interpreted from the constant rate test drawdown data of WW204832 and WW204838

5.1.2 Data interpretation and recommended yield

The interpretation and projections are shown in the following figures (Figure 22 to Figure 29). The estimated parameters and assumed barrier boundary were used to forward model drawdown for a planned production pumping period of 5 years. The discharge rate was adjusted so that the drawdown at the end of 5 years pumping without recharge does not reach the water strike(s). Recommendations for pumping and pump installation are given in Table 7.

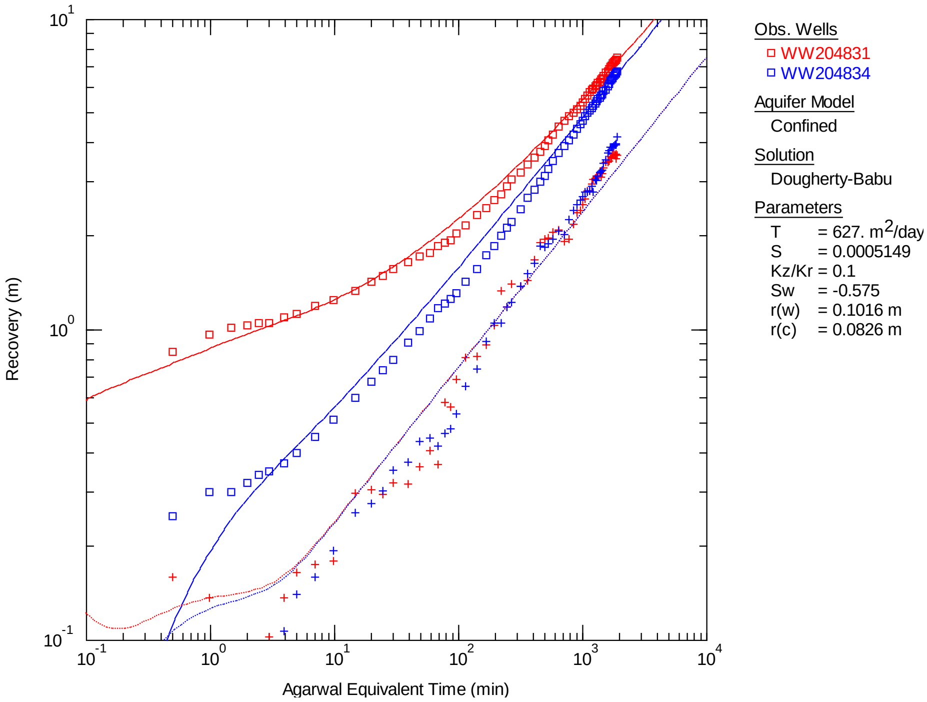


Figure 22: Water level recovery data interpretation following constant rate test of borehole WW204831. Drawdown data (squares), Drawdown derivatives (cross), and fitted lines are shown.

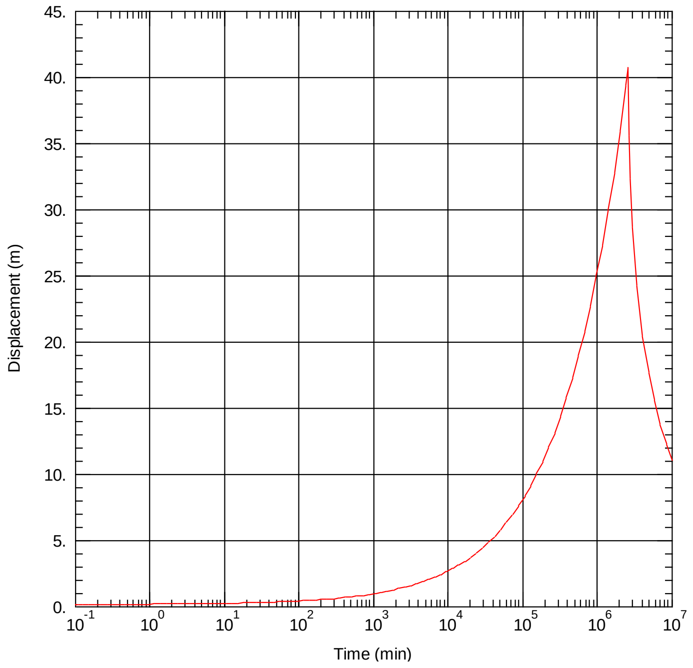


Figure 23: Projected drawdown in response to 5 years pumping based on interpretation above, borehole WW204831

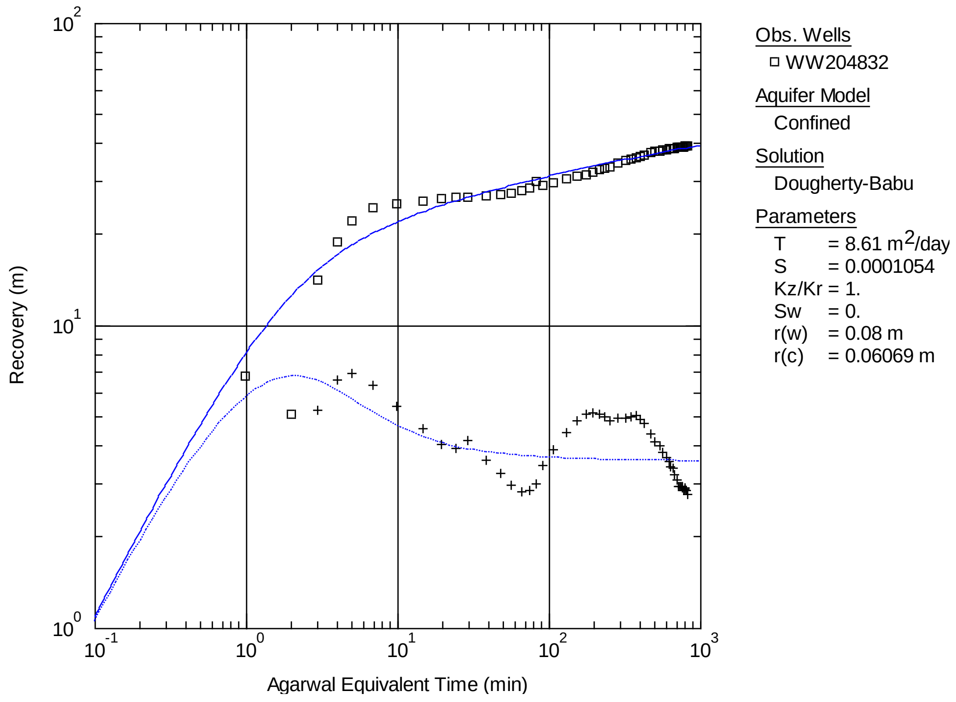


Figure 24: Water level recovery data interpretation following constant rate test of borehole WW204832. Drawdown data (squares), Drawdown derivatives (cross), and fitted lines are shown.

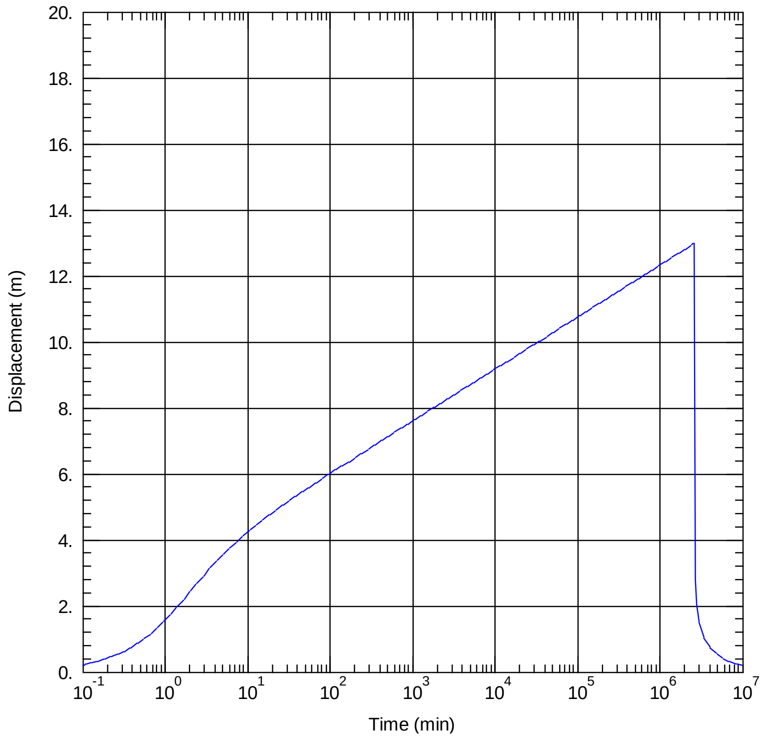


Figure 25: Projected drawdown in response to 5 years pumping, borehole WW204832

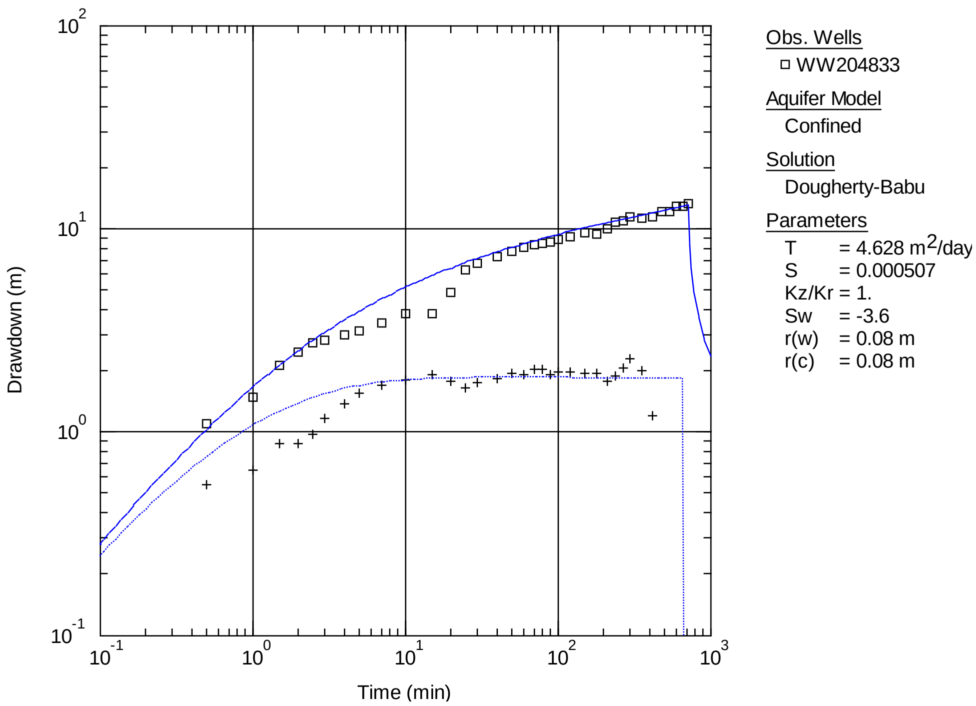


Figure 26: Constant rate test of borehole WW204833. Drawdown data (squares), Drawdown derivatives (cross), and fitted lines are shown.

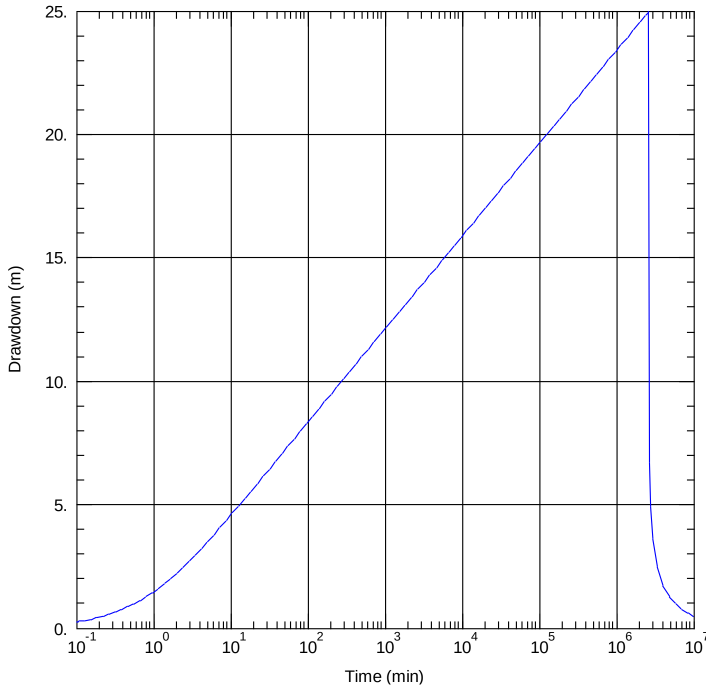


Figure 27: Projected drawdown in response to 5 years pumping, borehole WW204833

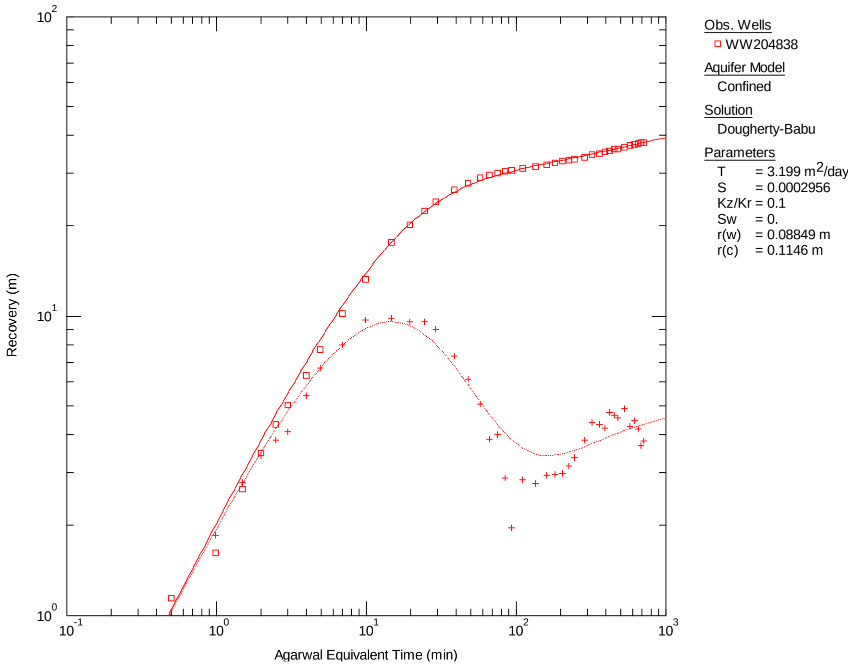


Figure 28: Water level recovery data interpretation following constant rate test of borehole WW204838. Drawdown data (squares), Drawdown derivatives (cross), and fitted lines are shown.

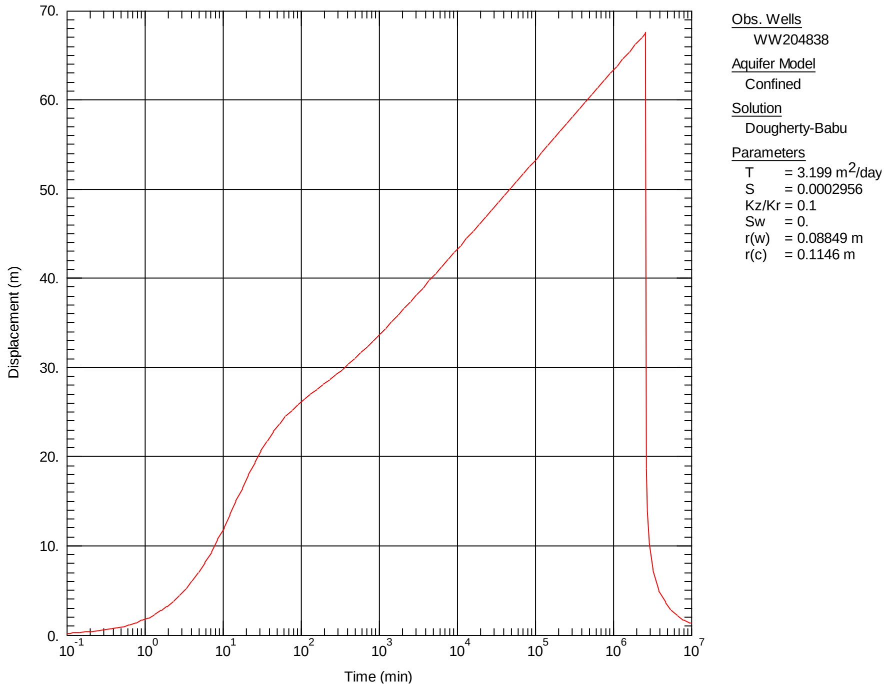


Figure 29: Projected drawdown in response to 5 years pumping, borehole WW204838

6 Monitoring of groundwater abstraction, water levels and quality

Recommended yield estimates require validation through monitoring of discharge and water level with time. The recommended yield may be adjusted with interpretation of such data. It is therefore recommended that water abstraction and water levels be recorded from production boreholes on a daily basis. Monitoring of water levels in pumped boreholes is to be recorded before daily resumption of pumping. The current water levels recorded are given in Table 5. Borehole details are given in Table 4. Monthly monitoring of water level is needed from the monitoring water points indicated in Table 5. In addition, rainfall in the project area is to be recorded as the Karibib meteorological station is not operational. From enquiry made with the station it was understood that the station has difficulties with availability of trained personnel to man the station.

Abstraction permit granted by the DWAF require that quarterly production records from each borehole are submitted to the Geohydrology Division (DWAF). The data should be evaluated after production pumping starts in addition to the scheduled submission to the Geohydrology Division. An initial assessment is recommended at the end of a month of production followed by periodic evaluation after each year of pumping. The monitored data from the production and monitoring boreholes should be assessed.

Table 5: Groundwater monitoring points in EPL5439

Water point / Borehole	Static water level (m bgl)	Date of measurement	Status of water point
WW204832	15.17	23/03/2017	Pumped

WW204833	13.48	20/03/2017	Pumped
WW204831	19.78	21/03/2017	Pumped
WW204830	37.47	19/03/2017	Monitoring borehole
WW204834	18.23	28/03/2017	Monitoring borehole
WW204835	18.70	30/03/2017	Monitoring borehole
WW204836	27.07	12/05/2017	Monitoring borehole
WW204838	15.06	15/05/2017	Pumped
Shaft	-	-	Pumped
Okongava borehole	-	-	Pumped

7 Monitoring of water quality

Water quality of production boreholes and monitoring boreholes given in Table 5 are to be assessed once every three basis according to the Water Act. Borehole details are given in Table 4. This includes wellhead parameters and laboratory analyses of major dissolved, and minor and trace constituents. The evaluation of such information should be done on a quarterly basis.

The first batch of samples was collected during the current program. A scan of possible constituents was done as reported in Appendix B. Based on the analyses a set of parameters have been identified for quarterly sampling and analyses (Table 6). The monitored parameters can be further refined after sampling and analyses are repeated.

Sampling procedure to be followed should include purging of unused boreholes before sampling (Weaver et al., 2007), recording of well head parameters, appropriate storage of samples, delivery to laboratory in time, and maintaining a Chain of Custody (CoC).

8 Conclusions

The following are concluded from the above.

- A baseline status of water quality and groundwater potential was assessed for the project area. The groundwater potential of the project area is limited due to low rainfall and high potential evaporation rates which is characteristic of the region.
- Fractured rock aquifers are present in the Damara Supergroup rocks. Aquifers are associated with faulted and karstified carbonate rock and contact zones with other rock types.
- Groundwater resources were identified in the current drilling campaign and a total recommended yield of 250 m^3/day from three boreholes is estimated. The water demand is not fully met at this stage of the program.

- Water quality are of Group B (acceptable quality) and Group C (low health risk) quality respectively. However boreholes WW204830 has elevated levels of magnesium and magnesium hardness and is not potable (Group D).

- Surface water resources are limited in the project area and supply from the available surface water resource can be challenging.

- A monitoring program for water abstraction and water level is to be initiated for the production boreholes. In addition, rainfall in the project area is to be monitored.

- Quarterly sampling of groundwater quality is to be undertaken. Parameters will be decided based on the analyses results of the first batch of samples.

Table 6: Wellhead, major, minor and trace constituents selected for analyse in groundwater

Wellhead parameters	Major constituents	Minor and trace constituents
Electrical conductivity pH Temperature Dissolved oxygen Alkalinity Water level	pH, Electrical Conductivity , Turbidity, Total Dissolved Solids, P-Alkalinity as CaCO3, Total Alkalinity as CaCO3, , Chloride as Cl^-, Fluoride as F^-, Sulphate as SO_4^{2-}, Nitrate as N, Nitrite as N, Ortho-Phosphate as PO_4, Colour, Sodium as Na, Potassium as K, Magnesium as Mg, Calcium as Ca	Lithium as Li, Boron as B, Strontium as Sr, Molybdenum as Mo, Cadmium as Cd, Antimony as Sb, Barium as Ba, Lead as Pb, Uranium as U, Aluminium as Al, Vanadium as V, Manganese as Mn, Iron as Fe, Cobalt as Co, Nickel as Ni, Copper as Cu, Zinc as Zn, Arsenic as As, Selenium as Se

9 Recommendations

The following recommendations are made.

- Four boreholes are recommended for production pumping (WW204831, WW204832, WW204833, and WW204838). The recommendations on pumping rates and pump installation are given in Table 7. The borehole locations are given in Figure 30.

- The boreholes WW204831, WW204832, WW204833 are recommended for use for mine operations exclusively. Borehole WW204838 is recommended for pumping at 88 m^3/day and this resource can be used to supply local community and also complement the mine water supply.

- An application for abstraction from the four boreholes will be made by the consultant to the Department of Water Affairs and Forestry (Geohydrology Division) on acceptance of this final report by the client.

- Groundwater production data and water level records are to be submitted to Geohydrology Division (DWAF) once an abstraction permit is issued. Monitoring programs for production boreholes are to be initiated with start of production pumping. The production records and water level data are to be evaluated and the recommended yield adjusted as needed.

- Monitoring of groundwater quality of production boreholes is to be carried out once every three months.
- Each pumping borehole is to be equipped with an electrical dipper access pipe to allow measurement of water level (or installation of a pressure transducer for automatic water level recording) while installing pumps.
- Water abstraction at each borehole is to be monitored with a water meter (totalising) for evaluation and submission to DWAF.
- Daily rainfall is to be monitored in the project area.

10 References

Dougherty, D.E and D.K. Babu, 1984. Flow to a partially penetrating well in a double-porosity reservoir, Water Resources Research, vol. 20, no. 8, pp. 1116-1122.

Miller (2008) The Geology of Namibia. Geological Survey of Namibia.

Miller, R.McG. 1983. The Pan-African Damara Orogen of S.W. Africa/Namibia. In: Miller, R.McG. (Ed.),

Evolution of the Damara Orogen of S.W. Africa/Namibia. Special Publication of the Geological Society of South Africa, 11, 431-515.

Weaver J, Cavé L and Talma S (2007) Groundwater Sampling. Water Research Commission, South Africa. TT 303/07.

Table 7: Recommendations for pumping of boreholes

Borehole	Latitude	Longitude	Elevation*	Depth (m)	Static Water Level (m)	Depth to water strikes (m)	Borehole nominal cased diameter (mm)
WW204833	-22.06932	16.00632	1298	150	14.15	16	146
WW204832	-22.07129	16.00737	1294	120	14.38	21	146
WW204831	-22.06796	16.00211	1302	105	19.28	34, 45, 91	146
WW204838	-22.12884	16.04655	1217	150	15.46	83, 122	146
Reservoir area	-22.10264	15.99631	1266	-		-	

*Waterpoint elevation derived from ASTER satellite image as shown in Figure 30.

Borehole	Depth (m)	Static Water Level (m)	Available Drawdown (m)	Discharge during test (m³/day)	Recommended yield (m³/day)	Modelled water level after 5 years of pumping (m)	Pump installation depth (m)	Water Quality
WW204833	150	14.15	25	110.4	95	39	50	Group C
WW204832	120	14.38	13	192	36	27	50	Group C
WW204831	105	19.28	41	576	120	60	75	Group C
WW204838	150	15.46	68	103.2	88	83	90	Group B
					334			

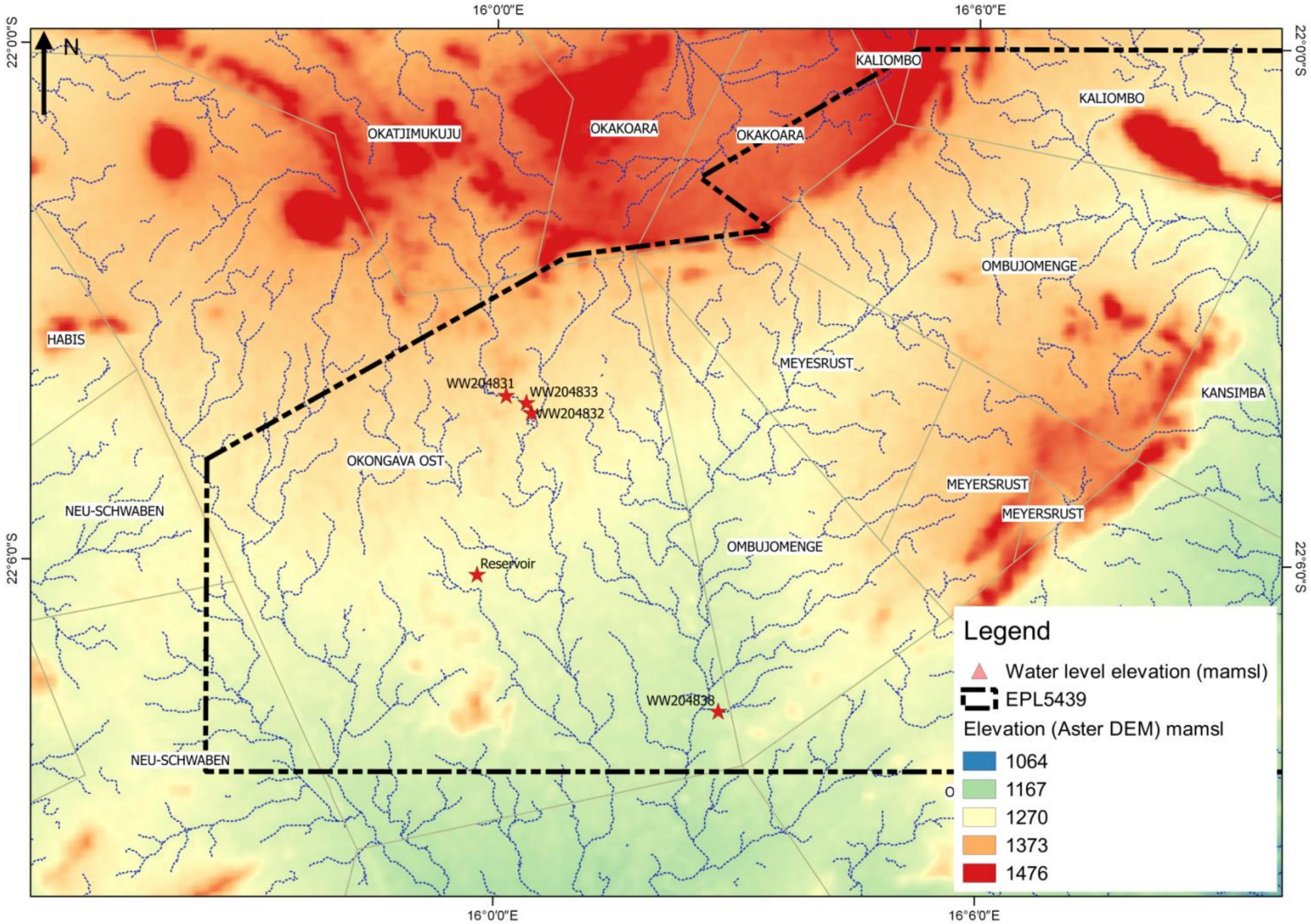


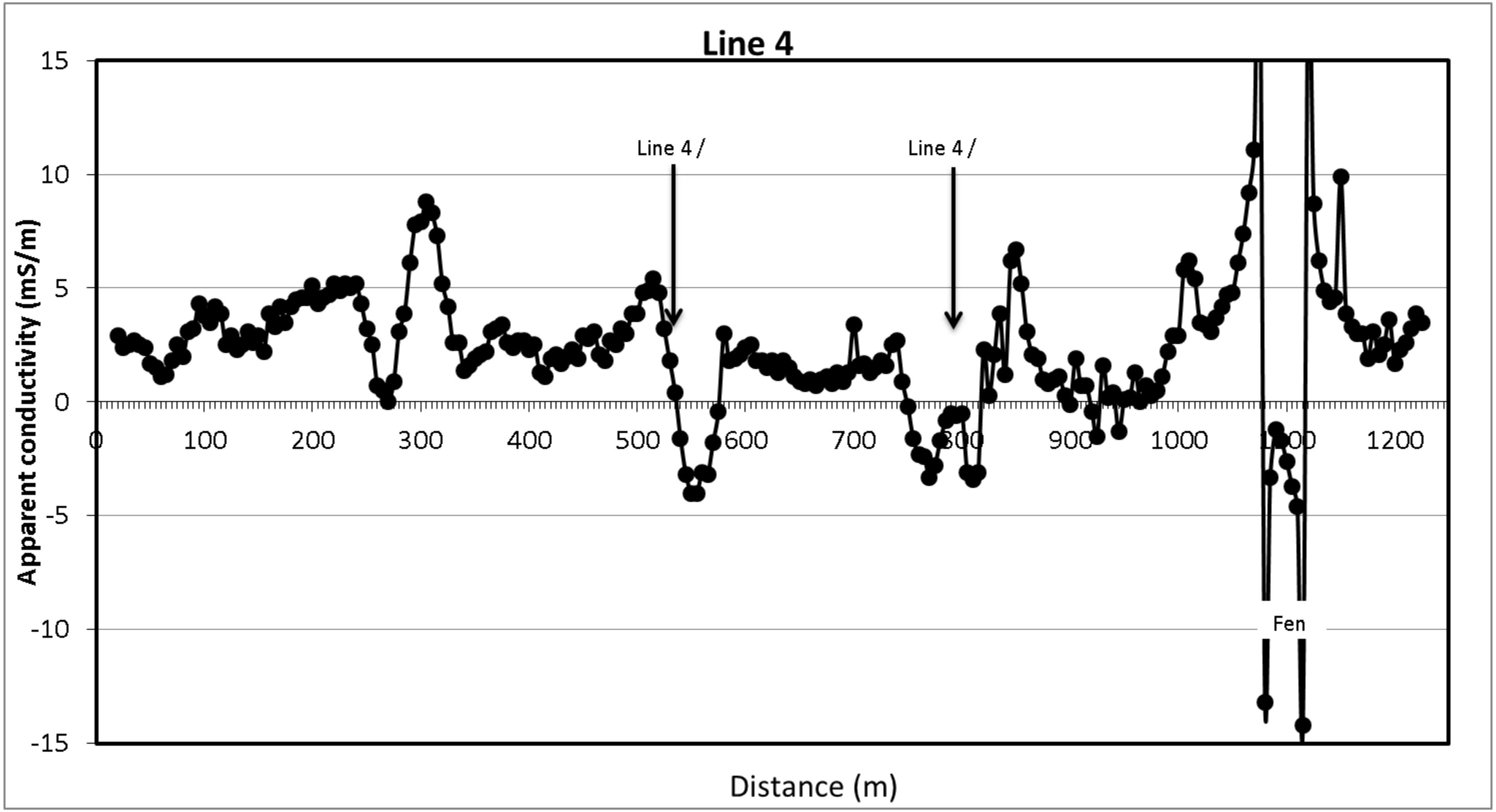
Figure 30: Location of production boreholes and position of reservoir

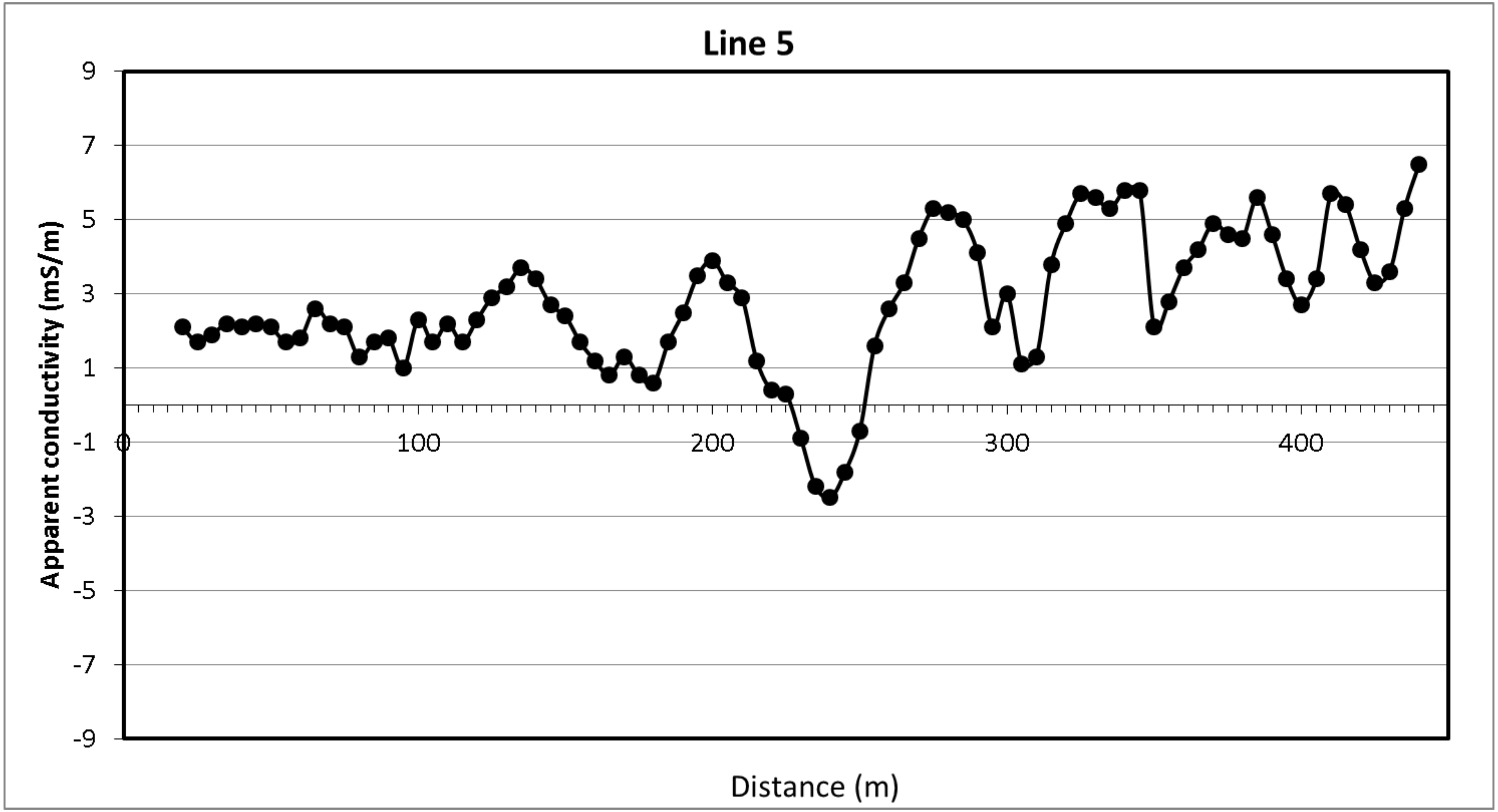
APPENDIX A – ELECTROMAGNETIC (EM34-3) PROFILING DATA PLOTS

Line 1
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
Apparent conductivity (mS/m)
0
100
200
300
400
500
600
700
800
Distance (m)
Line 1 /
430m


Line 2
15
10
5
0
-5
-10
-15
Apparent conductivity (mS/m)
0
100
200
300
400
500
600
700
Distance (m)

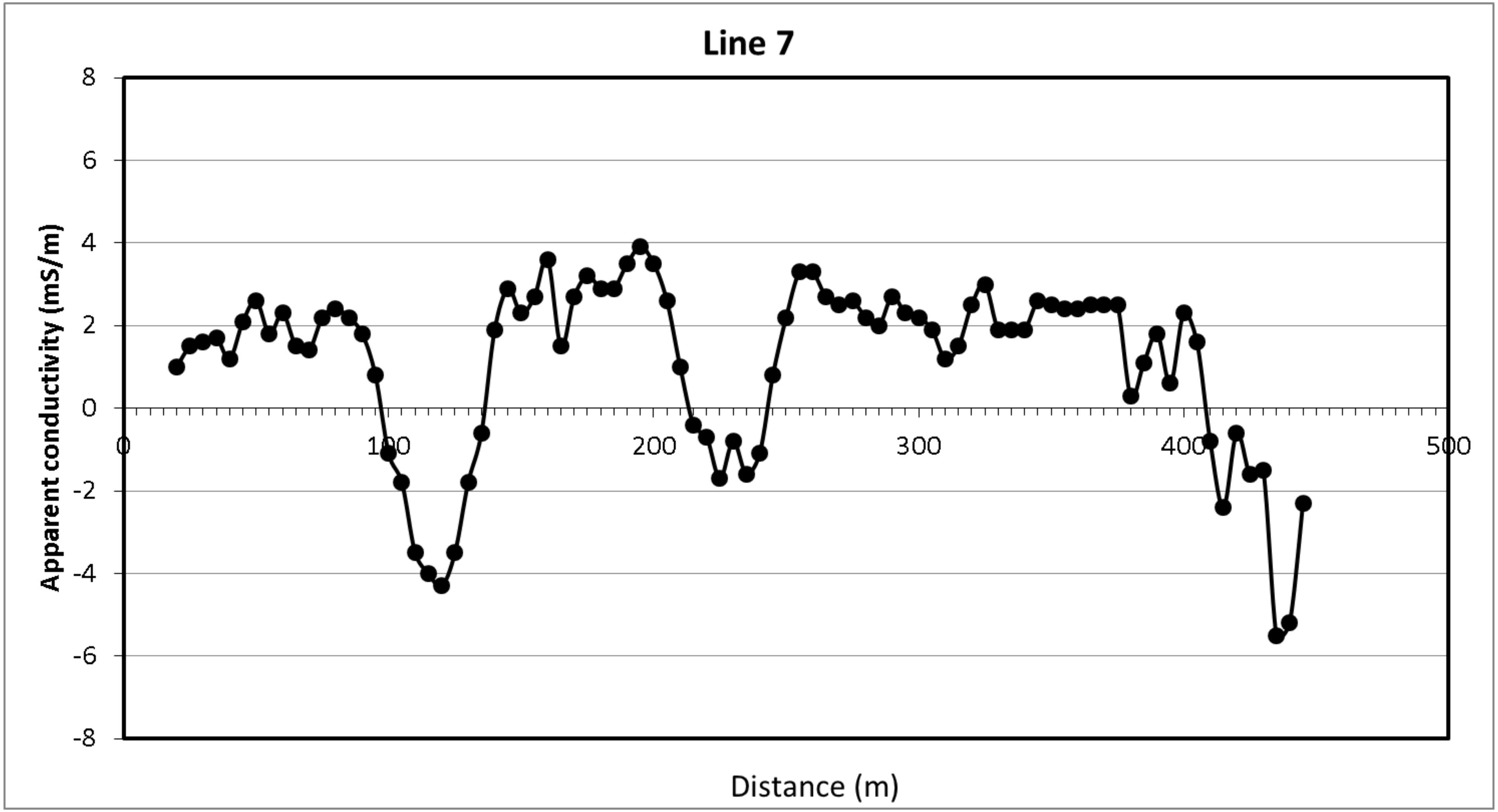

Line 3
7
5
3
1
-1
-3
-5
-7
Apparent conductivity (mS/m)
Line 3 / 120m
0
100
200
300
400
Distance (m)


Line 4
15
10
5
0
-5
-10
-15
Apparent conductivity (mS/m)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Line 4 /
Line 4 /
Fen
Distance (m)



Line 5
Apparent conductivity (mS/m)
9
7
5
3
1
-1
-3
-5
-7
-9
0
100
200
300
400
Distance (m)

Line 6
Apparent conductivity (mS/m)
6
4
2
0
-2
-4
-6
0
100
200
300
400
Distance (m)



Line 7
Apparent conductivity (mS/m)
8
6
4
2
0
-2
-4
-6
-8
0
100
200
300
400
500
Distance (m)

Line 8
Apparent conductivity (mS/m)
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
100
200
300
400
500
600
700
Distance (m)

Line 9
Line 9 /
295m
Apparent conductivity (mS/m)
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
100
200
300
400
500
600
700
Distance (m)

APPENDIX B – WATER QUALITY DATA

B1 – Guidelines for the quality of drinking water, the Water Act (Act 54 of 1956)

DETERMINANTS	UNITS	LIMITS FOR GROUPS*			
		A	B	C	D
Colour	mg/l Pt**	20			
Conductivity	mS/m 25 C	150	300	400	400
Total hardness	mg/l $CaCO_3$	300	650	1300	1300
Turbidity	N.T.U***	1	5	10	10
Chloride	mg/l Cl	250	600	1200	1200
Chlorine (free)	mg/l Cl	0,1- 5,0	0,1 – 5,0	0,1 – 5,0	5,0
Fluoride	mg/l F	1,5	2,0	3,0	3,0
Sulphate	mg/l SO_4	200	600	1200	1200
Copper	μg/l Cu	500	1000	2000	2000
Nitrate	mg/l N	10	20	40	40
Hydrogen Sulphide	μg/l H_2S	100	300	600	600
Iron	μg/l Fe	100	1000	2000	2000
Manganese	μg/l Mn	50	1000	2000	2000
pH****	pH-unit	6,0 – 9,0	5,5 – 9,5	4,0 – 11,0	4,0 – 11,0

* All values greater than the figure indicated.
**Pt = Platinum Units.
*** Nephelometric Turbidity Units
****The pH limits of each group exclude the limits of the previous group

Guidelines for the quality of drinking water, the Water Act (Act 54 of 1956) - continued

DETERMINANTS	UNITS	LIMITS FOR GROUPS			
		A	B	C	D*
Aluminium	µg/l Al	150	500	1000	1000
Ammonia	mg/l N	1	2	4	4
Antimonia	µg/l Sb	50	100	200	200
Arsenic	µg/l As	100	300	600	600
Barium	µg/l Ba	500	1000	2000	2000
Beryllium	µg/l Be	2	5	10	10
Bismuth	µg/l Bi	250	500	1000	1000
Boron	µg/l B	500	2000	4000	4000
Bromine	µg/l Br	1000	3000	6000	6000
Cadmium	µg/l Cd	10	20	40	40
Calcium	mg/l Ca	150	200	400	400
Calcium	mg/l $CaCO_3$	375	500	1000	1000
Cerium	µg/l Ce	1000	2000	4000	4000
Chromium	µg/l Cr	100	200	400	400
Cobalt	µg/l Co	250	500	1000	1000
Cyanide (free)	µg/l CN	200	300	600	600
Gold	µg/l Au	2	5	10	10
Iodine	µg/l I	500	1000	2000	2000
Lead	µg/l Pb	50	100	200	200
Lithium	µg/l Li	2500	5000	10000	10000
Magnesium	mg/l Mg	70	100	200	200
Magnesium	mg/l $CaCO_3$	290	420	840	840
Mercury	µg/l Hg	5	10	20	20
Molybdenum	µg/l Mo	50	100	200	200
Nickel	µg/l Ni	250	500	1000	1000
Potassium	mg/l K	200	400	800	800
Selenium	µg/l Se	20	50	100	100
Silver	µg/l Ag	20	50	100	100
Sodium	mg/l Na	100	400	800	800
Tellurium	µg/l Te	2	5	10	10

DETERMINANTS	UNITS	LIMITS FOR GROUPS			
		A	B	C	D*
Thallium	µg/l TI	5	10	20	20
Tin	µg/l Sn	100	200	400	400
Titanium	µg/l Ti	100	500	1000	1000
Tungsten	µg/l W	100	500	1000	1000
Uranium	µg/l U	1000	4000	8000	8000
Vanadium	µg/l V	250	500	1000	1000

B2 – Field data (wellhead parameters)

BOREHOLE NO.	Unit	WW204831	Shaft	Okongava	WW204832	WW204833	WW204830	WW204836	WW204838
Field data									
LOCATION		EPL5439	EPL5439	EPL5439	EPL5439	EPL5439	EPL5439	EPL5439	EPL5439
Latitude		-22.06795	-22.10356	-22.04884	-22.07129	-22.06907	-22.11938	-22.04813	-22.12884
Longitude		16.00214	15.99748	16.02733	16.00737	16.00746	16.02277	16.02820	16.04655
AQUIFER		Fractured	Fractured	Fractured	Fractured	Fractured	Fractured	Fractured	Fractured
SAMPLE TYPE		Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater
DATE SAMPLED		08-Apr-17	04-Apr-17	04-Apr-17	03-Apr-17	31-Mar-17	28-Mar-17	19-May-17	17-May-17
DATE ANALYZED		27-Apr-17	27-Apr-17	27-Apr-17	27-Apr-17	27-Apr-17	27-Apr-17	30-May-17	30-May-17
Depth	m	105	-	150	120	150	150	150	150
pH		7.13	7.92	6.96	7.11	7.08	7.41	7.46	6.52
Electrical Conductivity	µS/cm	1293	1694	1985	1513	1388	3280	1515	1225
Temperature	degree C	27.1	22.8	30.2	30.6			29.2	26.6
Alkalinity	mg/l CaCO3	458	541	499	583	545	360	429	239
Dissolved Oxygen	mg/l	3.27	5.13	2.69	2.84	2.83	3.93	7.27	5.32

B3 – Major constituents

BOREHOLE NO.	Unit	WW204831	Shaft	Okongava	WW204832	WW204833	WW204830	WW204836	WW204838
Laboratory data									
Laboratory		ANALAB	ANALAB	ANALAB	ANALAB	ANALAB	ANALAB	ANALAB	ANALAB
p H		7.50	8.20	7.20	7.40	7.50	7.80	8.00	8.00
Electrical Conductivity	mS/m	137.50	157.10	167.00	138.40	126.50	295.90	177.60	139.20
Turbidity	NTU	0.15	0.30	0.10	0.20	0.35	26.00	0.50	0.50
Total Dissolved Solids (cal.)	mg/l	921.25	1,052.57	1,118.90	927.28	847.55	1,982.53	1,190.00	932.64
P-Alkalinity as $CaCO_3$	mg/l	-	-	-	-	-	-	0.00	0.00
Total Alkalinity as $CaCO_3$	mg/l	497.00	555.00	465.00	550.00	525.00	385.00	467.00	219.00
Total Hardness as $CaCO_3$	mg/l	599.56	564.29	852.46	705.27	647.48	1,685.74	771.00	382.13
Ca-Hardness as $CaCO_3$	mg/l	154.81	247.20	317.12	182.28	169.80	454.45	290.00	312.13
Mg-Hardness as $CaCO_3$	mg/l	444.74	317.09	535.34	522.99	477.69	1,231.28	482.00	70.01
Chloride as Cl^-	mg/l	94.00	217.00	191.00	127.00	104.00	472.00	166.00	90.00
Fluoride as F^-	mg/l	0.60	1.50	0.60	0.80	0.70	0.60	0.80	1.30
Sulphate as SO_4^{2-}	mg/l	95.00	94.00	173.00	103.00	111.00	1,022.00	151.00	383.00
Nitrate as N	mg/l	12.00	5.70	24.00	8.10	9.30	24.00	28.00	1.53
Nitrite as N	mg/l							0.17	<0.01
ortho-Phosphate as PO_4	mg/l	0.16	2.10	0.50	0.73	1.00	0.44	0.28	0.10
Silica as SiO_2	mg/l	62.00	69.00	53.00	69.00	67.00	34.00	53.00	42.00
Colour	Pt		20.00					<10	<10
Chemical oxygen demand as O_2	mg/l	7.00	19.00	7.00	14.00	12.00	14.00	14.00	12.00
Total organic carbon as C	mg/l	0.65	3.30	0.85	0.68	0.73	0.35	1.10	0.31
Sodium as Na	mg/l	51.00	190.00	81.00	69.00	58.00	151.00	78.00	150.00
Potassium as K	mg/l	12.00	13.00	4.00	12.00	12.00	28.00	3.50	1.60
Magnesium as Mg	mg/l	108.00	77.00	130.00	127.00	116.00	299.00	117.00	17.00
Calcium as Ca	mg/l	62.00	99.00	127.00	73.00	68.00	182.00	116.00	125.00
Stability pH, at 25°C		7.01	6.76	6.74	6.90	6.94	6.69	6.80	7.06
Langelier Index		0.49	1.44	0.46	0.50	0.56	1.11	1.20	0.94
Ryznar Index		6.52	5.33	6.27	6.39	6.39	5.57	5.60	6.12
Corrosivity ratio		0.47	0.73	0.97	0.52	0.50	4.50	0.80	2.40

Parameter exceeding recommended maximum limits in **Group B** Human consumption **Group D** Livestock

B4 – Minor and Trace constituents

BOREHOLE NO.	Unit	WW204831	Shaft	Okongava	WW204832	WW204833	WW204830	WW204836	WW204838
Laboratory data									
Date Sampled		08-Apr-17	04-Apr-17	04-Apr-17	03-Apr-17	31-Mar-17	28-Mar-17	19-May-17	17-May-17
Lithium as Li*	µg/l	54.00	390.00	165.00	72.00	61.00	277.00	268.00	228.00
Beryllium as Be*	µg/l	0.06	0.04	0.07	0.08	0.08	0.12	2.40	0.19
Boron as B*	µg/l	110.00	162.00	128.00	122.00	116.00	156.00	102.00	83.00
Strontium as Sr*	µg/l	126.00	676.00	177.00	151.00	136.00	654.00	175.00	856.00
Molybdenum as Mo*	µg/l	4.30	5.30	2.80	5.70	5.30	2.90	2.50	3.40
Cadmium as Cd*	µg/l	0.03	0.03	0.05	0.05	0.01	0.04	0.09	0.04
Tin as Sn*	µg/l	0.07	0.08	0.07	0.07	0.06	0.15	0.04	0.06
Antimony as Sb*	µg/l	0.05	0.61	0.08	0.08	0.05	0.29	0.25	0.02
Barium as Ba*	µg/l	71.00	176.00	64.00	64.00	71.00	67.00	62.00	4.10
Thallium asTl	µg/l	0.07	0.09	0.15	0.12	0.09	0.16	0.18	0.16
Lead as Pb*	µg/l	0.60	0.12	1.00	0.94	1.70	1.70	1.70	0.87
Bismuth as Bi*	µg/l	0.03	0.03	<0.01	0.01	0.02	0.03	0.03	0.03
Uranium as U*	µg/l	12.00	66.00	53.00	28.00	25.00	919.00	53.00	62.00
Aluminium as Al*	µg/l	4.30	4.70	3.10	4.80	5.50	916.00	45.00	4.60
Titanium as Ti*	µg/l	0.23	0.06	0.12	0.12	0.14	99.00	1.90	0.81
Vanadium as V*	µg/l	16.00	81.00	9.50	20.00	16.00	13.00	13.00	4.50
Chromium as Cr*	µg/l	0.37	0.04	0.08	0.19	0.23	4.70	0.77	0.23
Manganese as Mn*	µg/l	0.56	10.00	0.23	2.50	1.70	51.00	10.00	49.00
Iron as Fe*	µg/l	12.00	4.20	6.40	56.00	7.90	1,274.00	99.00	126.00
Cobalt as Co*	µg/l	0.06	0.10	0.07	0.02	0.02	1.00	0.24	0.15
Nickel as Ni*	µg/l	0.09	0.47	0.70	0.41	0.28	5.60	0.81	0.16
Copper as Cu*	µg/l	0.64	1.60	1.00	0.71	0.92	3.10	1.30	0.78
Zinc as Zn*	µg/l	99.00	3.90	10.00	260.00	6.50	27.00	11.00	7.30
Arsenic as As*	µg/l	1.40	3.10	1.30	0.96	1.30	7.20	3.10	0.38
Selenium as Se*	µg/l	2.30	1.00	4.30	2.30	1.70	11.00	5.20	0.41
Silver as Ag*	µg/l	<0.05	0.16	0.09	<0.05	<0.05	<0.05	<0.05	<0.05
Mercury as Hg*	µg/l	1.20	0.19	1.50	1.40	1.90	1.20	0.81	2.70