abstraction from this groundwater resource is questionable, especially in the absence of a major recharge source. Throughout the last few decades concern was expressed by farmers in the Swartwater – Marnitz area that increased groundwater abstraction for irrigation purposes may relate to a regional drop in water levels. A study by Blecher (1993) attributed a drop in water levels of up to 20 m, to severe drought conditions, low storage capacity and limited recharge. According to this study the effects of abstraction for irrigation appeared to be localised and limited to the farms concerned. Similarly, Bush (1987) felt that declining water levels and yields for particular boreholes was an indication of site-specific dewatering due to the limited extent of the aquifers and their poor storage capabilities, and not a regional lowering of the water table.

Unfortunately no long term (e.g. > 20 years) monitoring data exist for the study area and as a result the actual trend of water levels in relation to recharge (rainfall), drought and abstraction for irrigation is not possible. However, the Limpopo DWA regional office installed several continuous water level loggers throughout the Limpopo Province in the last 2000s. Five of these monitoring boreholes fall within the larger study area of the proposed Moonlight operation, while three of these are within 20 km of the operation. The positions of these monitoring boreholes are illustrated in Figure 3.1 and summarised in Table 3.2. Borehole positions obtained from the GRIP and NGDB datasets are also show in Figure 3.1.

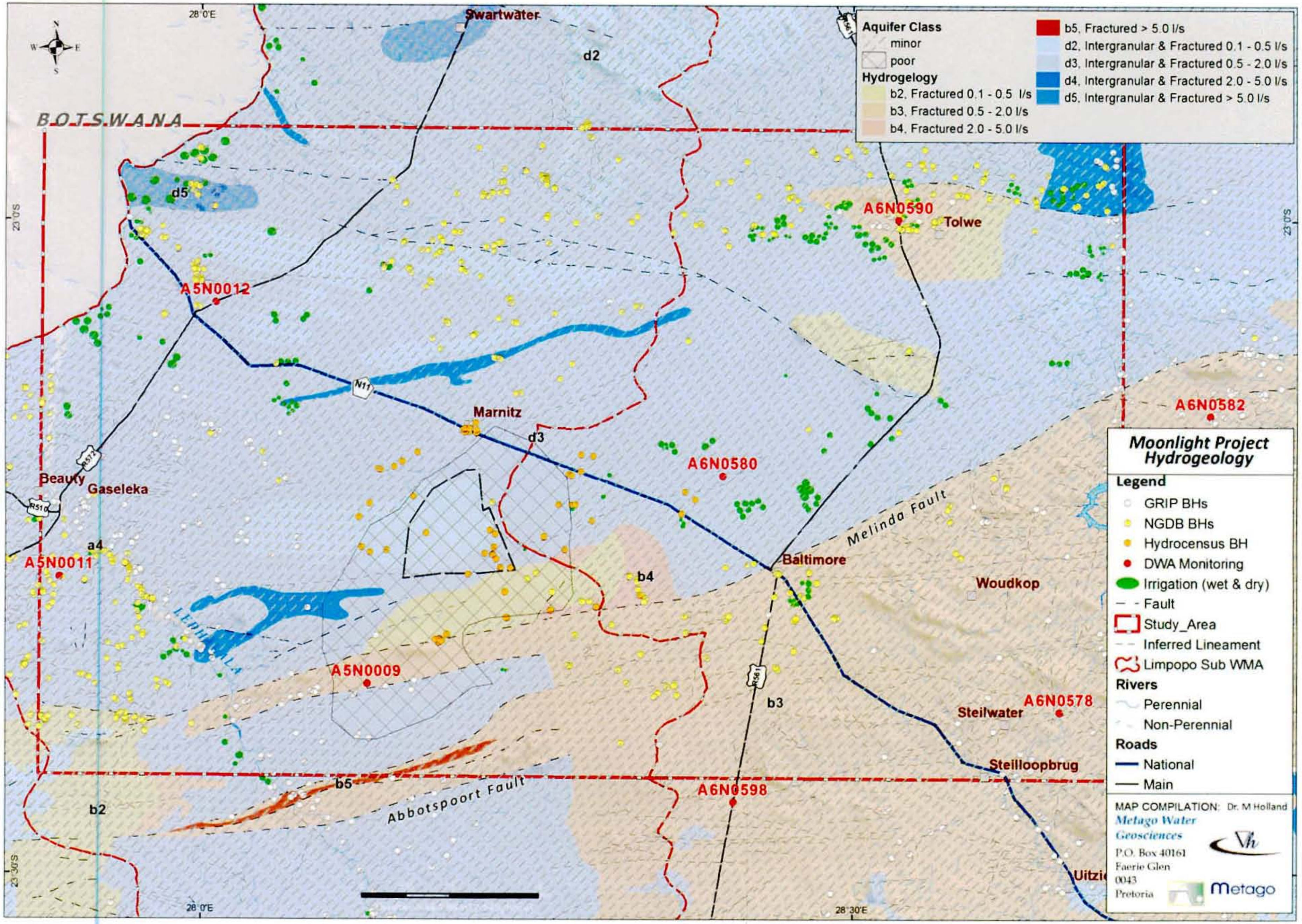
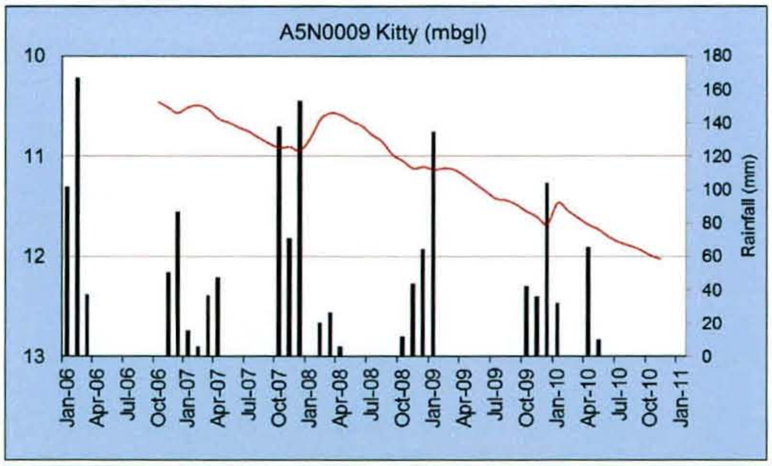


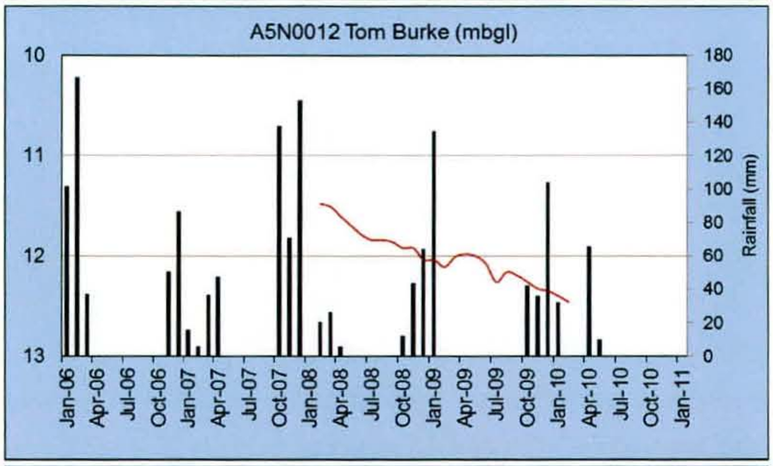
FIGURE 3.1: HYDROGEOLOGICAL AND BOREHOLE DISTRIBUTION MAP (SOURCE: PARSONS AND CONRAD, 1998 AND THE 1:500 000 PIETERSBURG HYDROGEOLOGICAL MAP).

TABLE 3.2: WATER LEVEL TRENDS OF SELECTED MONITORING STATIONS WITHIN THE STUDY AREA.

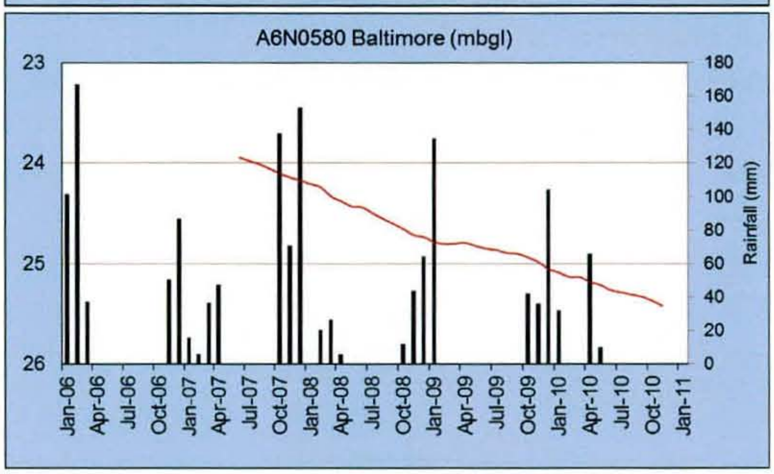
Station: A5N0009
Start Date: Oct-06
Last measured Date: Nov-10
Start water level:10.46 mbgl
End water level: 12.03 mbgl
Difference: -1.57 m
Monthly Rainfall Data: Tom Burke (Jan-06 to June-10)



Station: A5N0012
Start Date: Feb-08
Last measured Date: Nov-10
Start water level:11.48 mbgl
End water level: 12.46 mbgl
Difference: -0.98 m
Monthly Rainfall Data: Tom Burke (Jan-06 to June-10)



Station: A6N0580
Start Date: Jun-08
Last measured Date: Nov-10
Start water level: 23.94 mbgl
End water level: 25.42 mbgl
Difference: -1.48 m
Monthly Rainfall Data: Tom Burke (Jan-06 to June-10)



Based on the water level observations over the last 3 to 4 years, it is evident that very little active recharge occurred and a declining trend is observed for all 3 stations. Although a decrease in water levels is expected due to below average rainfall over the last couple of years (evident from cumulative rainfall graphs in section 2.2), decreasing water levels of approximately 0.3 m per year in the monitoring borehole near Baltimore suggest the potential impacts of over-abstraction for irrigation purposes.

3.1.1 AVAILABILITY OF GROUNDWATER RESOURCES

A summary of the groundwater resource in the two catchments under investigation is provided in Table 3.3.

TABLE 3.3: SUMMARY OF GROUNDWATER RESOURCE POTENTIAL AS PER WR2005.

Quat	Area (Km^2)	MAP	Mean Annual Contribution to River Baseflow (Mm^3/a)	Mean Annual Potential Recharge				Utilisable Potable Groundwater Exploitation Potential (Mm^3/a)		Annual Abstraction	Mean Annual Runoff
				Mm^3/a		% of MAP	% of MAP			Mm^3/a	Mm^3/a
				Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season		
A50H	1945	407	0.044	15.1	9.9	1.9	1.2	4.1	3.4	1.10*	8.88
A63A	1928	433	0.027	18.2	12.3	2.1	1.4	7.6	6.1	0.74*	16.48

* - see discussion below

According Water Resource Management Services Database (WARMS) obtained from the Department of Water Affairs in 2010, approximately 6 Mm^3/a are registered by water users in quaternary catchment A50H and approximately 10 Mm^3/a are registered in quaternary catchment A63A. It is clear that the annual abstraction rates specified by the WR2005 dataset are greatly underestimated. In both catchments more than 60 % of recharge is potentially registered to groundwater users, mainly for irrigation. Considering the variability of rainfall/recharge of the area the groundwater resources of these catchments can be regarded as heavily utilised. However, these figures may also be misleading as it is based on quaternary scale, while in actual fact the abstraction of groundwater for irrigation is concentrated around certain productive regions. Withdrawals from an aquifer might have a severe impact on individual water systems locally, but per square kilometre these withdrawals might be minor in terms of total recharge and discharge.

3.2 HYDROGEOLOGICAL FIELD INVESTIGATION

3.2.1 HYDROCENSUS

The first hydrocensus was conducted by Metago Environmental Engineers (Pty) Ltd within the proximity of the proposed mining activity (≈10 km radius), including the small town of Marnitz, as part of the pre-feasibility study conducted in July 2010. A follow up hydrocensus was conducted during April 2011 to expand on the existing dataset. A total of 64 boreholes were visited mainly for the purpose of 1) identifying groundwater users and verifying use (e.g. domestic etc.), 2) taking groundwater levels, and 3) sampling of selected boreholes to assess the water quality prior to mining activities. Nineteen water samples were collected from boreholes surrounding the Moonlight operation and will be assessed in subsequent sections. Details of the hydrocensus data collected are given in Appendix A. The locality of the borehole sites are shown on Figure 3.1. The majority of boreholes are for either domestic use and/or cattle/game feedlots. A number of boreholes are not in use or unequipped. Many of these are due to a lack of casing at depth leading to a collapse of the borehole. Alleged borehole yields vary from 0.1 l/s to more than 5 l/s with higher yields obtained towards the east of the Moonlight project area. The water levels measured during the hydrocensus vary from a minimum of 10 mbgl to more than 60 mbgl with an average of 37 mbgl. Water levels are considerably deeper in the Moonlight project vicinity (15 km radius) compared to the regional water levels (Table 3.4). The deeper water levels coincide with the surface watersheds and areas with low groundwater potential.

TABLE 3.4: WATER LEVEL DATA OBTAINED FROM HYDROCENSUS, GRIP AND NGDB DATASETS.

Area	*Nr. Of BHs*	**Water Level (mbgl)**		
		Min	*Max*	Mean
Larger study area	459	1	81	20
Moonlight (15 km radius)	32	10	60	37

3.2.2 GEOPHYSICS

A geophysical survey was conducted to pinpoint borehole drilling targets and to identify potential water bearing features. The geophysical traverses chosen were based on the inferred lineaments from ASTER image interpretations and are shown in Figure 3.2. Due to the dense vegetation at the time of the study the traverses were also limited to roads and fence lines. The geophysical work undertaken included magnetic, LUND resistivity and electromagnetic traverses. Based on the results which are included in Appendix B, potential drilling targets were identified.

3.2.3 DRILLING

A total of 12 new exploratory/test/ monitoring boreholes, designated TM-MWG01 to TM-MWG12 were drilled in the positions shown on Figure 3.2. The boreholes were drilled by Ramotse Drilling of Polokwane using the down-the-hole air percussion drilling technique. Details of the drilling results are given in Table 3.5. Geological and construction logs for each borehole are included as Appendix C. Boreholes TM-MWG 01, TM-MWG 11 and TM-MWG 12 were drilled based on the knowledge obtained from the exploration drilling results, while all other boreholes were drilled to target a specific geophysical anomaly. The preliminary site layout was considered to finalise drilling positions (Figure 3.2).

Despite drilling to various depths and targeting numerous geophysical anomalies, only a 30 % drilling success rate was achieved. The drilling results typify the low groundwater potential of the Moonlight project area. However, the drilling of these boreholes 1) confirmed the geology, including depth of weathering and fracturing, 2) enabled the estimation of hydraulic parameters of the aquifer from on-site pumping tests, and 3) provided potential monitoring sites for the proposed mining operation.

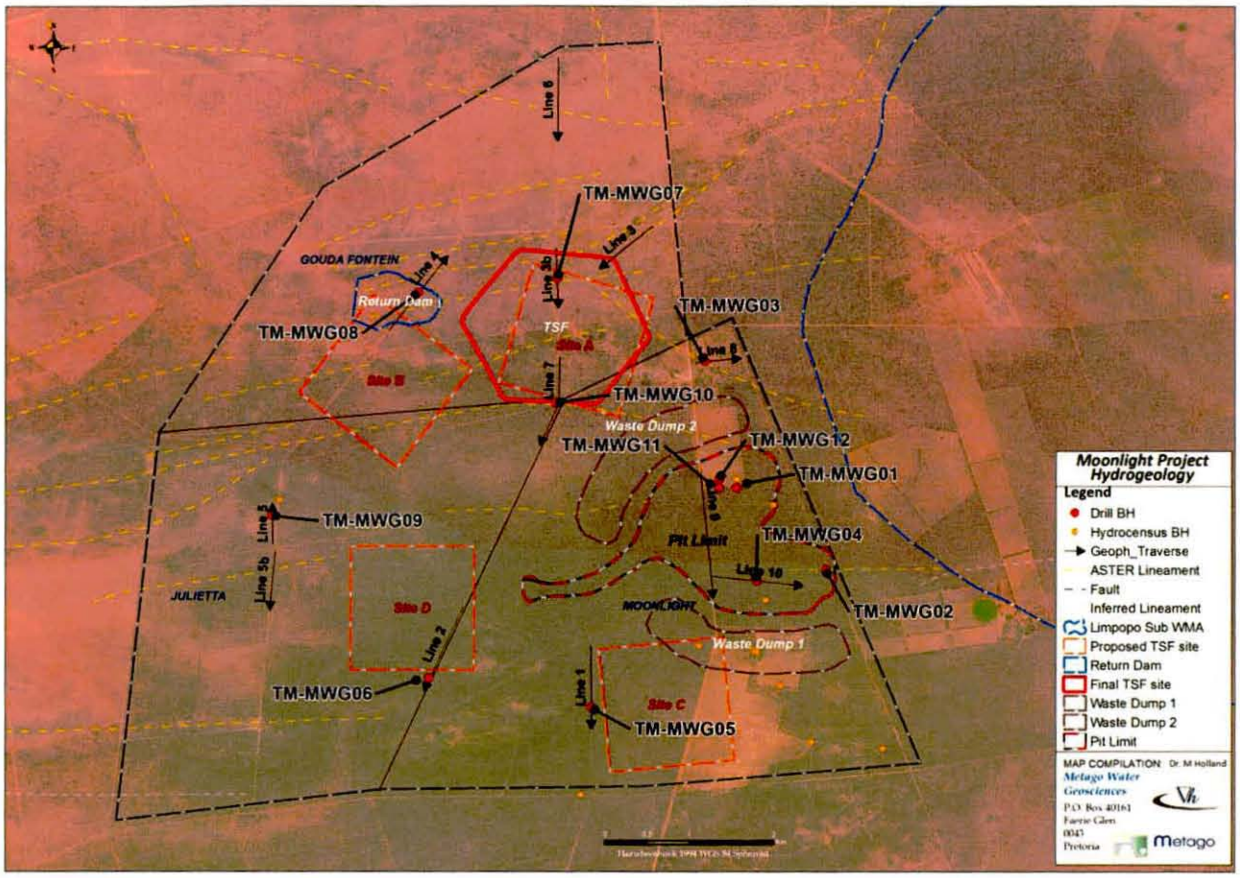


FIGURE 3.2: MAP SHOWING GEOPHYSICAL TRAVERSES AND NEW BOREHOLES DRILLED.

TABLE 3.5: SUMMARY OF BOREHOLES DRILLED.

Borehole ID	Locality	*Coordinates (LO 29 WGS 84)*		Elevation (mamsl)	BH Depth (mbgl)	Water level (mbgl)	Blow yield (l/s)
		X	Y				
TM-MWG01	Pit	-79631.7	-2571198	976.48	120	49.16	1.5
TM-MWG02	Inferred lineament	-78651.5	-2572162	969.68	100	dry	-
TM-MWG03	Line 8 - 110 m	-79983.8	-2569698	969.83	100	dry	-
TM-MWG04	Line 10 - 475 m	-79406.9	-2572304	973.61	196	52.56	0.35
TM-MWG05	Line 1 - 685 m	-81202.5	-2573821	955.40	100	dry	-
TM-MWG06	Line 2 - 820 m	-82972.7	-2573484	957.12	120	dry	-
TM-MWG07	Line 3b - 355 m	-81607.1	-2568725	953.45	100	dry	-
TM-MWG08	Line 4 545 m	-83120.1	-2568902	943.18	80	dry	-
TM-MWG09	Line 5 - 345 m	-84714.2	-2571561	945.02	110	dry	-
TM-MWG10	Line 7 - 555 m	-81611.2	-2570201	964.43	120	dry	-
TM-MWG11	Pit	-79823.8	-2571195	975.60	110	44.23	0.1
TM-MWG12	Pit	-79821.3	-2571095	975.31	120	43.51	1.3

Most of the boreholes were drilled through the weathered and fractured horizons into the underlying solid bedrock below. The weathering depths vary from 20 – 60 mbgl. Apart from TM-MWG01 and TM-MWG12 with measurable blow yields, no significant fracturing was identified, with only minor fracturing in places below the weathered horizon. Water levels in successful boreholes were recorded above the water strike depths confirming the semi-confined to confined nature of the aquifer. The wide variation in blow yields (0.1 to > 1 l/s) is characteristic of weathered and fractured heterogeneous aquifers with low permeability. However, the lack of groundwater intersected is a positive feature in terms of the proposed positioning of the TSF (Site A) (Figure 3.2). The TSF classification, geochemical description and preliminary design were conducted by Metago Environmental Engineers (MEE, 2011). Additional comments with regards to the proposed TSF sites (Figure 3.2) are summarised below:

- Site A; electrical resistivity profiles in the vicinity of Site A reveal weathering depths of 20 to 40 m. Although geophysics confirmed potential fissures no water was struck in two boreholes drilled to depth of a 100 m.
- Site B; an electrical resistivity profile conducted to the north of Site B reveal weathering depths of 20 to 35 m. No significant fractures were identified from ground geophysics. Borehole TM-MWG08 drilled to 80 m struck no water.
- Site C; an electrical resistivity profile conducted to the west of Site C reveal weathering depths in excess of 30 to 50 m. No significant fractures were identified from ground geophysics. Borehole TM-MWG05 drilled to 100 m struck no water. However, existing water supply boreholes towards the east of Site C would suggest a slightly better groundwater potential compared to the rest of the proposed TSF sites.
- Site D; an electrical resistivity profile conducted at Site D reveal weathering depths in excess of 30 to 50 m. Three anomalies interpreted as potential fracture zones were identified from the geophysical traverse. However, borehole TM-MWG06 drilled to 120 m struck no water. Slightly shallower depths to water tables are expected for site D (and Site C).

3.2.4 BOREHOLE PUMPING TESTS

Each borehole was tested to determine the hydraulic parameters of the aquifer, and to collect purged water samples for chemical analysis. Two types of pumping tests were performed to assess the hydraulic properties of the aquifers:

1. Step drawdown tests (SDT), during which the borehole is pumped at a constant discharge rate for up to 60-minutes, after which the step is repeated at progressively higher discharge rates. After the test is stopped, the residual drawdown over time is measured until ~95% recovery of the water level has been reached.
2. Constant discharge tests (CDT) pump a borehole for a predetermined time at a constant rate, and the drawdown over time in at least the pumping borehole is recorded. Discharge measurements are taken at intervals to ensure that a constant discharge rate is maintained throughout the test period.

The recovery follows directly after pump shut down until ~95% recovery of the water level has been reached.

Step tests and constant discharge rate tests were run on 4 of the 12 boreholes drilled. An additional 4 tests were carried out on existing boreholes identified during the hydrocensus. The following process was followed for estimating aquifer parameters based on the pumping test data.

1. Develop a conceptual understanding of the geological setting of the test.
2. Create the diagnostic plots from pumping test data and define the flow regime. Pumping test data were analysed with the software package AQTESOLV Pro version 4.5.
3. Choose the appropriate analysis method(s) (i.e. Theis, 1935; Cooper and Jacob, 1946; Hantush and Jacob 1955; Neuman, 1974; Moench, 1997) and determine the aquifer and well parameters from the curve fitting of the drawdown (and derivative) and/or the recovery data.
4. Drawdowns influenced by fluctuating pumping rates should rely on an accurate description of the recovery data. The recovery of a pumped aquifer can be interpreted in the same way as the drawdown by using diagnostic plots. Through a simple transformation of the time variable, Agarwal (1980) devised a procedure that uses solutions developed for drawdown analysis (i.e. the Theis type-curve) to analyze recovery data.

Details and the results of the pumping tests carried out are given in Table 3.6, and fitted plots of drawdown versus time for each test included in Appendix D. The positions of the tested boreholes are shown on Figure 3.3. The most common behaviour of boreholes tested in the study area is an inflection of the drawdown at intermediate times, reflected by a pronounced double porosity dip in the derivative. Early pumping times are characterised by well bore storage effects and linear flow through fractures, followed by a characteristic bilinear flow regime indicative of flow in fractures and the matrix. At late time, the system either tends toward a typical infinite acting radial flow asymptote or boundary conditions may be encountered. The low yielding boreholes features the obvious influence of barrier boundaries which increases the rate of drawdown as the limits of the fissure systems are reached by the pumping effects.

TABLE 3.6: SUMMARY PUMPING TEST RESULTS.

Borehole ID	BH Depth (mbgl)	Water level (mbgl)	Constant Rate (l/s)	Time (min)	Pump Intake (mbgl)	Final Drawdown (m)	T-Value (m^2/d)	Recovery T-Value (m^2/d)	Likely K-value (m/d)
TM-MWG04	195	51.6	0.24	163	100	48.25*	0.1	0.1	0.001
TM-MWG01	199	42.04	0.3	1440	84.5	10.14	13	8	0.163
TM-MWG11	109	44.23	0.31	1440	100	41.47	0.1	0.1	0.001
TM-MWG12	119	44.7	1.35	1440	100	22.53	6	5	0.075
BH39	172	58	0.03	1440	101.46	39.68	0.1	0.1	0.001
BH4	60	15.39	0.3	1440	57.21	7.57	5	3	0.063

* - reached pump intake after 163 min.

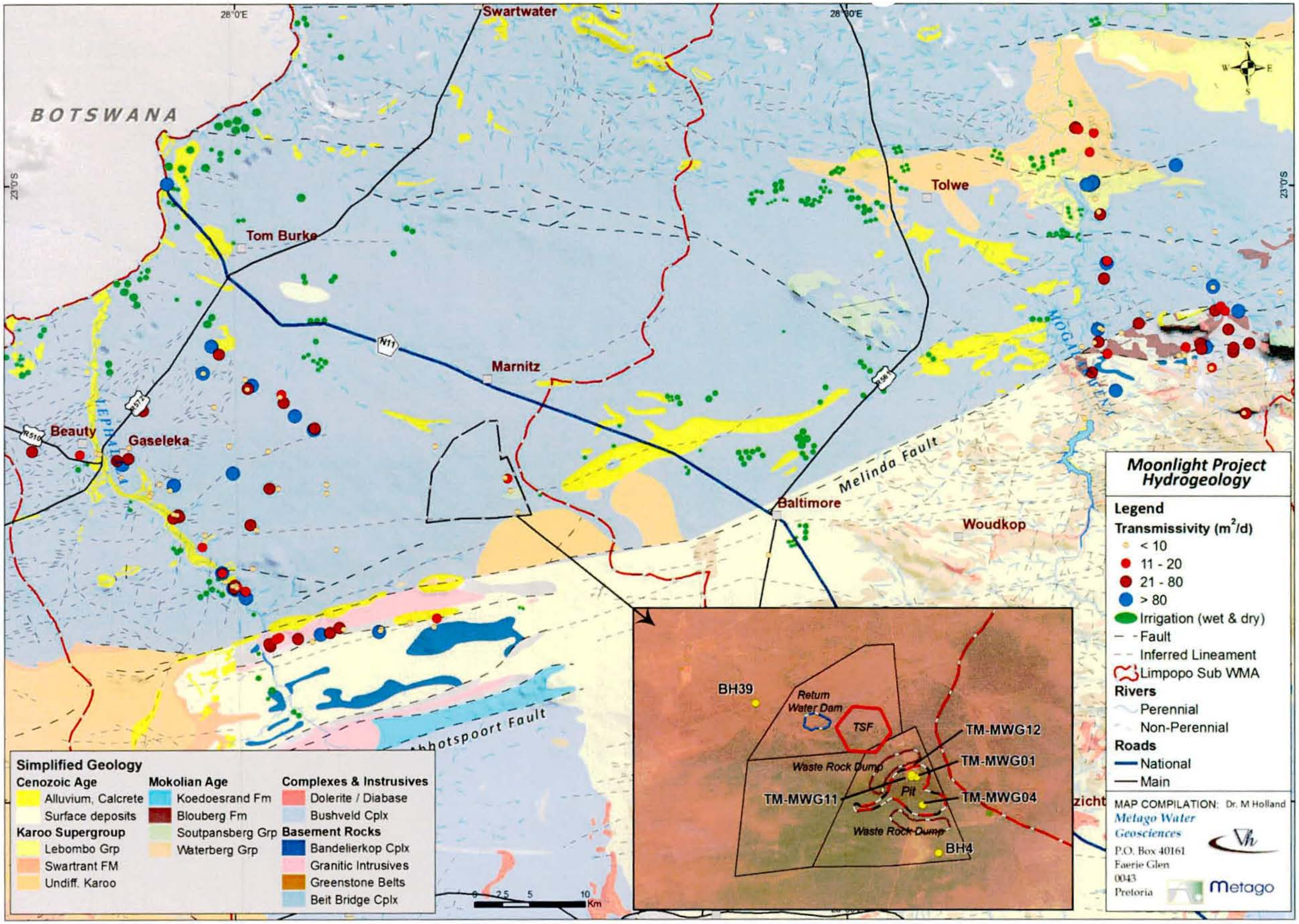


FIGURE 3.3: DISTRIBUTION OF TRANSMISSIVITY VALUES AND INSERT OF BOREHOLES TEST ON-SITE.

Hydraulic parameters

Numerous pumping test data primarily to recommend 'sustainable' abstraction rates for rural water supply schemes is captured in the GRIP dataset. Although the determination of aquifer parameters was not a priority in the GRIP framework, pumping tests of over 80 boreholes within the larger study area were analyzed using classical analytical models such as Theis (1935) and the Jacob's approximation (Cooper and Jacob, 1946) method. A total of 82 boreholes with transmissivity values occur within the larger study area but pertain mostly to the south and southwest of the Moonlight project area (Figure 3.3). Transmissivity ranges between 0.2 and 275 m^2/d with a geometric and harmonic mean of 13 and 6 m^2/d respectively (Figure 3.3). Although data is limited within each geological setting (Table 3.7), the variability of permeability is evident. It is important to note that the results do not reflect the variation between vertical parameters (e.g. regolith and lower fractured rock) but an averaged value over total aquifer depth.

TABLE 3.7: SUMMARY OF TRANSMISSIVITIES OBTAINED FROM THE GRIP DATASET.

Statistics	Combined	Beit Bridge Complex	Granites, mylonites, quartzites	Waterberg Group
Nr. of BHs	82	59	18	5
Min (m^2/d)	0.2	0.8	0.2	0.3
Max (m^2/d)	275.0	275.0	125.0	7.5
Median (m^2/d)	12.6	12.6	16.0	0.6
Geometric mean (m^2/d)	13.0	16.4	12.4	1.0
Harmonic mean (m^2/d)	3.3	6.4	2.2	0.7
Likely K-value*	0.04 – 0.16	0.07 – 0.27	0.02 – 0.15	0.009 – 0.08

* - Assuming an aquifer thickness of 80 m.

The hydraulic properties of weathered-fractured crystalline aquifers are highly variable and can change several orders of magnitude from one borehole to the next. However, regional hydraulic conductivities ranges can be compared to published values for crystalline aquifers found under similar conditions in other African countries (Table 3.8).

TABLE 3.8: HYDRAULIC CONDUCTIVITIES OF BASEMENT AQUIFERS.

Statistics	Conductivity (m/d)	Source
Malawi/Zimbabwe	0.08 - 0.7	Chilton and Foster (1995)
Zimbabwe	0.02 - 4.9	Wright (1992)
Uganda	0.04 - 0.7	Taylor and Howard (2000)
Ghana	0.22 - 2.2	Martin (2006)
Benin(Dogue)	0.005 - 0.02	Fass (2004)

3.3 GROUNDWATER ELEVATION AND FLOW DIRECTIONS

Water level data collected during the hydrocensus and from the newly drilled boreholes formed the basis of the groundwater level dataset. To increase the spatial distribution of the water levels measurements the National Groundwater Database and GRIP dataset was used and this increased the total number of groundwater level measurements to 171. Groundwater flow within the study area is mainly controlled by the geology of the region. Regionally the groundwater mimics the topography. Figure 3.4 shows the very good correlation (R^2=0.97) between absolute surface and groundwater table elevations in metres above mean sea level (mamsl) for the study area. The observed correlation is used to improve the interpolation of initial water levels for the numerical model in data scarce environments by applying co-kriging based on known topography (Bayesian interpolation).

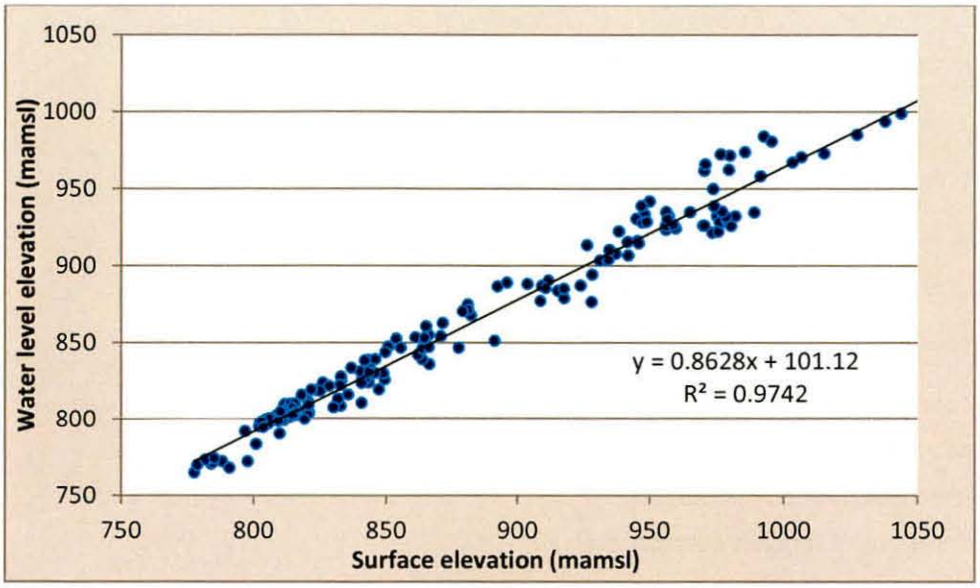


FIGURE 3.4: CORRELATION BETWEEN SURFACE TOPOGRAPHY AND GROUNDWATER ELEVATIONS.

The variability of groundwater table elevations is a function of the topography, and groundwater flows from higher lying ground towards lower lying ground and is generally towards the surface streams. However, due to the lack of major surface water drainages, groundwater flow paths can be considerably longer compared to areas with a dense drainage network.

3.4 GROUNDWATER QUALITY

Numerous site specific groundwater samples were taken in line with international standards and sampling protocols. Chemical analyses were performed by an accredited South African laboratory. All laboratory reports can be made available on request. It should be noted that no biological analyses have been undertaken and only inorganic elements have been considered. The following elements were analysed:

- Physical and organoleptic requirements: EC, TDS and pH
- Major ions: Ca, Mg, Na, K, Cl, HCO_3, NO_3 as N, F, NH_4
- Trace elements: Ag, Al, As, B, Ba, Be, Bi, Cd, Co, Cr, Cu, Fe, Li, Mn, Mo, Ni, P, Pb, S, Sb, Se, Si, Sn, Sr, Ti, W, Zn and Zr.

The accuracy of the chemical analyses was evaluated according to missing main components, plausibility of the single values as well as acceptable ion (charge) balance errors as determined by the electro-neutrality (E.N):

$$E.N\,[\%] = \frac{\sum cations\,[meq/L] - \left|\sum anions\,[meq/L]\right|}{\sum cations\,[meq/L] + \left|\sum anions\,[meq/L]\right|} \cdot 100\%$$

While aqueous solutions should be electrically neutral, an error of 5 % for a sample analysis is generally considered reasonable. The criterion is relaxed to 10 % for low-mineralised samples.

3.4.1 Results

The water quality results for major ions obtained from the analysis of 25 groundwater samples are shown in Table 3.9 and the position of the BHs sampled is illustrated in Figure 3.5.

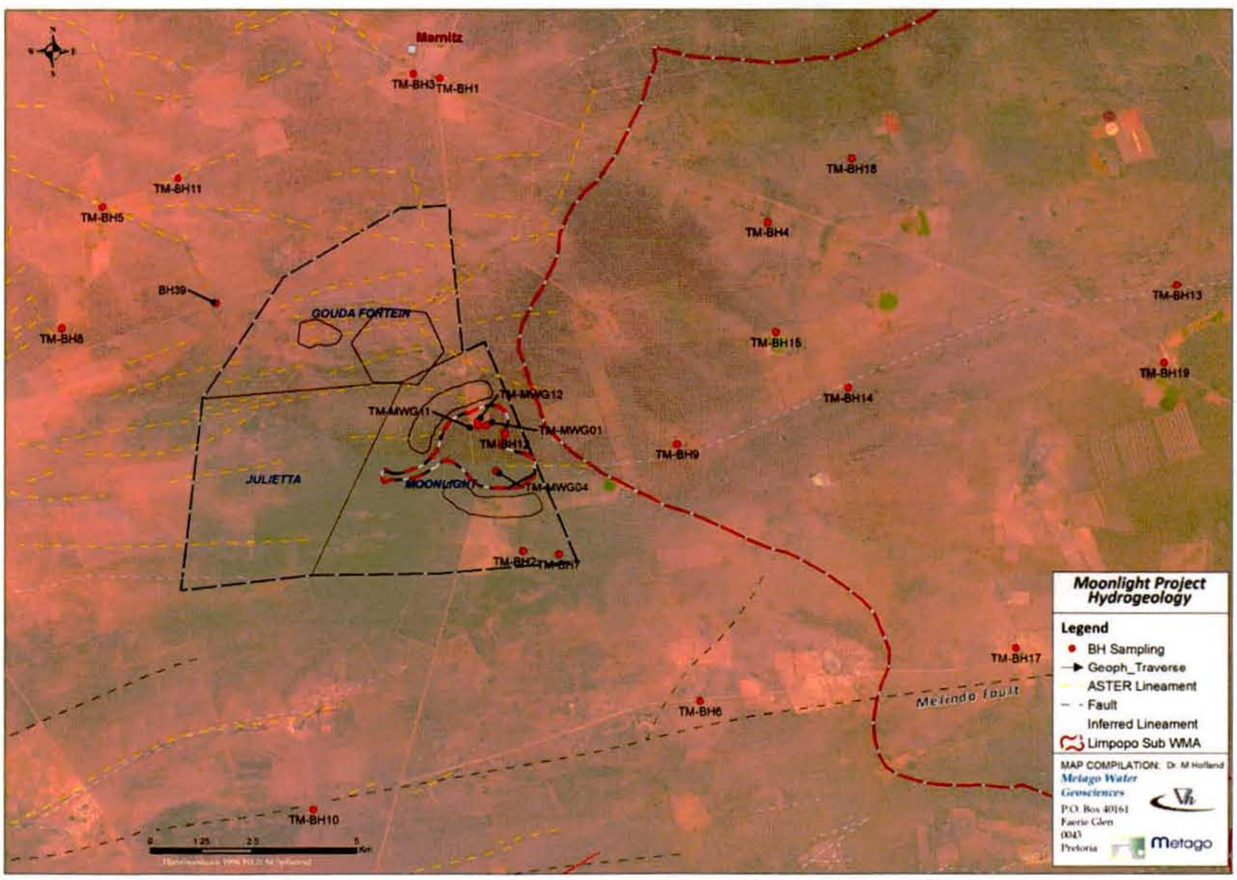


Figure 3.5: Spatial location of BHs sampled.

TABLE 3.9: POTABILITY CLASSIFICATION OF THE BOREHOLES SAMPLED

BHs	Date	EC	TDS	pH	Ca	Cl	F	Mg	NO_3 as N	K	Na	SO_4	Zn	Cd	Cr	Cu	Fe	Mn	Ni	Se
Units		mS/m	mg/l	-	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
TM-BH13	19/04/11	87.4	576	7.5	67	76	0.5	27	15	2.7	59	11	0.078	6	<25	<25	75	<25	<25	34
TM-BH14	19/04/11	74.9	482	7.4	51	46	0.5	26	6.4	3.3	33	9	<0.025	6	<25	<25	<25	<25	<25	33
TM-BH15	19/04/11	80.8	542	7.6	62	51	0.5	32	18	2	52	7	0.314	6	<25	<25	326	<25	<25	30
TM-BH16	19/04/11	200	1150	7.3	67	367	0.6	43	1.8	5.6	264	24	<0.025	6	<25	188	<25	<25	<25	42
TM-BH17	20/04/11	240	1476	7	116	572	0.3	59	7.3	7.7	255	31	<0.025	7	<25	<25	114	<25	<25	49
TM-BH18	20/04/11	69.6	478	7.5	84	32	0.3	28	7	2.9	18	5	0.075	6	<25	<25	<25	<25	<25	28
TM-BH19	21/04/11	94.1	622	7.5	87	99	0.6	32	13	2.9	50	12	<0.025	6	<25	<25	75	<25	<25	32
TM-BH 1	19/07/10	96.4	585	8.1	73	70	0.9	45	16	9.5	79	22	<0.025	<5	<25	<25	<25	<25	<25	<20
TM-BH 2	20/07/10	140	829	7.6	122	183	0.7	51	40	11	95	24	<0.025	<5	<25	<25	<25	<25	<25	<20
TM-BH 3	20/07/10	143	890	7.7	120	131	0.9	68	58	11.7	85	49	<0.025	<5	<25	<25	<25	<25	<25	<20
TM-BH 4	19/07/10	97.1	585	7.8	71	70	0.8	57	5.3	7.1	75	29	<0.025	<5	<25	<25	<25	<25	<25	<20
TM-BH 5	21/07/10	159	954	8.1	80	198	1.5	73	49	8.6	139	34	<0.025	<5	<25	<25	<25	<25	<25	<20
TM-BH 6	21/07/10	426	2402	7.3	142	1161	0.8	131	4.1	9.3	536	246	0.045	<5	<25	<25	<25	<25	<25	<20
TM-BH 7	21/07/10	232	1324	7.5	159	480	0.8	54	3.1	15.1	243	136	0.066	<5	<25	<25	197	<25	<25	<20
TM-BH 8	22/07/10	181	1087	7.8	106	226	0.8	111	58	14.9	86	44	<0.025	<5	<25	<25	<25	<25	<25	<20
TM-BH 9	19/07/10	79.2	459	7.9	65	71	0.7	34	9.1	2.7	55	13	0.155	<5	<25	<25	74	<25	<25	<20
TM-BH 10	21/07/10	84.3	476	7.4	57	97	0.9	21	6.8	12.4	80	22	<0.025	<5	<25	<25	<25	<25	<25	<20
TM-BH 11	19/07/10	115	677	7.6	85	98	1	54	23	9.8	74	21	0.084	<5	<25	<25	<25	<25	<25	<20
TM-BH 12	23/07/10	64.6	362	8.2	37	61	0.7	24	6.4	7.3	58	9	0.195	<5	<25	<25	<25	<25	<25	<20
TM-MWG01	13/04/11	65.3	424	7.3	44	55	0.1	26	5.8	5.4	58	11	n.a	n.a	n.a	<20	<50	210	n.a	n.a
TM-MWG04	24/03/11	77.2	501	7.4	56	65	0.2	33	2.7	4.6	68	18	n.a	n.a	n.a	<10	<10	10	n.a	n.a
TM-MWG11	11/04/11	66.7	433	7.1	47	56	0.1	27	3.3	4.5	54	9	n.a	n.a	n.a	<20	<50	30	n.a	n.a
TM-MWG12	15/04/11	77.1	501	6.9	51	88	0.1	31	11.3	5	60	11	n.a	n.a	n.a	<20	<50	10	n.a	n.a
BH 39	20/04/11	119.7	778	7.6	51	61	1.2	56	5.7	8.7	134	28	n.a	n.a	n.a	<10	<10	10	n.a	n.a
BH4	19/04/11	83.3	541	6.9	64	69	0.2	27	18.3	4.9	73	12	n.a	n.a	n.a	<20	<50	<10	n.a	n.a
Recommended drinking water quality limits (SANS:241, 2006)																				
Class I: (Recommended operational limit)		<150	<1000	5.0-9.5	<150	<200	<1.0	<70	<10	<50	<200	<400	<5.0	<5	<100	<1000	<200	<100	<150	<20
Class II: (Max. allowable)		150-370	1000-2400	4.0-10	150-300	200-600	1.0-1.5	70-100	10.0-20	50-100	200-400	400-600	5.0-10	5.0-10	100-500	1000-2000	200-2000	100-1000	150-350	20-50
Class II: (Consumption period, max.)		7 years	7 years	No limit	7 years	7 years	1 year	7 years	7 years	7 years	7 years	7 years	1 year	6 months	3 months	1 year	7 years	7 years	1 year	1 year

n.a = not analysed

All groundwater samples were compared to the water quality guidelines for acceptable drinking water specified by the South African National Standard (SANS 241:2006). It describes two classes of drinking water: class I is considered to be acceptable for lifetime consumption, and is the recommended compliance limit. Class II is considered to represent drinking water for consumption for a limited period. This class specifies a water quality range that poses an increasing risk to consumer's dependant on the concentration of the determinant within the specified range.

Reported results for the other dissolved inorganic constituents analysed (e.g. those not discussed above) were either within commonly accepted limits for drinking water quality, or below the detection limits of the laboratory's analytical equipment.

Less than half the samples obtained from the hydrocensus and the pumping tests are within the recommended drinking water quality limit, while five samples exceed the maximum allowable limit. The most noticeable elements of concern for water consumption are nitrate (measured as nitrogen (N)). Elevated nitrate levels is common throughout the Limpopo Province and may in most cases be related to anthropogenic activities such as inappropriate on-site sanitation and livestock concentration at watering points near boreholes (Holland, 2011). However, non-anthropogenic sources possibly related to evaporative enrichment of dry and wet deposition, biogenic point sources through N-fixing organisms or to a geogenic origin may play a role in contributing to the elevated nitrate concentrations. Elevated fluoride is observed in three samples. In contrast to nitrate, the occurrence of fluoride is primarily controlled by geology and climate. Therefore, there are no preventative measures under the given spatial limits of a water supply to avoid contamination. Several samples show major ion concentrations (e.g. Na, Cl) and subsequently electrical conductivities beyond acceptable limits. This can be related to low recharge values resulting in long residence times for selected samples (e.g. is not actively being mixed with recently recharged water). Sample TM-BH-13 to TM-BH-19 has elevated concentrations of trace elements such as Fe, Se and Cd and may indicate anthropogenic sources, however, the concentrations is within acceptable limits.

A geochemical and mineralogical characterisation of the Moonlight ore body (i.e. future tailings) has been carried out by AMEC and described in Report A029-11-R1090 (MEE, 2011) as part of the preliminary design of the TSF. The results of the characterisation have indicated that the tailings material is highly unlikely to give rise to acid rock drainage (ARD) due to the lack of significant quantities of sulphides in the ore body (below 0.05%), and the alkaline neutralizing potential of other minerals present in the tailings material. Furthermore, there is unlikely to be any metal leachability issues since the tailings contains only small amounts of Mg, Al, Ca, Ti and K. Leachate from the TSF is therefore unlikely to adversely impact the quality of the groundwater in the vicinity of the TSF. Although, some groundwater quality samples (e.g. TM-BH6 to TM-BH8) indicate elevated levels of Mg, Ca and K compared to the other samples (Table 3.9), Al and Ti was below detection limit for boreholes analysed.

An indication of water types can be obtained by plotting the samples on a piper diagram (Figure 3.6). The major water types identified are Ca-Mg-HCO_3 and Na-Cl/HCO_3. The dominant Ca-Mg-HCO_3 facies suggests weathering of silicate and ferromagnesian minerals (from the minerals that forms the mineralogy of Gneiss) as a major source of mineralization. The water chemistry appears to evolve from a Ca-Mg-HCO_3 towards a Na-Cl predominance. Samples with high TDS value (> 1000 mg/L) have a Na-Cl type of water and this might be due to the replacement of calcium by sodium through cation exchange in the aquifer matrix. Samples with significantly higher chloride and sodium content can indicate relatively old groundwater at the end of chemical development.

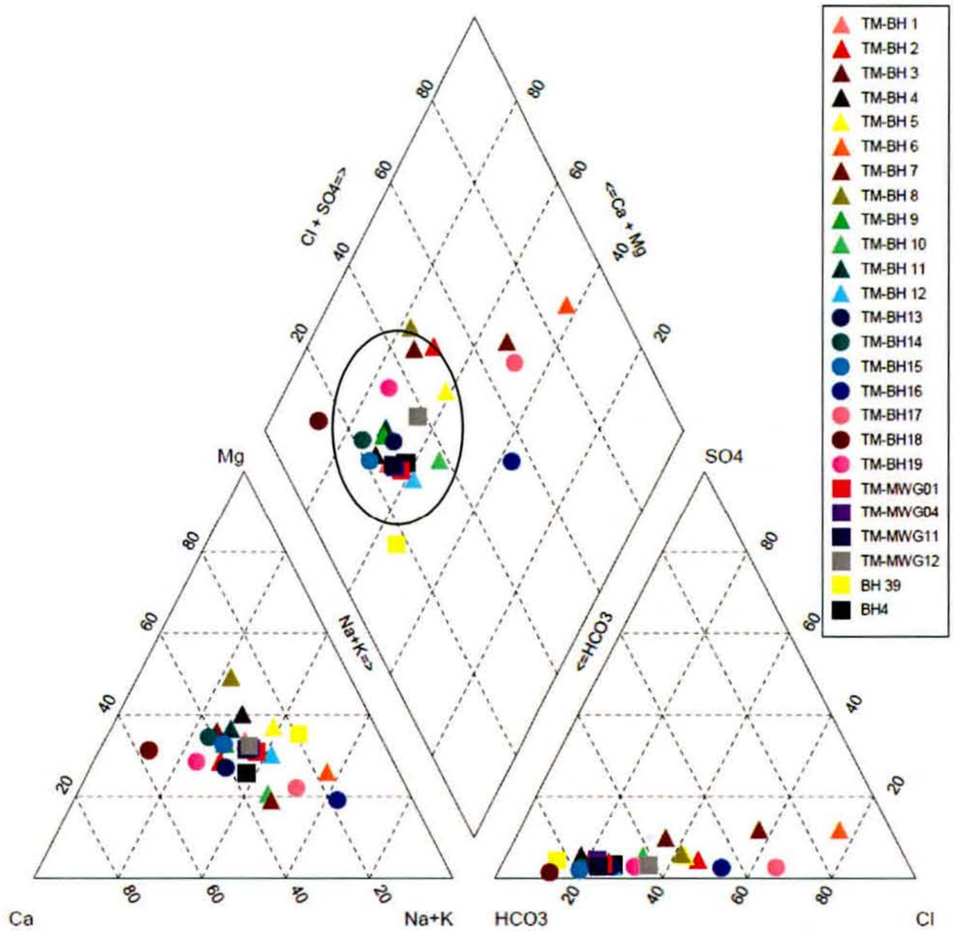


FIGURE 3.6: PIPER DIAGRAM OF HYDROCENSUS AND PUMPING TEST SAMPLES.

3.5 GROUNDWATER CONCEPTUAL MODEL

As a rule fresh unweathered basement rock (such as the granulite-grade metamorphic Limpopo Belt) occurring in the area has very low primary porosity, permeability and storage capacities. The possible occurrence of groundwater is thus related to secondary hydrogeological properties developed from the process of weathering, faulting, fracturing and the influence of intrusives (e.g. dykes). As a result two main aquifer types exist in the project area: an upper weathered/fractured rock aquifer, and a deeper fractured bedrock aquifer (Figure 3.7).

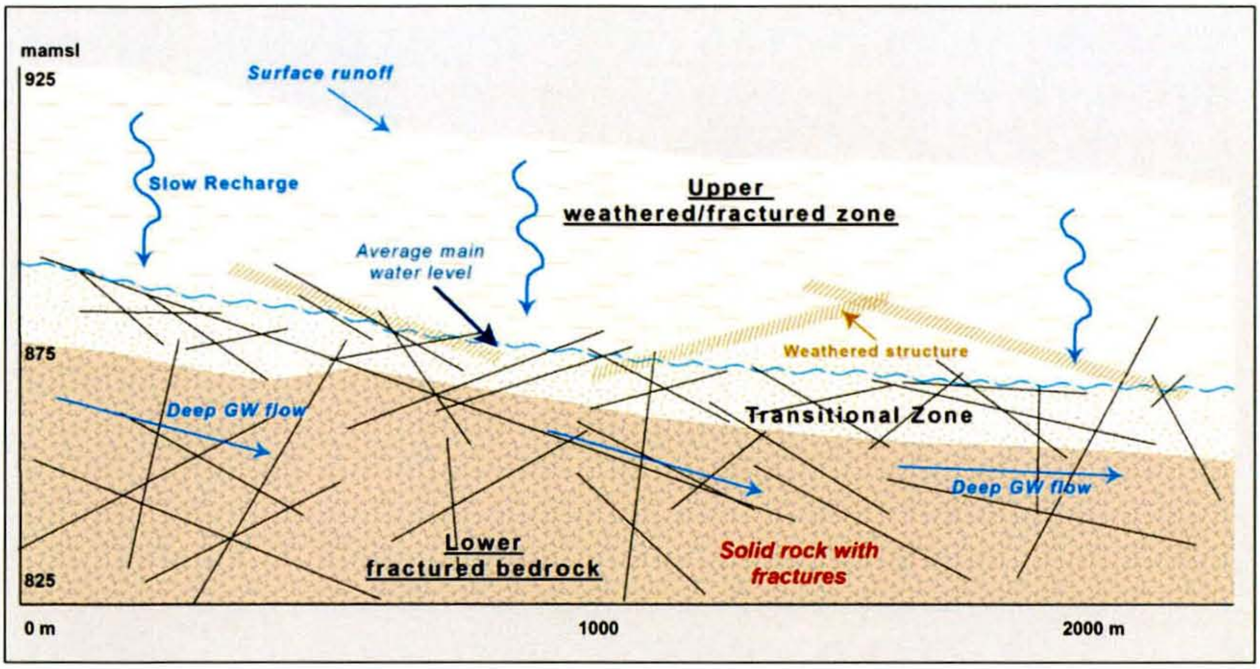


FIGURE 3.7: SIMPLIFIED CONCEPTUAL HYDROGEOLOGICAL CROSS SECTION AT MOONLIGHT.

3.5.1 UPPER WEATHERED/FRACTURED AQUIFER

Compared to tropical humid basement aquifers, the more arid Limpopo region is characterised by a thinner weathered overburden where flow is predominantly in the fissure/fracture flow in the upper bedrock. Regional water levels are often located at the base of weathering resulting in a relatively thin saturated aquifer. If the weathered overburden (regolith) does not contain any water then the water table may move free in the fractures. However, it is important to note that all percolating water must pass through the weathered overburden before the deeper fractured system is reached. The fractured bedrock is generally saturated and is likely to be confined or semi-confined, whilst the upper aquifer is unconfined.

In-situ weathering of the hard rocks in the Moonlight project area is thought to be relatively deep, extending to depths of 50 m or more, as a result of the relatively high topographic setting. This area is also characterised by deeper water strikes (> 60 mbgl) compared to the lower lying areas, where water bearing features may be struck at depths of 20 to 30 mbgl. From a hydrogeological point of view the weathered/fractured upper zone can be regarded as a single relatively permeable zone, in which groundwater is found in the weathered matrix as well as within fractures/fissures, weathered bedding planes and other linear features in the upper bedrock (transitional zone).

3.5.2 DEEPER FRACTURED AQUIFER

Groundwater storage and flow in the deeper aquifer is thought to depend on faults, bedding planes, fractures, contact zones and other discontinuities in the bedrock, since primary porosities are likely to be very low in these well-lithified metamorphic rocks. The success of a deeper borehole striking sufficient water therefore depends mainly on the number and interconnectivity of such features intersected during drilling. Boreholes drilled to a depth of 200 m within the proximity of the proposed Moonlight pit struck water between 80 and 120 mbgl suggesting the occurrence of water bearing fractures at depth below the weathered zone. Hydraulic properties in the deeper aquifer are highly variable, reflected in the range of blow yields obtained from boreholes in the area (see Table 3.5). Recharge to the deep aquifer from the overlying shallow aquifer is likely to be via discrete pathways, resulting in a damped response to rainfall, and is thought to be relatively poor due to the considerable thickness of the upper weathered zone. Bulk storage of groundwater is relatively low, and groundwater flow directions will be on a more regional scale compared to the shallow aquifer, driven by regional topographic highs (Figure 3.8). Groundwater residence times are likely to be of the order of years, or more, leading to more mineralized groundwater.

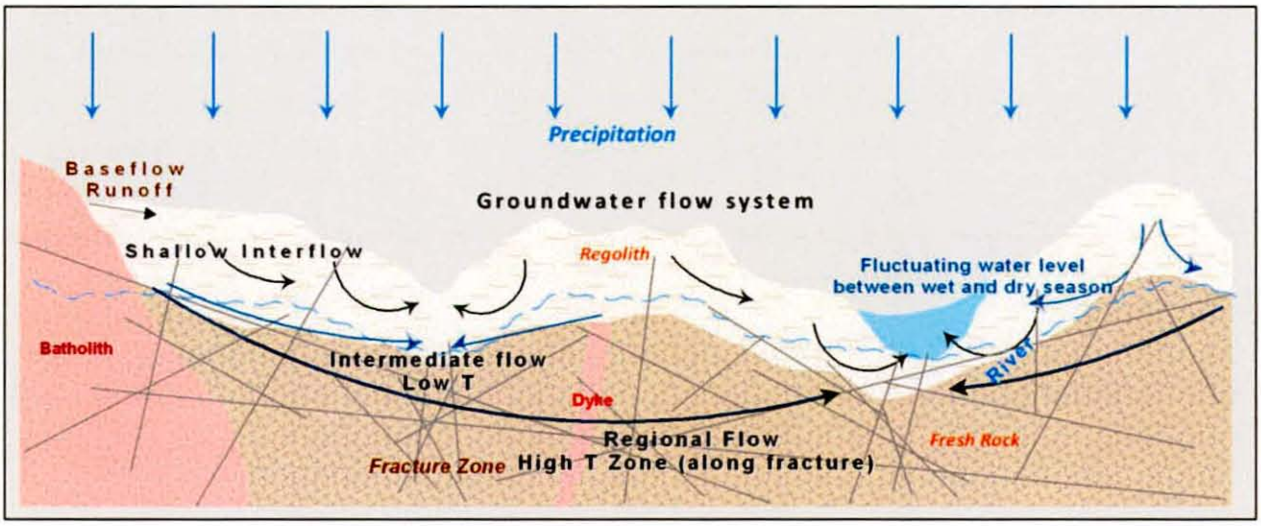


FIGURE 3.8: SIMPLIFIED FLOW SYSTEM FOR CRYSTALLINE BASEMENT TERRAIN.

4 GROUNDWATER FLOW MODEL

4.1 MODEL SOFTWARE CHOICE

The developed conceptual groundwater model was converted into a numerical groundwater model to assess groundwater flow rates and directions. The software code chosen for the numerical modelling work was the modular 3D finite-difference ground-water flow model MODFLOW, developed by the United States Geological Survey (USGS) (MacDonald and Harbaugh, 1988). The code was first published in 1984, and since then has undergone a number of revisions. MODFLOW is widely accepted by environmental scientists and associated professionals. MODFLOW uses the finite-difference approximation to solve the groundwater flow equation. This means that the model area or domain is divided into a number of equal-sized cells – usually by specifying the number of rows and columns across the model domain. Hydraulic properties are assumed to be uniform within each cell, and an equation is developed for each cell, based on the surrounding cells. A series of iterations are then run to solve the resulting matrix problem, and the model is said to have "converged" when errors reduce to within an acceptable range. MODFLOW is able to simulate steady and non-steady flow, in aquifers of irregular dimensions, as well as confined and unconfined flow, or a combination of the two. Different model layers with varying thicknesses are possible. The edges of the model domain, or boundaries, typically need to be carefully defined, and fall into several standard categories. Various pre- and post-processors are available for MODFLOW, aimed at making data input and 2-D and 3-D visualisation faster and simpler. In the case of the Moonlight groundwater flow model, the internationally accepted package GMS 7.1 (Groundwater Modelling System) was used.

4.2 GEOMETRIC STRUCTURE

Considering that the Moonlight project area straddles the surface watershed, the model network extends over a larger area than only the proposed mining area to ensure that the model boundaries will not affect simulated results. In order to represent both drainage catchments as well as the proposed mining operation, a regional three-layer steady-state groundwater model was chosen. The model domain was discretised into a 850 X 550 grid block uniform mesh (35 x 85 km in extent), with uniform horizontal grid blocks sizes of 100 m X 100 m and a total model thickness of 300 m below surface. The top elevation of the model is based on the 25 m x 25 m digital elevation model obtained from Directorate Survey and Mapping, with the bottom elevation offset by an inferred depth to weathering layer, ranging between 35 and 65 mbgl. The fractured lower aquifer was divided into two layers mainly for numerical purposes. The bottom of the second layer was off-set to 180 m below surface to represent the deeper fractured aquifer (and to incorporate the pit depth), while the third layer extending to 300 m below surface represents the low permeability solid bedrock.

The two upper model layers were subdivided into 8 lateral zones to reflect the different hydrogeological units and geological structures (Figure 4.1). The granulite gneiss differentiation is mainly based on the variation in groundwater potential observed in the larger area (see Figure 3.1). The Baltimore and Tolwe area is known for its large scale irrigation from groundwater abstraction, while southeast of Marnitz, along the surface watershed, the groundwater potential is considerably less. The brittle fault zone known as the Melinda Fault can be regarded as highly permeable geological structure and has been the target of numerous water supply projects in the past. The fault zone together with the contact zone of the younger strata and the metamorphic rocks of the Limpopo Mobile Belt may provide significant groundwater storage and flow. However, the Melinda fault stretches for 100s of kilometres and is not regarded as a water bearing feature throughout its extent (Whitehead, 2008). Although the groundwater potential of the Melinda fault requires more intrusive investigation, it was incorporated into the groundwater model (Figure 4.1).

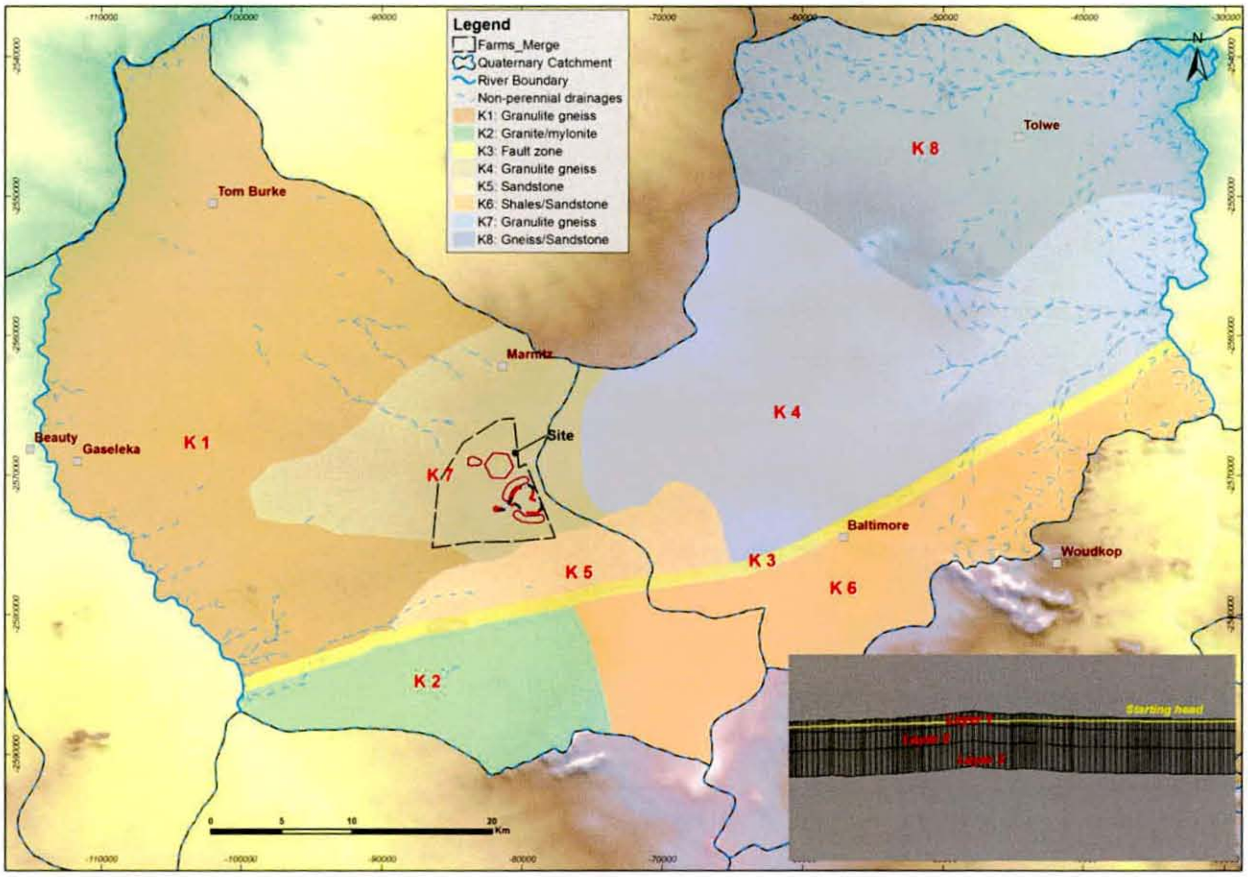


FIGURE 4.1: HYDRAULIC CONDUCTIVITY ZONES AND LAYERS USED IN THE MOONLIGHT MODEL.

Based on the established correlation between topography and groundwater elevation (see Figure 3.4), surface water catchment boundaries also define groundwater divides and were therefore incorporated into the model as outer (no-flow) boundaries (Zero specified flux Neuman Type II boundary condition). The western and eastern boundary follows the Lephalala, Limpopo and Mogalkwena River line, i.e. groundwater can discharge into the river line, but not flow across it. Such a situation represents a typical gaining river system, where groundwater on either side of the river/drainage discharges into it, but does not underflow it. This boundary is represented numerically by what is referred to as a "constant head" boundary condition (Dirichlet Type I boundary condition).

4.3 GROUNDWATER SOURCES AND SINKS

Groundwater enters the model domain as direct recharge from rainfall, with a mean annual precipitation (MAP) of 419 mm as recorded by South African Weather Services (SAWS) for the region (see Table 3.2). Groundwater recharge is estimated to be approximately 1 % per annum (Vegter, 1995; GRA II). Conservative recharge rates assigned to the model were 0.8 % of MAP for the higher lying region along the southern edges of the model domain, while 0.6 % of MAP was used over most of the model. This translates to an annual recharge rate of approximately 3 mm per annum respectively.

Water leaves the model domain via perennial (e.g. Limpopo, Lephalala and Mogalakwena) and non-perennial rivers. The non-perennial river courses were therefore described using MODFLOW's drain package. The chosen approach ensures no water losses from the non-perennial rivers into the model domain, as would be the case if these river stretches were modelled with MODFLOW's river package. The river boundaries were assigned constant heads to represent an outflow boundary. It is assumed that most of the groundwater recharge, occurring within the study area discharges internally to the surface drainage systems. The elevation of each drain cell was carefully aligned with the height of the model DEM at that point with an incision of 2 m below surrounding topography. An equivalent river bed conductance of 1 m^2/day per meter of river (drain) length was assumed, describing the hydraulic connection between the aquifers and river system.

4.4 INITIAL CONDITIONS

The initial conditions specified in the model were as follows:

- Starting heads were interpolated from measured field data using Bayesian interpolation (Figure 3.4), i.e. co-kriging using the established correlation between surface topography and groundwater elevation.
- Average hydraulic conductivities for the different aquifers as determined by hydraulic tests, the GRIP dataset and literature values (see section 3.2.4).
- A vertical anisotropy factor of 5 was used in the regional groundwater flow model.
- Effective porosity were taken from literature and specified as 2 % for the weathered/fractured layer and 1 % for the lower fractured layers. Porosity values affect only the transport model and do not influence the outcome of the steady-state flow model.

4.5 MODEL CALIBRATION

Using the 171 groundwater level data points as described in section 3.3, a steady-state calibration of the groundwater flow model was performed. The model was run with the initial conditions and the hydraulic conductivities adjusted using sensible boundaries and the automatic MODFLOW calibration package PEST until a best fit between measured and computed heads was achieved. A good correlation coefficient R^2 between modelled and observed values of 98 % with a squared root mean error of 8.6 m was achieved for the steady-state calibration of water levels (Figure 4.2). It should be noted that the water level data have been accumulated over a number of years under various conditions and may potentially be influenced by long-term climatic fluctuations, seasonal rainfall and changes in groundwater abstraction by farmers, communities and mines.

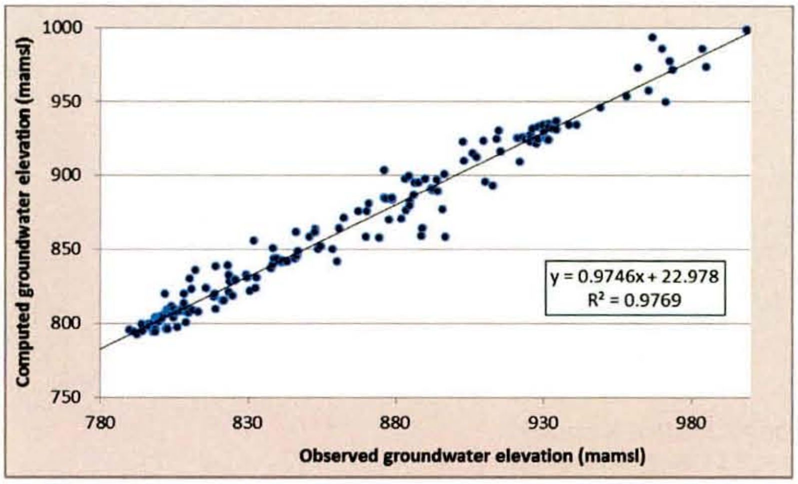


FIGURE 4.2: STEADY-STATE CALIBRATION OF THE MOONLIGHT REGIONAL MODEL.

The corresponding calibrated hydraulic conductivity values (Table 4.1) compare reasonably well with the conductivities determined by the hydraulic tests and literature values (section 3.2.4). The regional steady-state groundwater contours (Figure 4.3) are as expected closely related to the topography, and groundwater flows from higher lying ground towards lower lying areas, where it discharges into the drainage lines respectively rivers. The influence of the fault zone on the groundwater contours is clearly evident. The less permeable gneisses north of the fault zone result in a slight retardation of flow, and flow is enhanced in the orientation of the fault zone. Based on the hydraulic gradient the Melinda Fault is recharged mainly via the Waterberg Group sandstones to the south. Groundwater flow from the centre of the modelled domain is away to the east and west of the hydraulic groundwater divide (more or less to the east of the surface water divide).

TABLE 4.1: SUMMARY OF CALIBRATED HYDRAULIC CONDUCTIVITY VALUES

K-Zone	Hydraulic Conductivity (m/d)
	Layer 1
Granulite gneiss	0.01 - 0.3
Granite, mylonites	0.2
Fault zone	0.5
Sandstone	0.08
Shales	0.09
	Layer 2
Granulite gneiss	0.005 - 0.05
Granite, mylonites	0.01
Fault zone	0.5
Sandstone	0.008
Shales	0.009
	Layer 3
Combined	2.0E-04

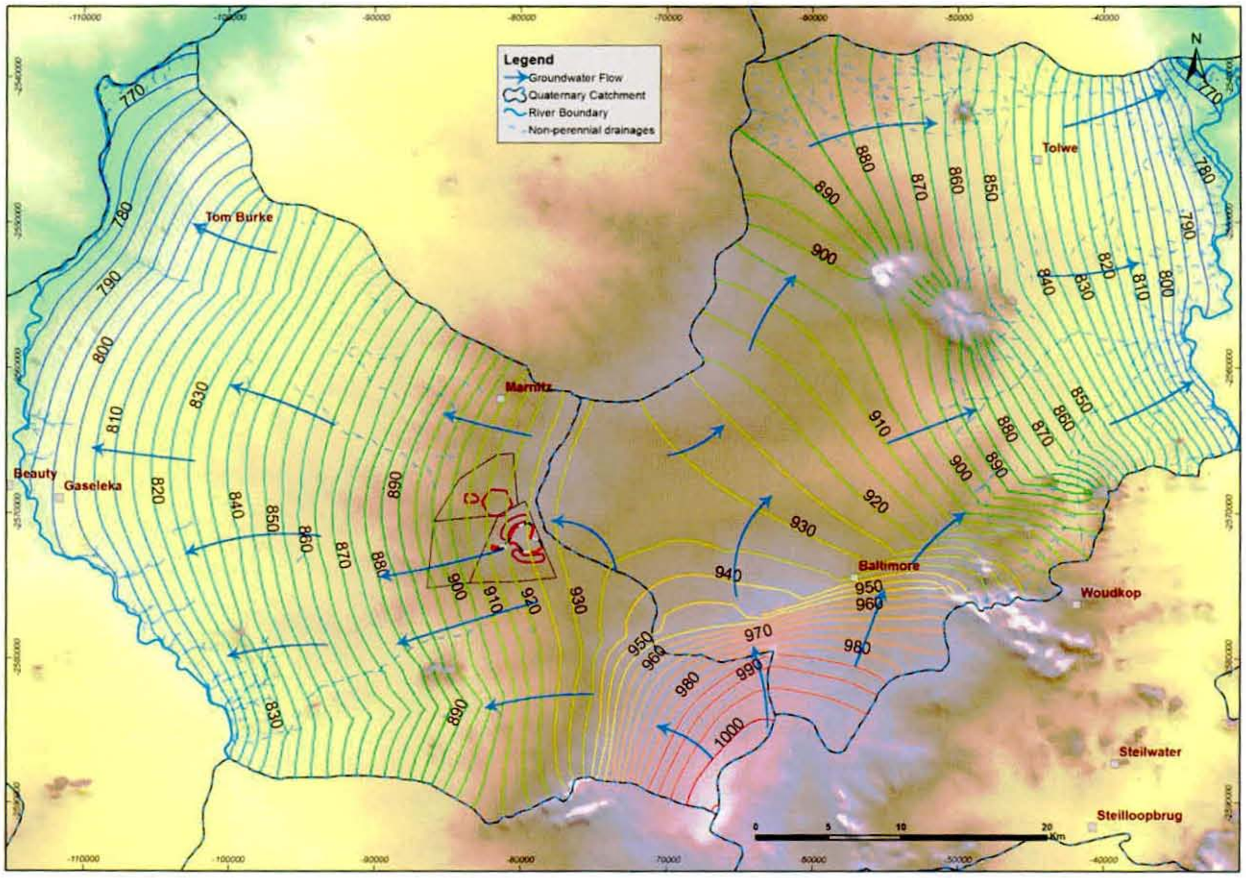


FIGURE 4.3: MODELED GROUNDWATER CONTOURS.

After the set of parameters that resulted in the best match to the observed water levels was determined, a sensitivity analyses was performed. The sensitivity analysis indicated that the numerical groundwater model is sensitive for changes in hydraulic conductivity and recharge.

4.6 PIT INFLOWS (STOCHASTIC MODEL APPROACH)

Following the calibration of the flow model, the proposed opencast (pit) was integrated into the model domain and a leakage boundary assigned to it. It is assumed that any water inflows entering the mine are removed by pumping and that the pit represent therefore the lowest drainage elevation.
The estimated inflow rates are based on annual average (steady-state) groundwater inflows into the pits and do not account for direct rainfall (only the groundwater recharge component thereof) and surface run-off into the pit or for potential seepage from a perched aquifer. Any steady-state groundwater model is likely to overestimate groundwater inflows, as it does not account for the increasing dewatering of the aquifer with time due to pit inflows and hence reduced yields. However, in the absence of groundwater level measurements over time (e.g. hydrological year) the chosen approach is justified.

Due to the inherent uncertainty associated with regional numerical groundwater flow models, a stochastic model approach was chosen to estimate ranges of pit inflow rates for the life of mine (30 years). A stochastic model approach tackles uncertainty by using a set of equally probable models with randomised parameters. Each realisation of the normal distributed hydraulic conductivity values defines a model instance for which the inflow rates are calculated. In general 50 model instances were calculated for the life of mine. The data presented in Table 4.2 comprises the median inflow rates into the open pit after 30 years when the excavation had reached a maximum depth of 160 mbgl, and the 25 and 75 % quartiles of modelled inflow rates as a measure of dispersion of the calculated values (giving the central 50 % of all model realisations). In general, median values are considered to be robust averages not affected by single outliers, as experienced in selected stochastic model runs. Once the final life of mine (pit development) for the various phases becomes available the model should be updated to reflect each stress period.

TABLE 4.2: GROUNDWATER INFLOW RATES INTO OPEN PIT (TO A DEPTH OF 160 M).

25% Quartile [m^3/d]	75% Quartile [m^3/d]	Median Inflow [m^3/d]	Median Inflow [l/s]
480	831	699	8.1

In general, groundwater inflow to open pits having low permeability rocks with relatively low fracture density and connectivity has shown that fractures can initially yield substantial volumes of water that decrease rapidly over time. The degree to which this occurs depends on how well connected the fracture network is over large areas. The mod flow model assumes that the fracture network is connected enough to be simulated as a porous media at the regional scale. In practice, the long-term groundwater inflow is likely to be less than the simulated rate. Variations in aquifer transmissivity and faults may result in aquifer compartmentalization.

4.6.1 IMPACTS ASSOCIATED WITH PIT INFLOWS

The modelled inflow rate of ~8 L/s (~690 m^3/d) (see Table 4.2) for the open pit equates to a moderate reduction in recharge of the local area, leading to the lowering of groundwater heads shown in Figure 4.4. Dewatering of the pit will create drawdown in the regional groundwater system, propagating outward from the open pit. Dewatering effects will be most dramatic in the vicinity of the open pit, decreasing rapidly away from the pit. Since drawdown propagation away from the open pit depended on the transmissivity and storage properties of the rock units, the cone of depression was not concentric. The furthest extent of the zone of influence (as defined by the 2 metre drawdown contour) at the end of the mining phase (30 years) was predicted to be approximately:

- 3 km west and 3.5 km to the southwest, and
- 2 km east and 4 km northwest from the open pit

Assuming re-use or other environmentally acceptable disposal practices of the groundwater entering the pits, the environmental impacts associated with the pit inflows are primarily associated with the interception of ambient groundwater flow. The pits capture groundwater, which would have under natural conditions, provided baseflow to the rivers, or contributed to deeper regional groundwater flow. It is expected that the potential impacts of the pit inflows on the regional groundwater flow are:

- Highly likely to occur.
- Widespread and will impact beyond the site boundaries.
- Of moderate severity with partial loss of discharge and regional groundwater flow for the affected catchment.
- Reversible over time once pit dewatering stops.

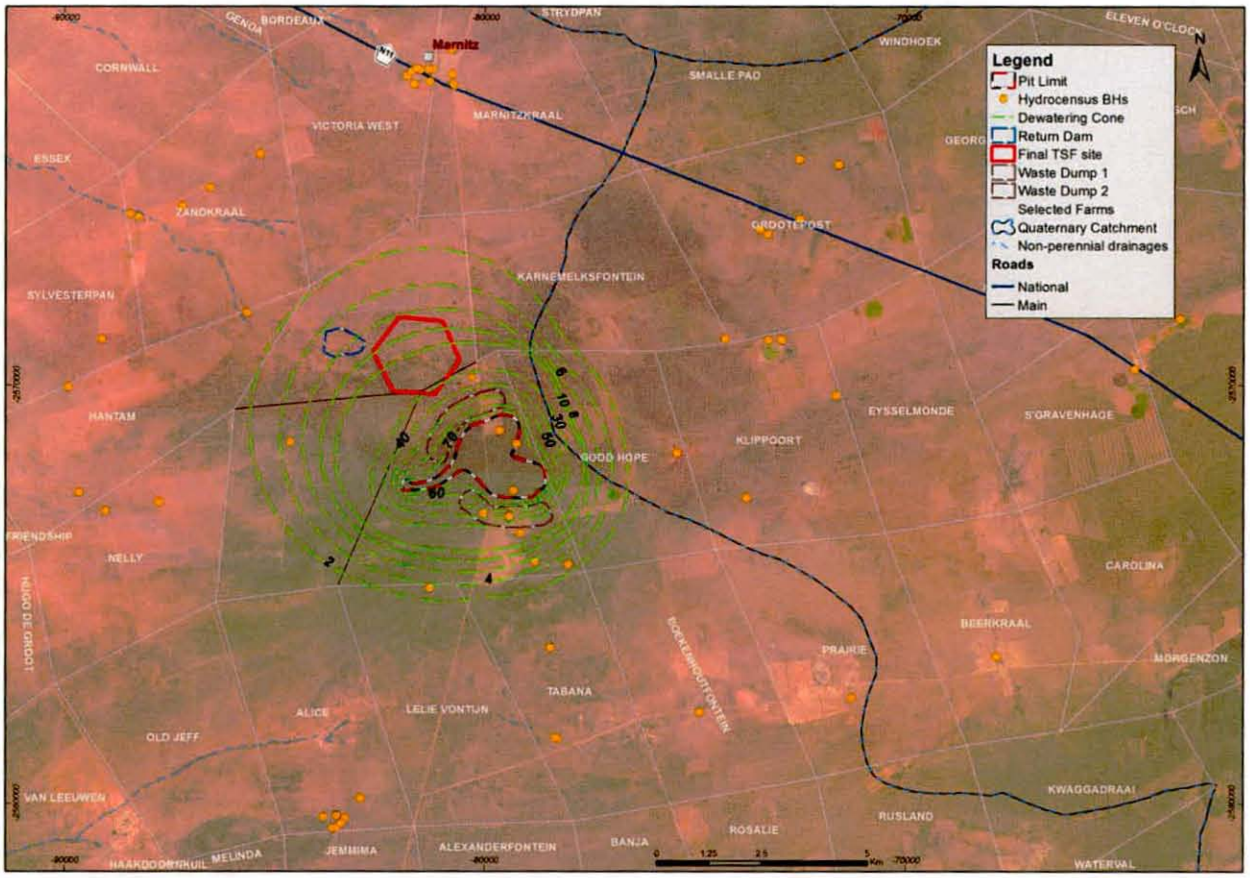


FIGURE 4.4: DEVELOPMENT OF CONE OF DEPRESSION DUE TO PIT INFLOWS FOR LIFE OF MINE (30 YEARS, NO MITIGATION).

The extent of the impact of the drawdown depression due to pit dewatering may be greatly reduced due to enhanced recharge (seepages) from the TSF and WRD located within the proximity of the open pit. By incorporating the expected leakage rate of 150 m^3/day from the TSF (based on the seepage analysis assessment by MEE, 2011) and assigning higher recharge rates for the WRDs, the zone of influence of the dewatering cone is greatly reduced (Figure 4.5). The mounding of the water table underlying the TSF is evident towards the northwest of the open pit. Predicted groundwater level drawdown for later years of mining can significantly be improved by observation data from earlier years and subsequent updates of the groundwater model.

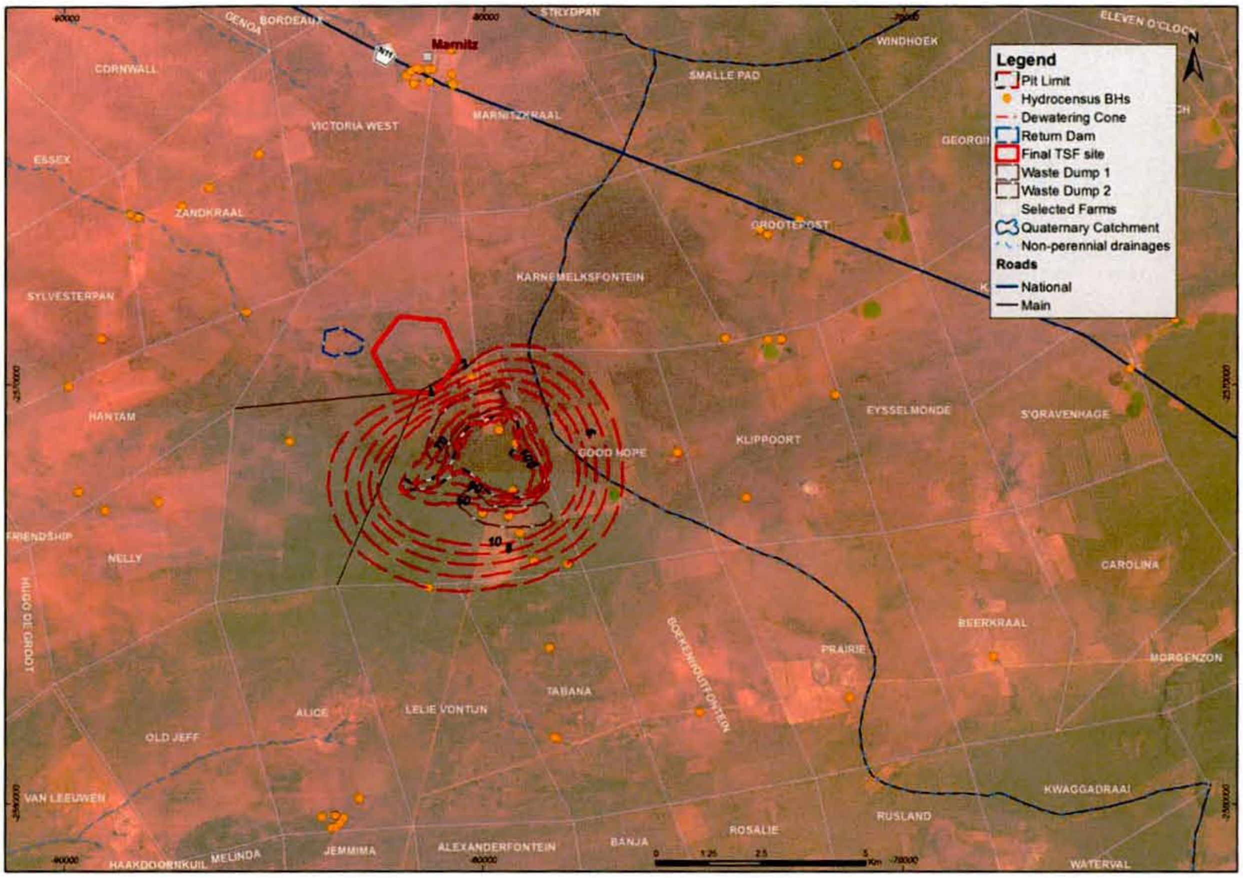


FIGURE 4.5: DEVELOPMENT OF CONE OF DEPRESSION DUE TO PIT INFLOWS FOR LIFE OF MINE (30 YEARS, INCORPORATING TSF SEEPAGE RATES).

4.6.2 POST CLOSURE

After cessation of mining operations the water level in the pit is expected to slowly rebound to create a new stable water table. It is difficult to predict whether a significant pit lake will form as no comprehensive pit-lake study has been performed to date. The rate at which the pit fills, and the ultimate depth and stage of the pit-lake, depends on the pit-lake water balance. Depending on the relative magnitudes of the water balance components, a pit could remain dry or a pit-lake could form. It is expected that due to evaporation eventually exceeding inflow (evapotranspiration is predicted to be greater than rainfall and runoff); the open pit will therefore always act as a sink with a zone of depressed water levels. This drawdown and associated cone of depression can be advantageous by capturing potential process area contaminants and preventing their migration away from the immediate facility area. The influence of the pit water at closure on regional groundwater quality is thus thought to be small. The quality of the pit water will largely depend on the leachate from both the TSF and WRDs, in addition to the acid generation potential of the pit walls. Although, the development of an acidic pit is not expected based on the geochemical characterisation results, variations in conditions (e.g. recycling of water, evaporation, surface water run-off) can result in an overriding control on the geochemical evolution of the pit lake. A slight change is expected in the quality of the pit water compared to local groundwater after post-closure.

5 CONTAMINANT TRANSPORT MODEL

The impacts on the groundwater quality due to leakage from the tailings storage facilities (TSFs) were evaluated with the three-layer transport model using the internationally accepted MT3DMS code. The proposed Moonlight TSF, return water dam together with the waster rock dumps were incorporated into the model domain as a recharge boundary. The estimated leakage rate of the proposed TSF of 150 m^3/d was used as the recharge rate over the entire footprint area of the TSFs. Similarly, higher recharge rates were assigned to the waste rock dump (WRD) representing leakage or seepage. Following the precautionary principle, only advective-dispersive (longitudinal dispersivity 50 m) transport of potential pollutants without any retardation or transformation is considered. The impacts of potential pollution sources on the groundwater quality are therefore conservative.

In the absence of data for the leachate composition, a constant unit (recharge) source concentration was assumed and all initial concentrations set to zero. The calculated concentrations presented are therefore fractions of the unit source concentration and must be added to any potential background concentration. All source concentrations were specified as 100% and the modelled plumes represent therefore percentages of actual source concentrations. Since no element specific retardation or transformation is modelled, concentrations for individual elements of concern can be easily derived by multiplying given percentages with the respective source concentration for an element.

5.1 CONTAMINATION SIMULATION (OPERATION FOR 30 YEARS AND NO MITIGATION)

The contaminant transport model has been used to simulate the impacts of the TSF and WRDs on groundwater quality. The following scenario has been considered:

- Operational for a 30 year life of mine followed by closure and rehabilitation. The closure and rehabilitation plan described below is of a conceptual nature only, and presumes that the TSF will remain as a permanent on-surface facility.
    - This scenario accounts for reduced seepages from the TSF and WRDs after mine closure. The actual TSF seepage rates to the ground may reduce by 60 %, over 15 years after decommissioning of the TSF. A of continuous TSF source strength (concentration) was assumed, although a reduction may occur over time. It provides therefore a worst case scenario for the groundwater impact assessment.

5.1.1 IMPACT ASSOCIATED WITH SEEPAGE FROM THE PROPOSED TSF AND WRDS

Despite the conservative approach of constant source strengths and consideration of advective-dispersive transport only, lateral spreading of potential pollutants is limited to the close proximity of the TSF and WRDs (Figure 5.1). A contaminated groundwater plume is not expected to extend beyond the site boundaries as the open pits will act as long term groundwater sinks and will therefore "capture" contaminated groundwater emanating from the TSF and WRDs. However, structural heterogeneities (e.g. fault zones) in the subsurface unaccounted for in the model can greatly enhance contaminant transport and invalidate the model predictions. Groundwater quality monitoring in the vicinity of the TSF and WRDs is therefore strongly recommended in order to verify the model predictions. The potential impacts associated with the TSF and WRD on the ambient groundwater quality are:

- The intensity of the impact is a minor deterioration of the ambient groundwater quality within the site boundary.
- Highly likely to occur but of minor severity.
- Long-term beyond closure with minimal increases of pollutant concentration.

In addition no neighbouring boreholes outside the project area are impacted from these potential contaminant sites and the selected TSF and WRD sites should be suitable from a hydrogeological point of view.

6 RECOMMENDATIONS

Recommendations are given based on information on hand, considering the proposed mining operation and protection of the groundwater resource.

Predicted inflow rates for later years of mine development can significantly be improved by observation data from earlier years and subsequent updates of the groundwater model. In addition:

- On-going modelling (monitoring) of the TSF contaminant plume can be used to determine the need for a seepage interception system.
  - Additional mitigation measures such as cut-off trenches and/or scavenger wells can be implemented to address the long term plume migration.
- Element specific retardation or transformation should be modelled for elements of concern. These predicted concentrations should replace the percentages of actual source concentrations used in this assessment.
- Establishment of a transient groundwater flow model once groundwater levels over a (hydrological) year become available.

6.1.1 PROPOSED MONITORING PROGRAMME

To monitor the impact of the dewatering depression and potential contaminants spreading off-site, monitoring boreholes should be drilled towards the east of the open pit and towards the west and southwest of the TSF and WRDs. Due to the low success rates of water yielding boreholes, appropriate drilling budgets should be made available to allow for dry boreholes and drilling to greater depths. The geophysical survey conducted during this study provides additional drilling targets (Appendix B). However, additional geophysics might be required to pinpoint monitoring boreholes. The suggested target areas for monitoring boreholes are provided in Figure 6.1.

- Boreholes should be ideally be equipped with water level and EC loggers, however due to the costs involve the following manual monitoring runs are proposed:
  - Monthly water levels and quarterly groundwater sampling runs.
- The sampling run should include field measurements pH, EC, redox potential, and TDS. While laboratory analysis should include pH, EC, TDS, alkalinity, major ions and trace elements, as listed in section 3.4. Analysis of biological constituents (e.g. *Total Coliform Bacteria, E.coli*) should be taken to establish background conditions.
- Water quality analyses results should be classified in terms of the DWAF Guidelines for Domestic Water Supply (1999) or the SANS 241, 2006 standards for Drinking Water Specifications.

Implementation of such a groundwater monitoring programme is essential, as it forms a legally defensible database against which any claims of surrounding land owners or the Department of Water Affairs and mitigation measures can be gauged.

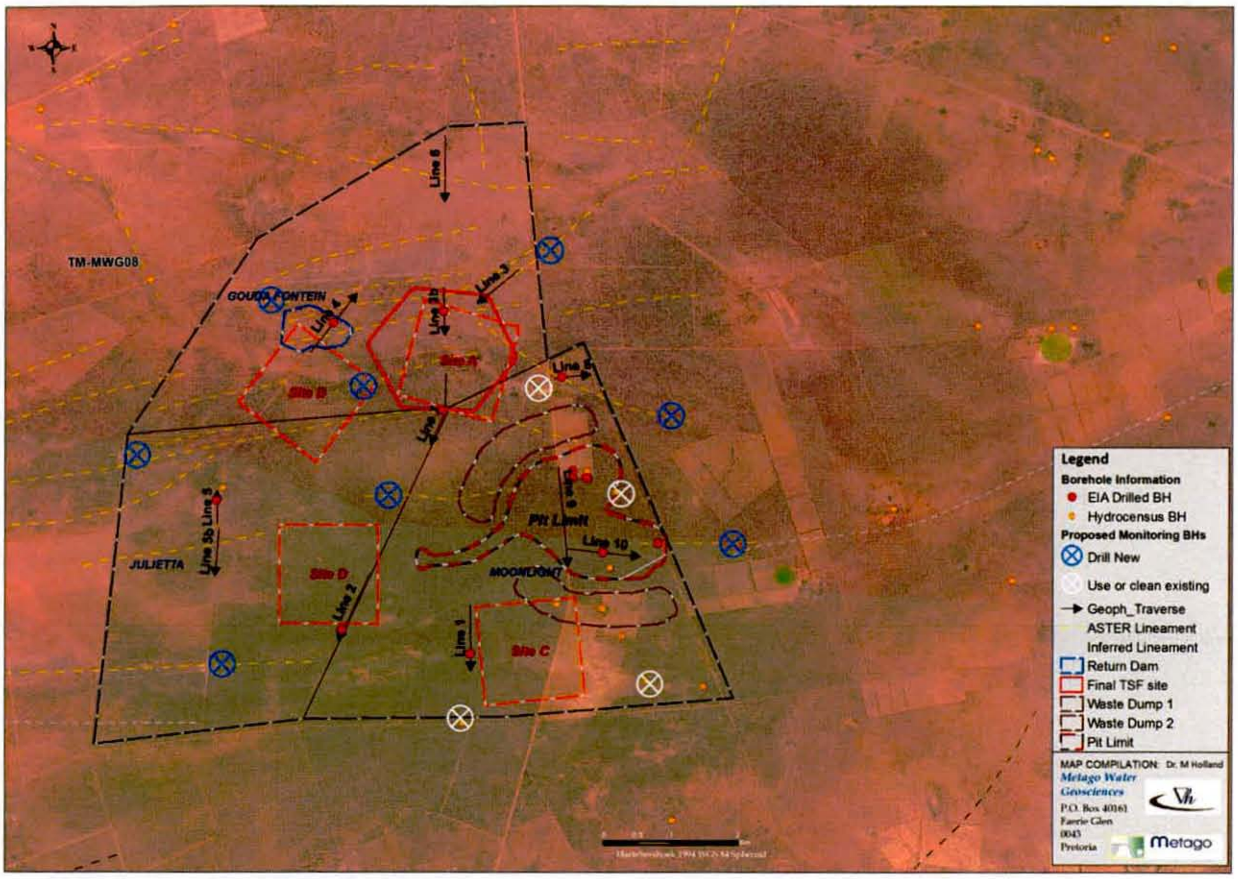


FIGURE 6.1: PROPOSED BOREHOLE LOCALITIES FOR THE MONITORING PURPOSES.

7 CONCLUSION

The main finding of the hydrogeological investigation can be summarised as follows:

- The Moonlight operation is situated on the eastern edge of quaternary catchment A50H, a sub-catchment of the Lephalala River. Immediately to the east lies the A63A quaternary catchment which drains towards the Mogalakwena River.
- The mean annual rainfall is highly variable, which makes the area prone to droughts. As a result groundwater recharge is minimal with many below average rainfall years not contributing to recharge at all. Declining water levels have been noted since the early 1950s and recent observations suggest that the drop in water levels may be attributed to over-abstraction locally in addition to below average rainfall years.
- Based on the volume of registered water use (mainly for irrigation) and considering the variability of rainfall, the groundwater resources in the two catchments can be regarded as heavily utilised. However, withdrawals from an aquifer might have a severe impact on local water systems, but per square kilometre these withdrawals might be minor in terms of total recharge and discharge.
- According to the hydrocensus results the majority of boreholes within the vicinity of the Moonlight project area are for either domestic use and/or cattle/game feedlots. Larger scale abstraction for irrigation purposes occur towards Baltimore, Tolwe and the Lephalala River.
- The project area is underlain by highly heterogeneous weathered/fractured basement aquifer with a mean water level of 37 mbgl. The low success rate, the low strike frequency and, consequently deep drilling can be ascribed mainly to the deeply weathered and fractured zones lacking permeability.
- The aquifer can be divided into an unconfined weathered/fractured upper zone and an underlying semi-confined fractured bedrock aquifer formed by secondary openings in the crystalline rocks of the Limpopo Mobile Belt.
- Regional groundwater flows from the higher lying areas to lower lying discharge areas and generally reflection of the topography.
- More than half the groundwater samples taken during the investigation suggest acceptable limits. However, many are within the maximum allowable limits while some exceed the prescribed drinking water quality. This is mainly as a result of elevated nitrate concentrations. Elevated Na and Cl in samples can be considered as relatively old groundwater at the end of chemical development and/or due to low recharge.
    - Overall the groundwater quality is therefore considered to be good to marginal.
- The calibrates regional steady-state groundwater contours are as expected closely related to the topography, and groundwater flows from higher lying ground towards lower lying areas. The influence of the Melinda Fault on the groundwater contours is clearly evident, where flow is enhanced in the direction of the faults, due to the lower permeability gneisses to the north. Based on the hydraulic gradient the Melinda Fault is recharged mainly via the Waterberg Group sandstones to the south.

- The results of the numerical modelling suggest that by dewatering at a rate of approximately 8 l/s for 30 years of operation will create a cone of depression of approximately 3 km radius. It is expected that water levels in the pit will recover slowly after mine closure but will not recover to pre-dewater levels as evaporation will exceed inflows. As a result the pit will always act as a sink with depressed water levels around it and will therefore "capture" contaminated groundwater emanating from the tailings storage facility (TSF) and waste rock dumps (WRD). A slight change is expected in the quality of the pit water compared to local groundwater after post-closure.
- The results of the contaminant transport numerical modelling indicate that impacts due to TSF and the WRDs are likely to be localised and limited to the site extent.
    - Plume migration is predominantly vertical, with a trend of lateral migration at depth.
- The proposed monitoring programme will ensure the collection of water level data and groundwater water samples in the vicinity of the proposed TSF and open pit.

7.1.1 ASSUMPTIONS AND UNCERTAINTIES

It is important to note that a numerical groundwater model is a representation of the real system. It is therefore at most an approximation, and the level of accuracy depends on the quality of the data that are available. In addition, the model assumes that the fracture network is connected enough to be simulated as a porous media at the regional scale. As a result to develop a model of an aquifer system, certain assumptions have to be made and are necessary to allow numerical stability and robustness of the model. More specific assumptions relating to the groundwater model include:

- Prior to development the groundwater system is in equilibrium and therefore in steady state.
    - In any natural system, natural climatic variations (as well as human activities) are constantly affecting the equilibrium of the groundwater system. Nevertheless, steady state is an appropriate starting point for any numerical model where the objective is to determine the impact on groundwater associated with a specific stressor.
- In the absence of a time series of groundwater level data for the mining area, a steady-state model was chosen for the groundwater model.
- The aquifer is unconfined to semi-confined and recharged directly by rainfall. No other recharge sources exist.
- Constant head boundaries were used to simulate the Lephalala and Mogalakwena Rivers. Constant head boundaries can potentially allow a limitless supply (or sink) of groundwater to or from a system, however, these boundaries were regarded as a sufficient distance away from the proposed mining area to minimise this effect.
- A conservative approach was followed so that the real case should be better than the modelled case.
- The excavation of the open pit was simulated as a one-time excavation for a single time step. This condition will apply a very high stress on the system and is likely to overestimate

groundwater inflows, as it does not account for the increasing dewatering of the aquifer with time due to pit inflows and hence reduced yields.

  - In the absence of transient data at the time of the study (e.g. long-term groundwater levels and mine development plans) the chosen approach is justified and is considered an acceptable approach.
  - Results of this kind of simulation allow having a first estimation of pumping requirements or mine dewatering.

- A pit depth of 160 m was assumed over the proposed lateral extent of the open pit.
- In the absence of data for the leachate composition, a constant unit (recharge) source concentration was assumed. All source concentrations were specified as 100% and the modelled plumes represent therefore percentages of actual source concentrations.

Numerical groundwater models are the best tool available to quantify groundwater and mass balances, which can be used to make decisions. Improvements to the model predictions can be realized through appropriate hydrogeological analysis and data collection to fulfil critical information gaps.

(Project Hydrogeologist) **(Project Reviewer)**

Metago Water Geosciences (Pty) Ltd

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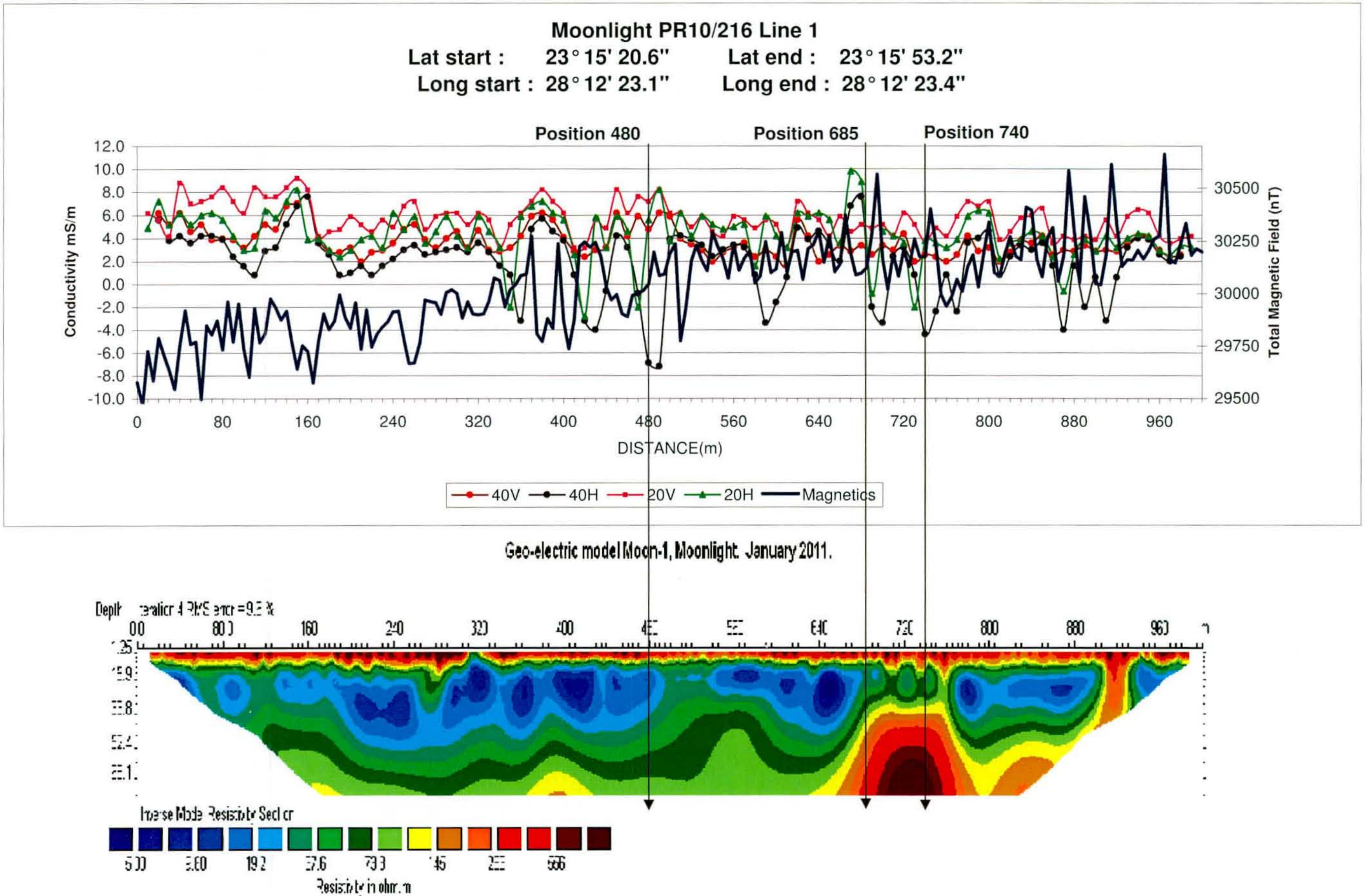
APPENDIX A: SUMMARY OF HYDROCENSUS

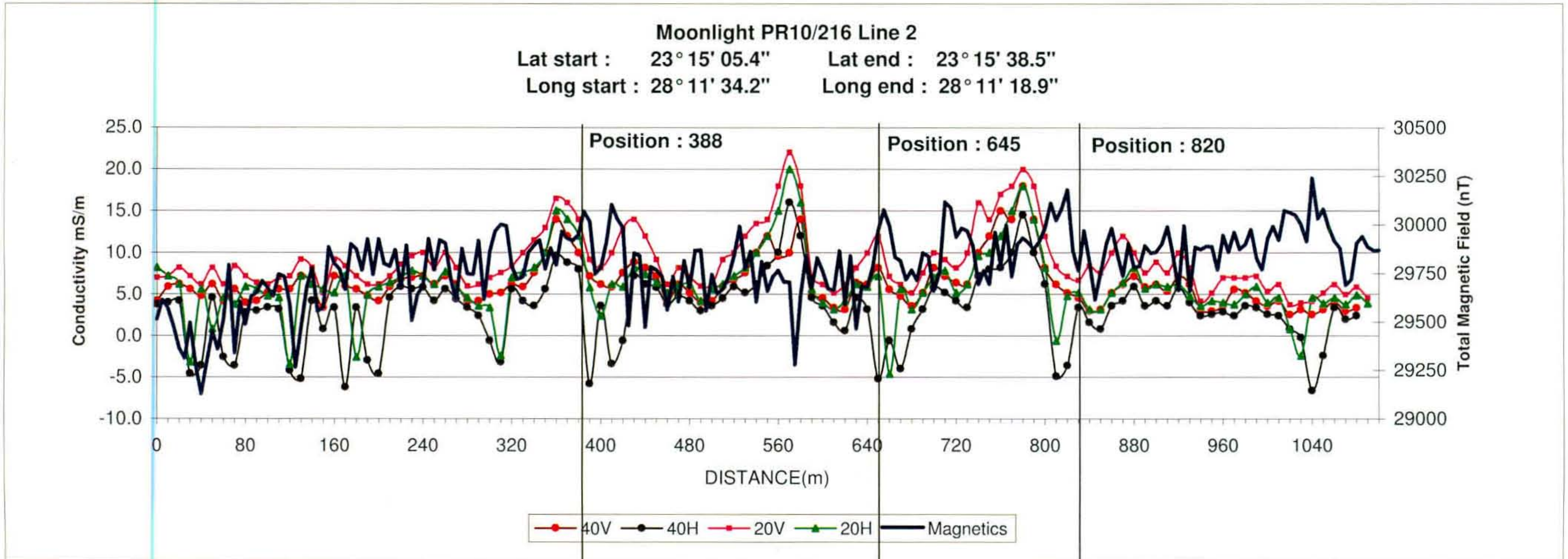
Owner	Alleged yield (l/h)	Site ID	BH Label	Sample ID	Latitude	Longitude	WL (mbgl) (N/P = not possible)	Water application (N/A = not applicable)	Comments
Mr. Jackson	-	Portion 5 of Marnitz 54 LR	BH1	TM-BH1	-23.16348	28.21164	N/P	Domestic use and garden irrigation	
Dr. Christo Pieenaar	-	Portion 1 of Moonlight 111 LR	BH2		-23.16309	28.21137	29.5	N/A	
			BH3		-23.25612	28.224	36.5		Not equipped
			BH4	TM-BH2	-23.26613	28.22994	N/P	Domestic use and garden irrigation	Equipped submersible
			BH5		-23.25579	28.21794	N/P		
			BH6		-23.25635	28.22386	N/P	Game drinking	
			BH7		-23.25644	28.22412	18.85	N/A	
			BH8		-23.25086	28.22505	N/P		Not equipped
			BH9		-23.26006	28.22662	34.3		Not equipped
Mr. Erwin Kruger	6500	Portion 1 of 54 Marnitz 54 LR - Kruger African Safari's	BH10		-23.15996	28.20663	31.3	Domestic use	
			BH11		-23.16134	28.20068	35-45	Domestic use	
			BH12		-23.16099	28.21124	35-45		
			BH13		-23.15573	28.21103	35-45		
Mr. Andre Du Plessis		Victoria West 75 LR Portion	BH14	TM-BH3	-23.16252	28.20594	N/P	Domestic use and garden irrigation	
			BH15		-23.16306	28.20234	N/P	Cattle drinking	
			BH16		-23.16029	28.20176	60		
Mr. Attie Mahne	5000	Grootepost 80 LR	BH17	TM-BH4	-23.19473	28.28254	N/P	Domestic and cattle drinking	5 equipped boreholes and 2 unequipped boreholes
			BH18		-23.19583	28.28441	32.89		
Mr. Scheepers	1400	Portion 0 of Zandkraal 74 LR, portion 1 of Hantam 114 LR and portion 1 of Nelly 113 LR	BH19	TM-BH5	-23.19135	28.13809	N/P	Domestic use and crop irrigation	
			BH20		-23.19066	28.13609	N/P	Domestic use and crop irrigation	
			BH21		-23.22793	28.12156	39.6		
			BH22		-23.25066	28.12384	39.65		
Pastor Petrus Aucamp	12500	Portion 1 of Victoria West 75 LR	BH23		-23.16002	28.20363	N/P	Domestic use, irrigation of church	Vegetables
			BH24		-23.15974	28.20303	N/P		
			BH25		-23.15999	28.20575	30.85	N/A	
Mr. Danie Meyer	10000	Portion 0 of Boekenhoutfontein 108 LR	BH26	TM-BH6	-23.29889	28.26816	10	Cattle drinking	Water for household use
Mr. Attie Mahne	35000	Alice 131 LR and portion 0 of Old Jeff 130 LR	BH27		-23.32075	28.18335	38.7	N/A	Collapsed at 60m
			BH28		-23.32135	28.18533	N/P		Collapsed at 60m
			BH29		-23.32344	28.18238	N/P	Cattle drinking	
			BH30		-23.32329	28.18337	N/P	N/A	
			BH31		-23.32105	28.18027	32.4		Collapsed at 60m
			BH32		-23.32083	28.1833	N/P		Collapsed at 60m
			BH33		-23.31715	28.18895	N/P	Domestic use	
			BH34	TM-BH10	-23.32243	28.18444	N/P		

Summary of hydrocensus (continued)

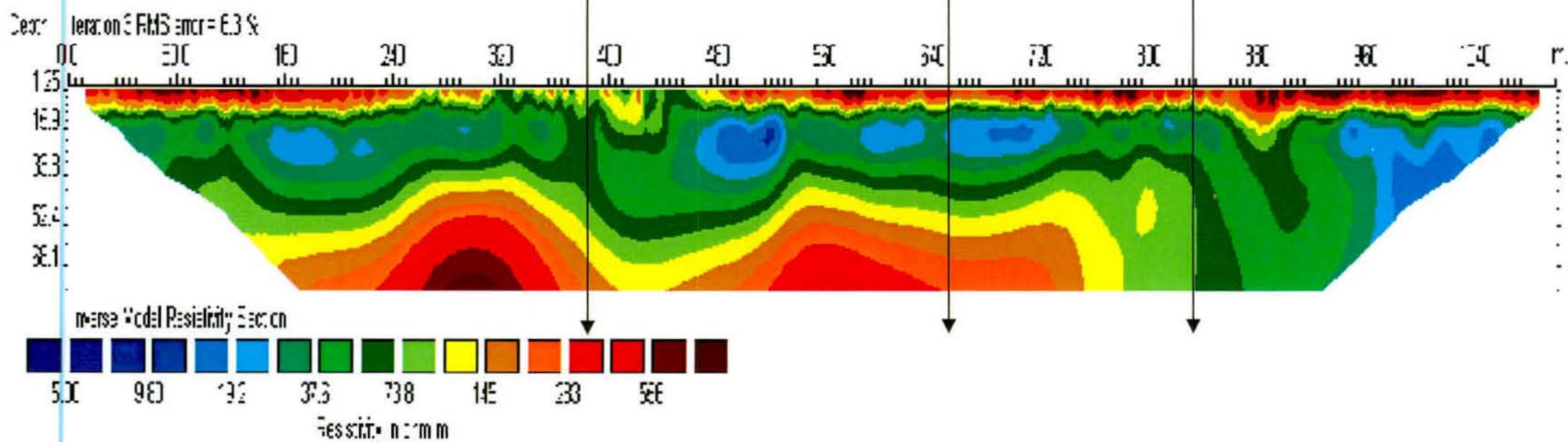
Owner	Alleged yield (l/h)	Site ID	BH Label	Sample ID	Latitude	Longitude	WL (mbgl)	Water application	Comments
Mrs. Minderd Spoelstra		Tabana 133 LR	BH35	TM-BH7	-23.26682	28.23757	N/P	Home/lodge use and game drinking	
			BH36		-23.28483	28.23341	N/P		
			BH37		-23.30446	28.23509	28.8		
			BH38		-23.30422	28.23461	N/P		Water from borehole 4 had a slight smell
Mr. Andre Du Plessis	1500	Goudafontein 76 LR, portion 3 and 2 of Moonlight 111 LR, portion 6 of Victoria West 75 LR, portion 0 of Hantam 114 LR, Portion 0 of Nelly 113 LR, Palala Game Farms	BH39		-23.2122	28.16312	44.5	N/A	
			BH40	TM-BH8	-23.2177	28.12934	51.7	Domestic use	Pump at 63 mbgl.
			BH41		-23.25295	28.14253	N/P	N/A	
			BH42		-23.2547	28.12997	>60		
			BH43		-23.27178	28.20535	45		
			BH44		-23.24014	28.17306	>60		
Mr. Eli Stroh	45500	Karnemelksfontein 78 LR and portion 1 of Good Hope 109 LR	BH45		-23.21833	28.27443	25.3	Cattle drinking	Higher yields compared to others
			BH46	TM-BH9	-23.24289	28.26318	N/P		
Mr. Elrick Viljoen		Portion 1 of Zandkraal 74 LR	BH47		-23.17797	28.16634	35	Domestic use	
			BH48	TM-BH11	-23.18514	28.1547	N/P		
			BH49		-23.18912	28.14837	N/P		
Mr. Corneels Coetzee	15000	Remaining extent of Moonlight 111 LR - Philamina Coetzee Trust	BH50	TM-BH12	-23.24066	28.22586	N/P	Domestic use and cattle drinking	Equipped
			BH51		-23.23789	28.22195	40	N/A	Open hole left by prospecting drillers
Mr. A Jonker	75000	Bloemendal 99	BH52	TM-BH13	-23.20842	28.37153	N/P	Domestic use	Run by daughter Mrs Muller
	> 200000		BH53		-23.21450	28.37936	N/P	Domestic use	5 boreholes all about 30 mbgl
Mr. A Oosthuizen	-	Klippoort 106LR	BH54	TM-BH14	-23.23061	28.30006	N/P	Farm irrigation (crops)	Strong yields
			BH55	TM-BH15	-23.21861	28.28444	N/P	Domestic use	
			BH56		-23.21856	28.28750	20.9	N/A	
			BH57		-23.25261	28.27922	8.8		
P Badenhorst	-	Prairie	BH58	TM-BH16			N/P	Domestic use	Borehole 1 km south of house
			BH59		-23.29592	28.30328	N/P	Garden irrigation	3 boreholes approx. 18 mbgl (low yields)
Mr. W Russouw	-	Beerkraal	BH60	TM-BH17	-23.28722	28.33667	N/P	Domestic use	pump a few hundred meters from hous
Mr. H Du Plessis	8000	Grootepos 80 LR	BH61	TM-BH18	-23.18092	28.30075	N/P	Domestic use and garden irrigation	
	-		BH62		-23.17972	28.29175	22	Game Farm and B&B	
			BH63		-23.19261	28.29175	27		
Mr. D Ehlers	> 32000	S'gavenhage	BH64	TM-BH19	-23.22525	28.36878	27	Crop irrigation	bh told is 42 m and 5 other bh about 56 m

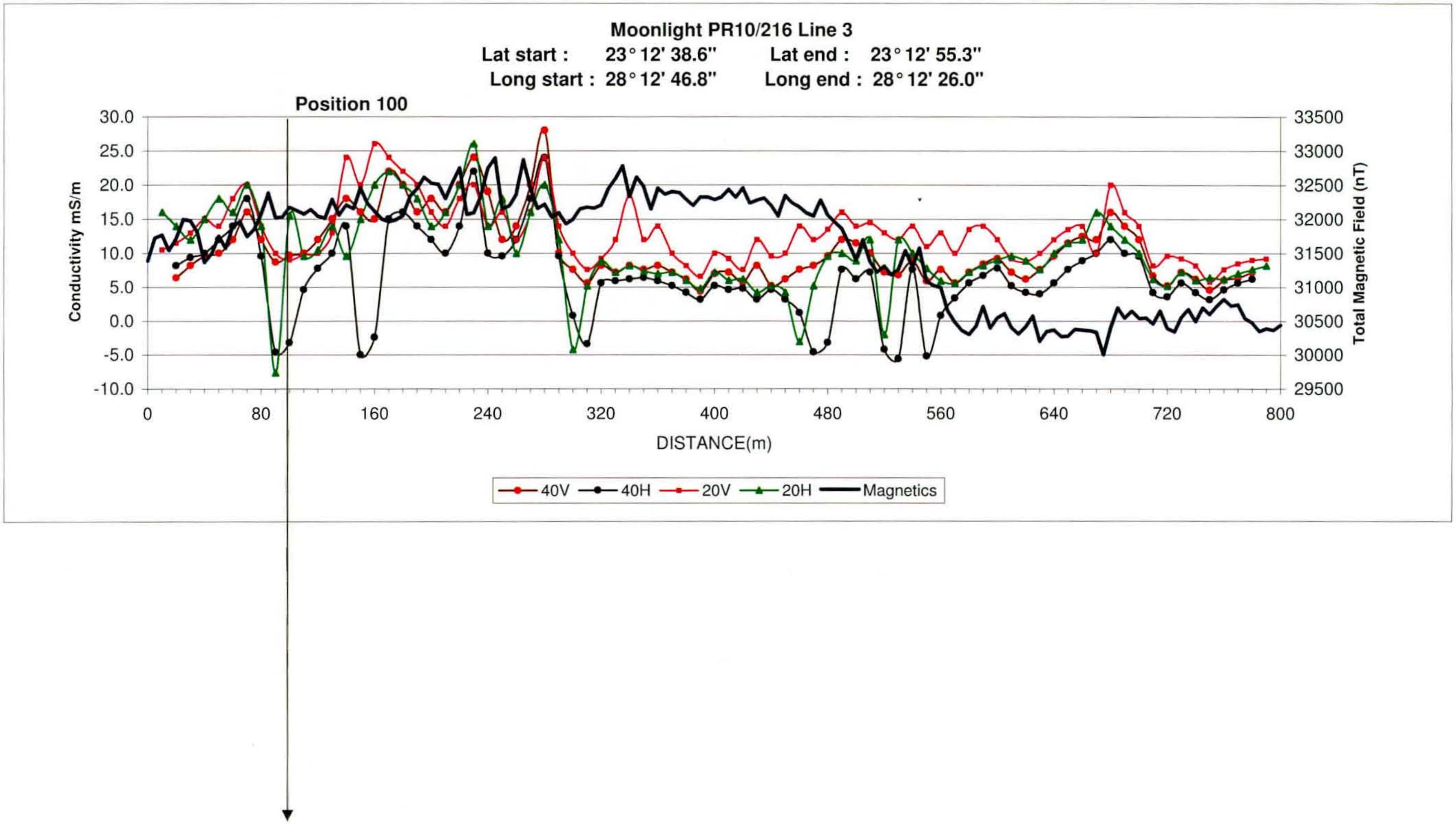
APPENDIX B: GEOPHYSICS

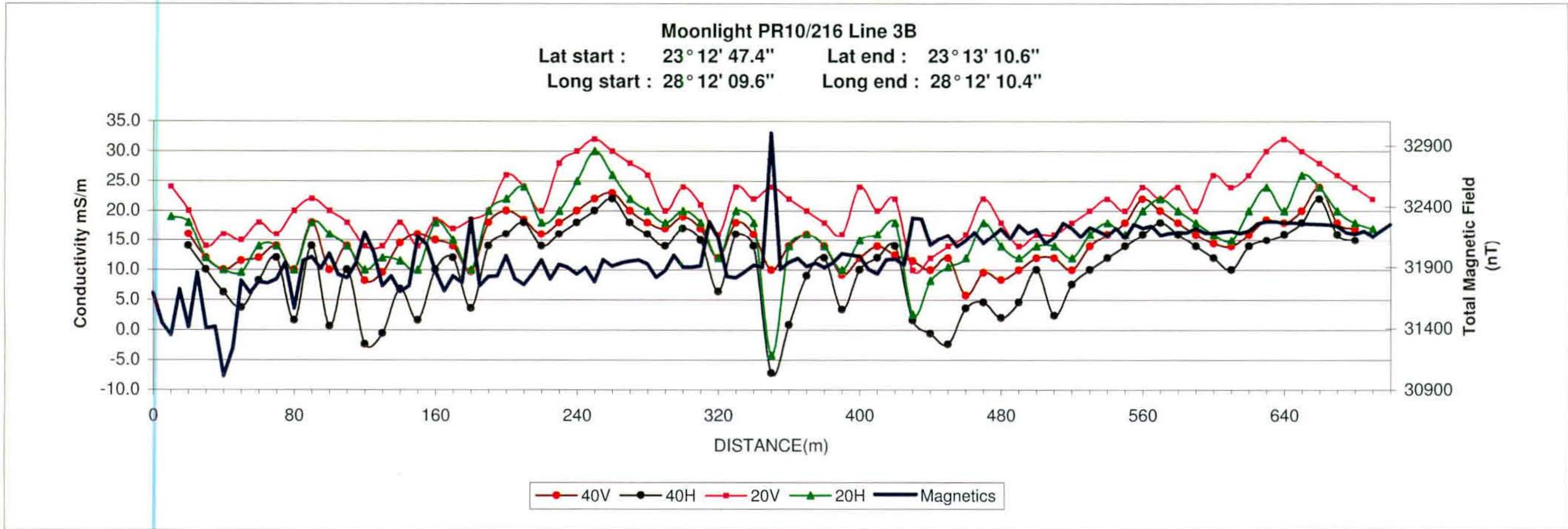

Moonlight PR10/216 Line 1
Lat start : 23° 15' 20.6"
Lat end : 23° 15' 53.2"
Long start : 28° 12' 23.1"
Long end : 28° 12' 23.4"
Position 480
Position 685
Position 740
Conductivity mS/m
Total Magnetic Field (nT)
DISTANCE(m)
40V
40H
20V
20H
Magnetics
Geo-electric model Moon-1, Moonlight. January 2011.
Resistivity in ohm.m



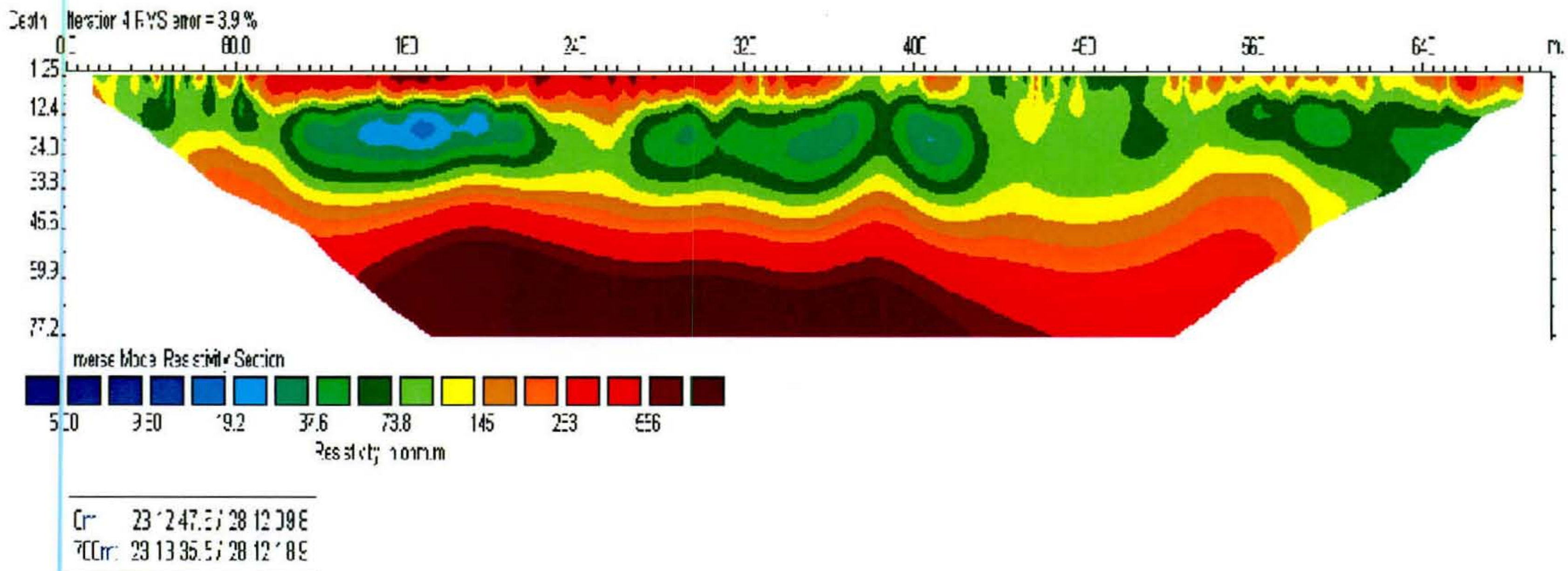
Geo-electric model Moon-2, Moonlight. January 2011.

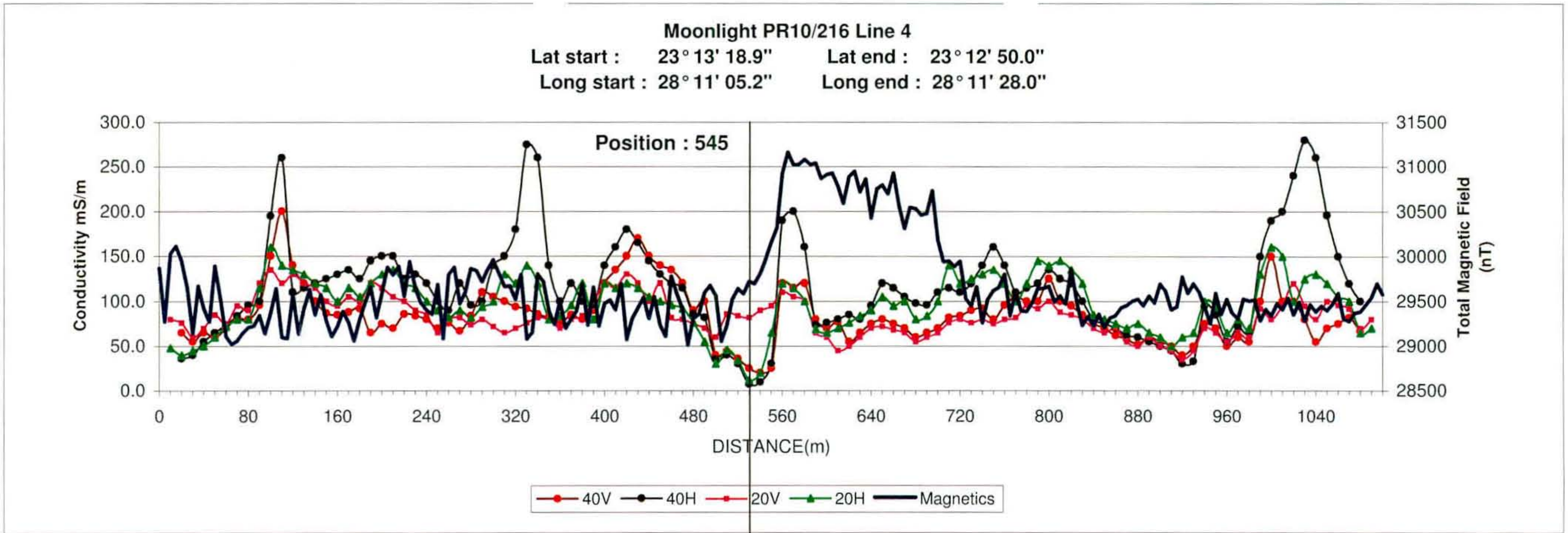



Moonlight PR10/216 Line 3
Lat start : 23° 12' 38.6" Lat end : 23° 12' 55.3"
Long start : 28° 12' 46.8" Long end : 28° 12' 26.0"
Position 100
Conductivity mS/m
Total Magnetic Field (nT)
DISTANCE(m)
40V
40H
20V
20H
Magnetics

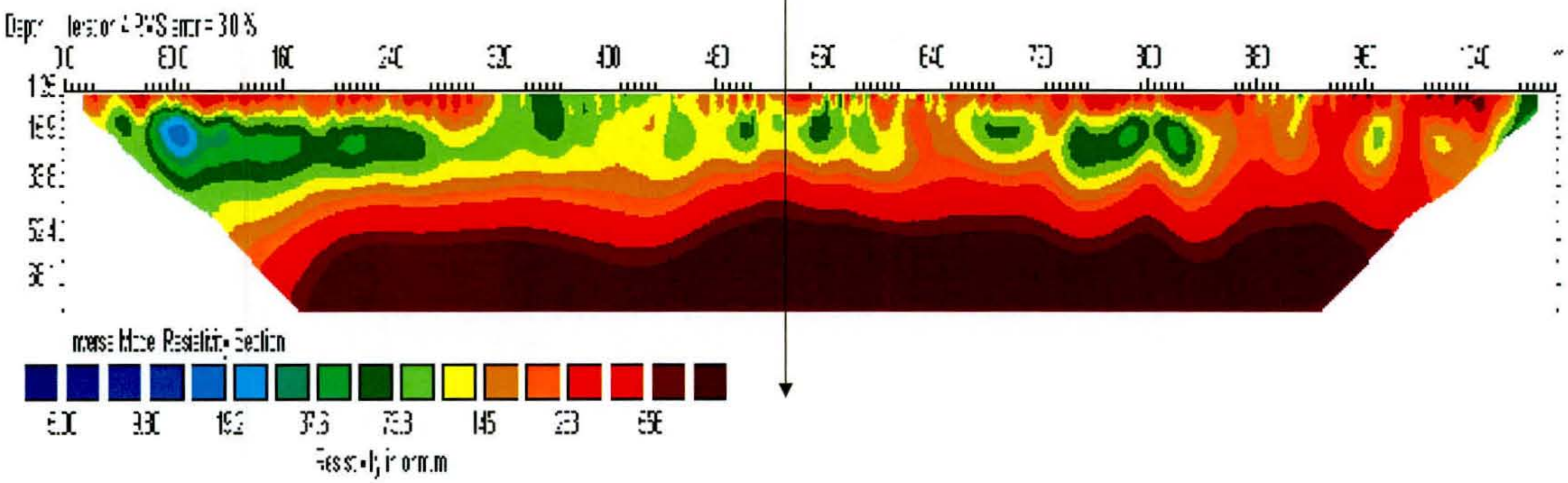


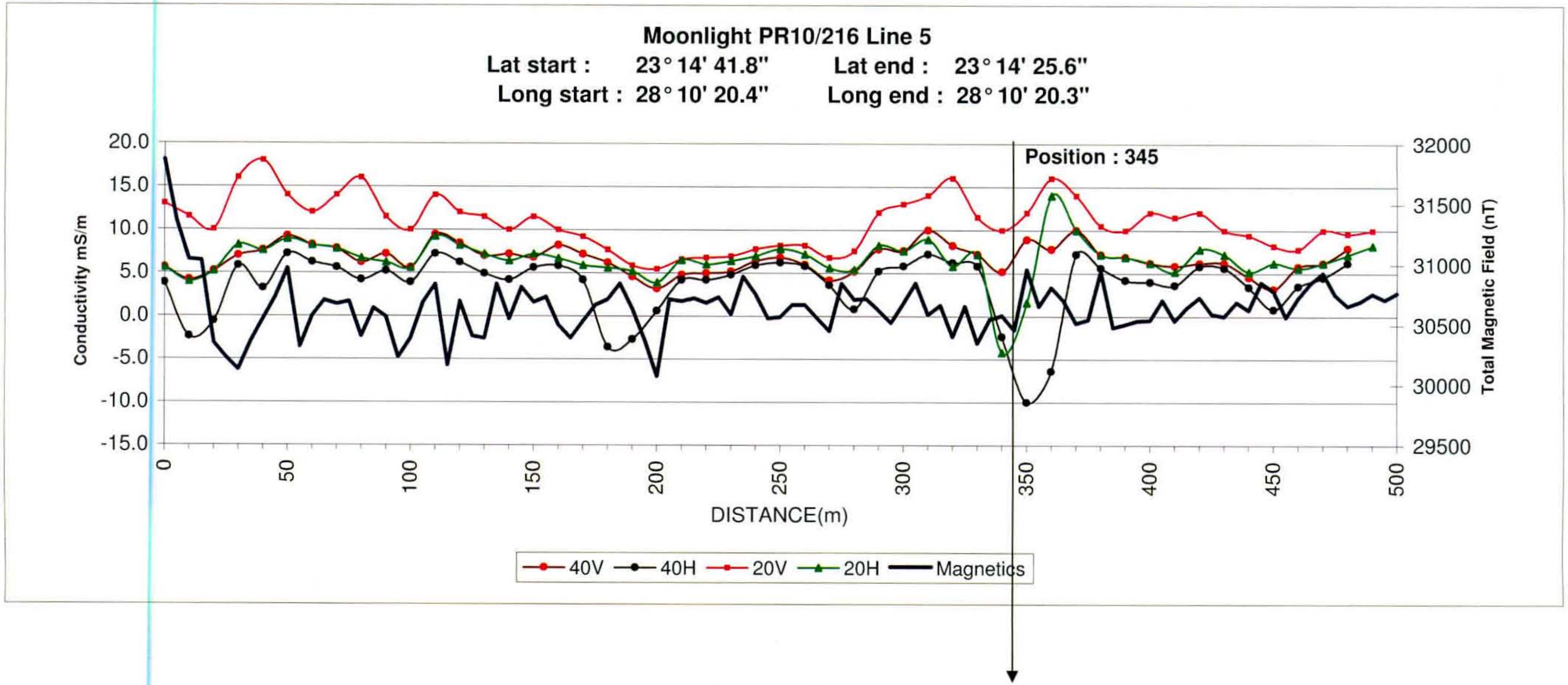
Geo-electric model Moon-3, Moonlight. January 2011.



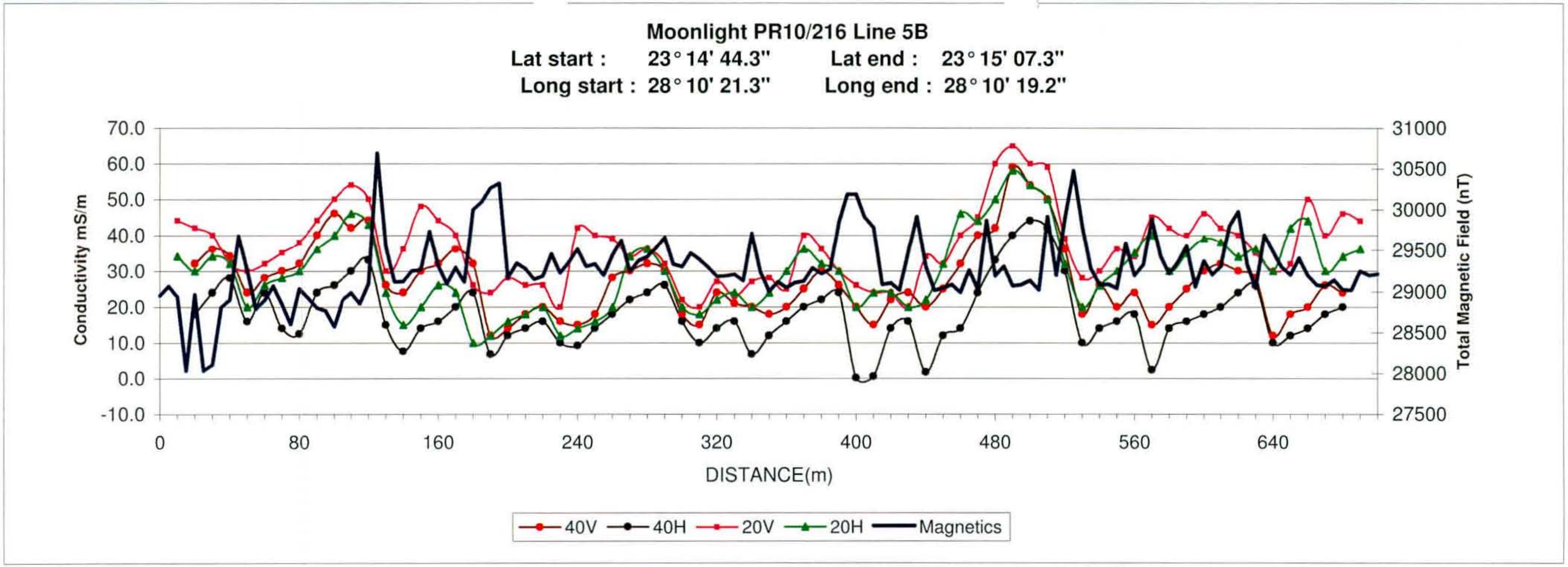


Geo-electric model Moon-4 Moonlight January 2011.

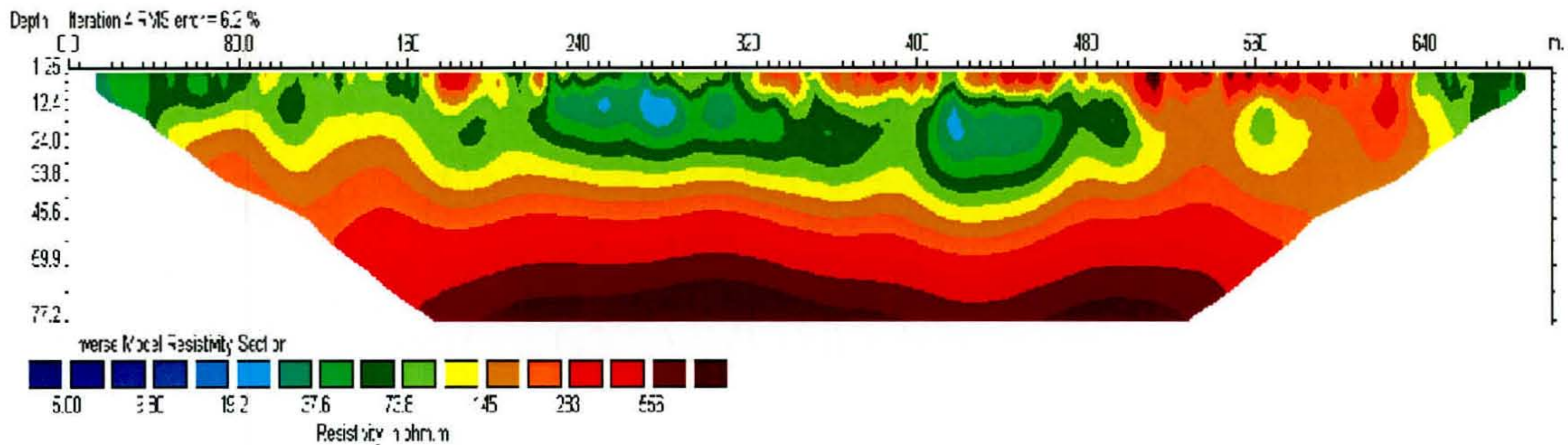




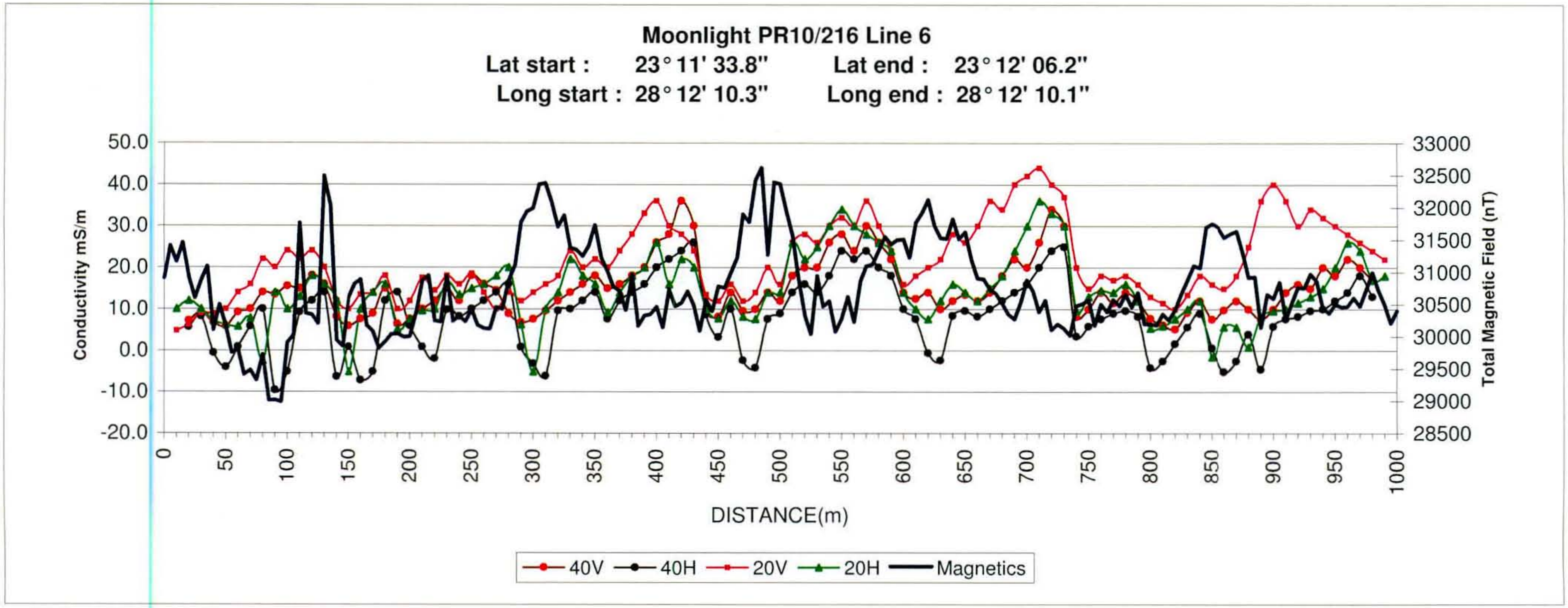
Moonlight PR10/216 Line 5
Lat start : 23° 14' 41.8" Lat end : 23° 14' 25.6"
Long start : 28° 10' 20.4" Long end : 28° 10' 20.3"
Position : 345
Conductivity mS/m
Total Magnetic Field (nT)
DISTANCE(m)
40V
40H
20V
20H
Magnetics

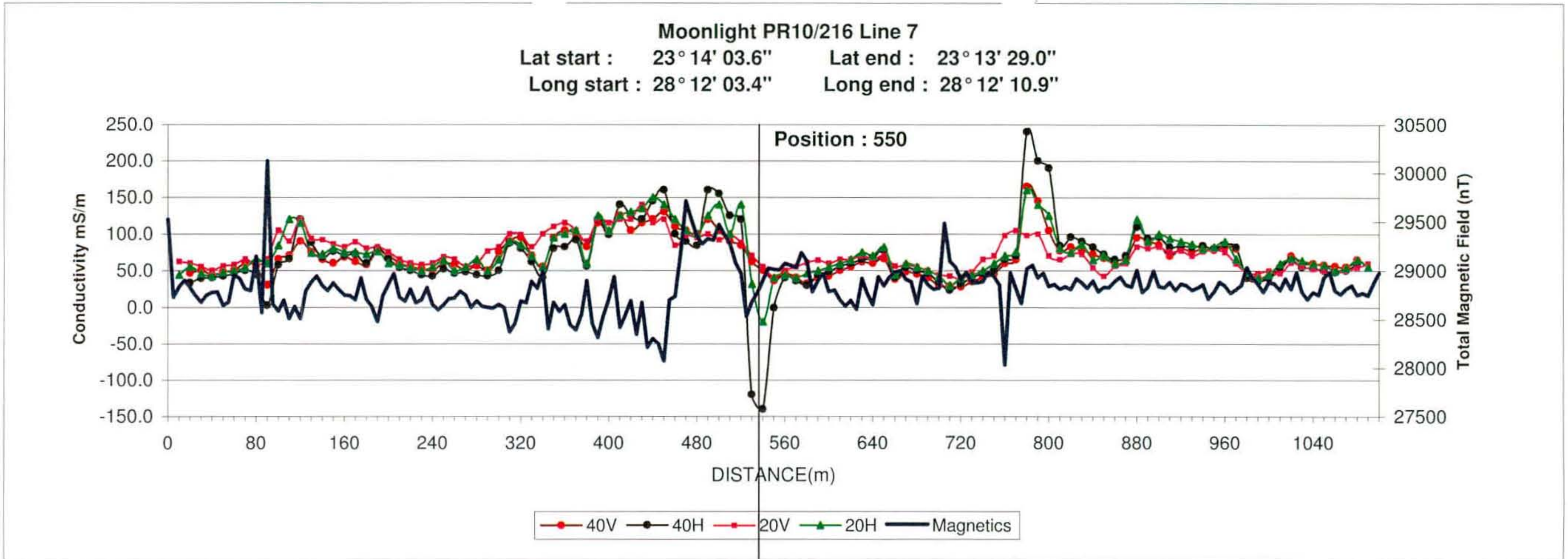


Geo-electrical model Moon-5b, Moonlight. January 2011.

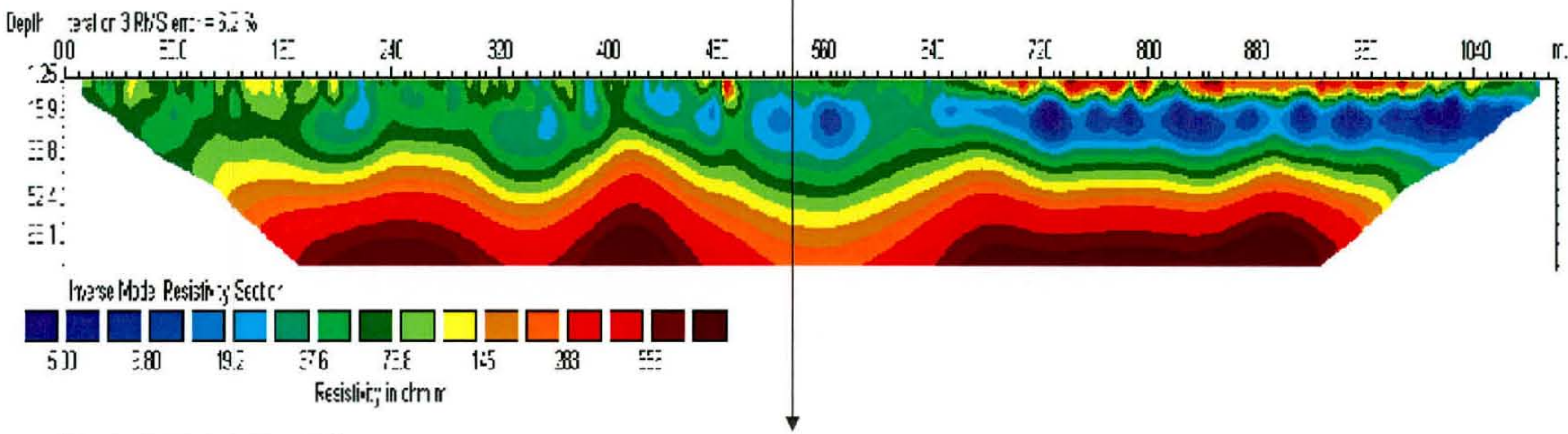


0m: 23 14 44.3 ; 28 10 21.3
700m: 23 15 07.4 ; 28 10 19.2

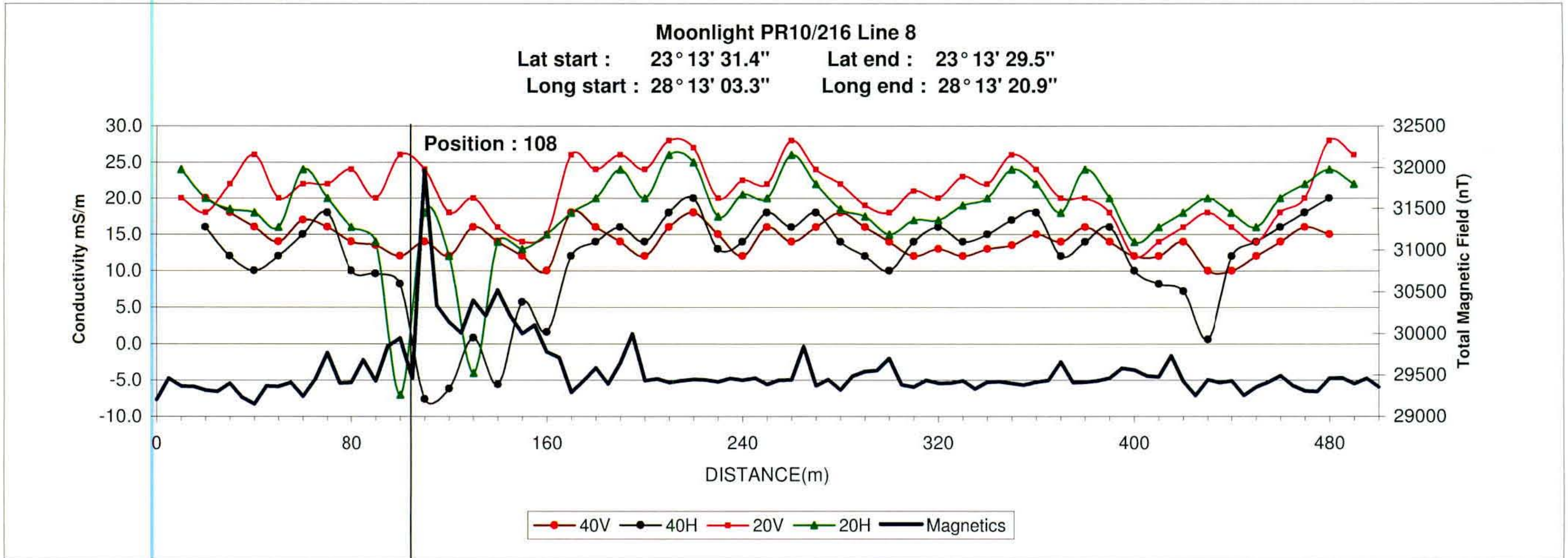

Moonlight PR10/216 Line 6
Lat start : 23° 11' 33.8" Lat end : 23° 12' 06.2"
Long start : 28° 12' 10.3" Long end : 28° 12' 10.1"
Conductivity mS/m
Total Magnetic Field (nT)
DISTANCE(m)
40V
40H
20V
20H
Magnetics



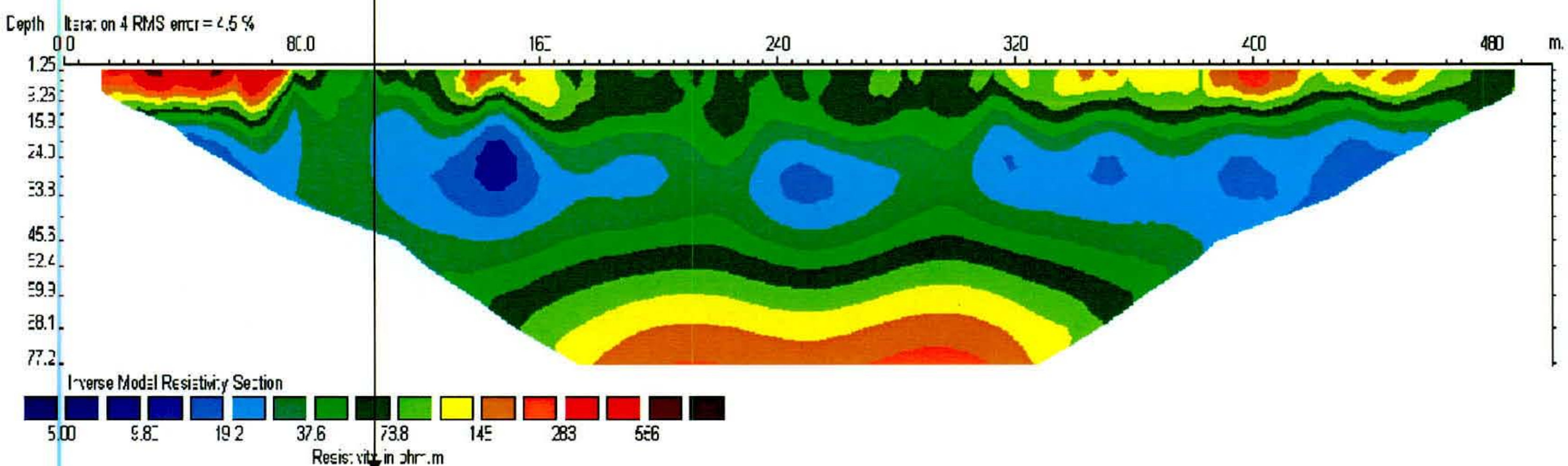
Geo-electrical model Moon-7, Moonlight. January 2011.



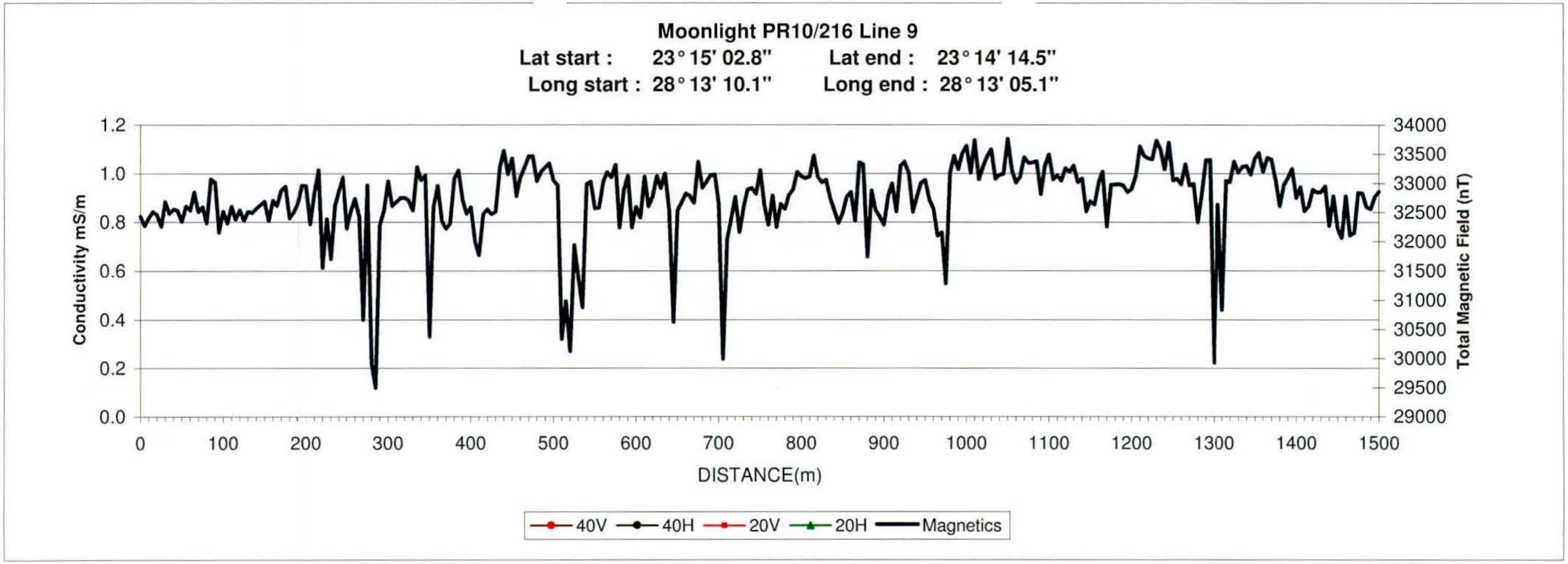
0m : 23 14 03.7 ; 28 12 03.3
1100m : 23 13 29.1 ; 28 12 10.7



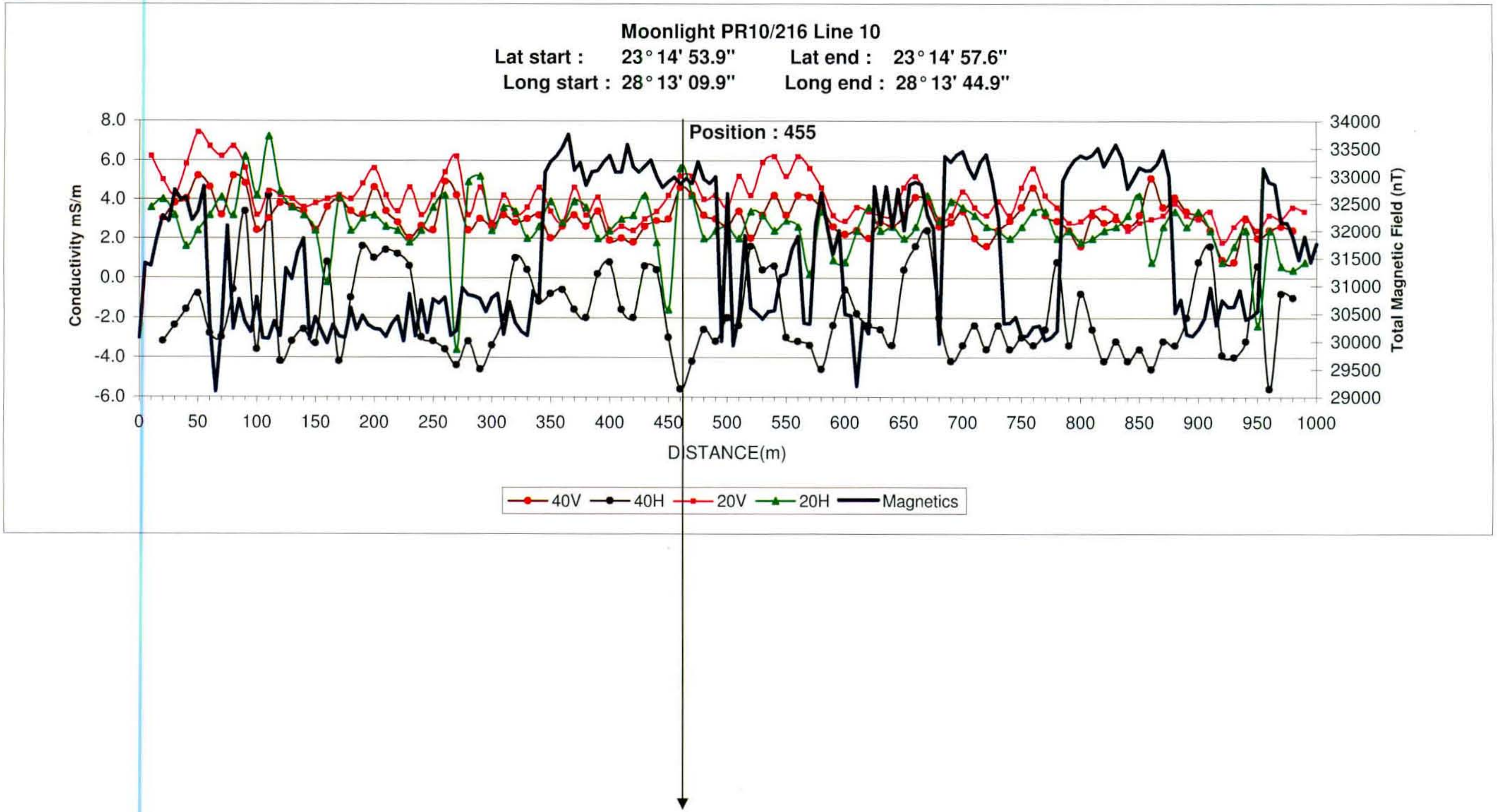
Geo-electrical model Moon-8, Moonlight. January 2011.



0m: 23 13 31.3 ; 28 13 03.5
500m: 23 13 29.4 ; 28 13 21.2



Moonlight PR10/216 Line 9
Lat start : 23° 15' 02.8" Lat end : 23° 14' 14.5"
Long start : 28° 13' 10.1" Long end : 28° 13' 05.1"
Conductivity mS/m
Total Magnetic Field (nT)
DISTANCE(m)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
34000
33500
33000
32500
32000
31500
31000
30500
30000
29500
29000
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
40V
40H
20V
20H
Magnetics


Moonlight PR10/216 Line 10
Lat start : 23° 14' 53.9" Lat end : 23° 14' 57.6"
Long start : 28° 13' 09.9" Long end : 28° 13' 44.9"
Position : 455
Conductivity mS/m
Total Magnetic Field (nT)
DISTANCE(m)
40V
40H
20V
20H
Magnetics

APPENDIX C: BOREHOLE LOGS

Borehole Construction and Geological Log

Date compiled: 2011/04/07

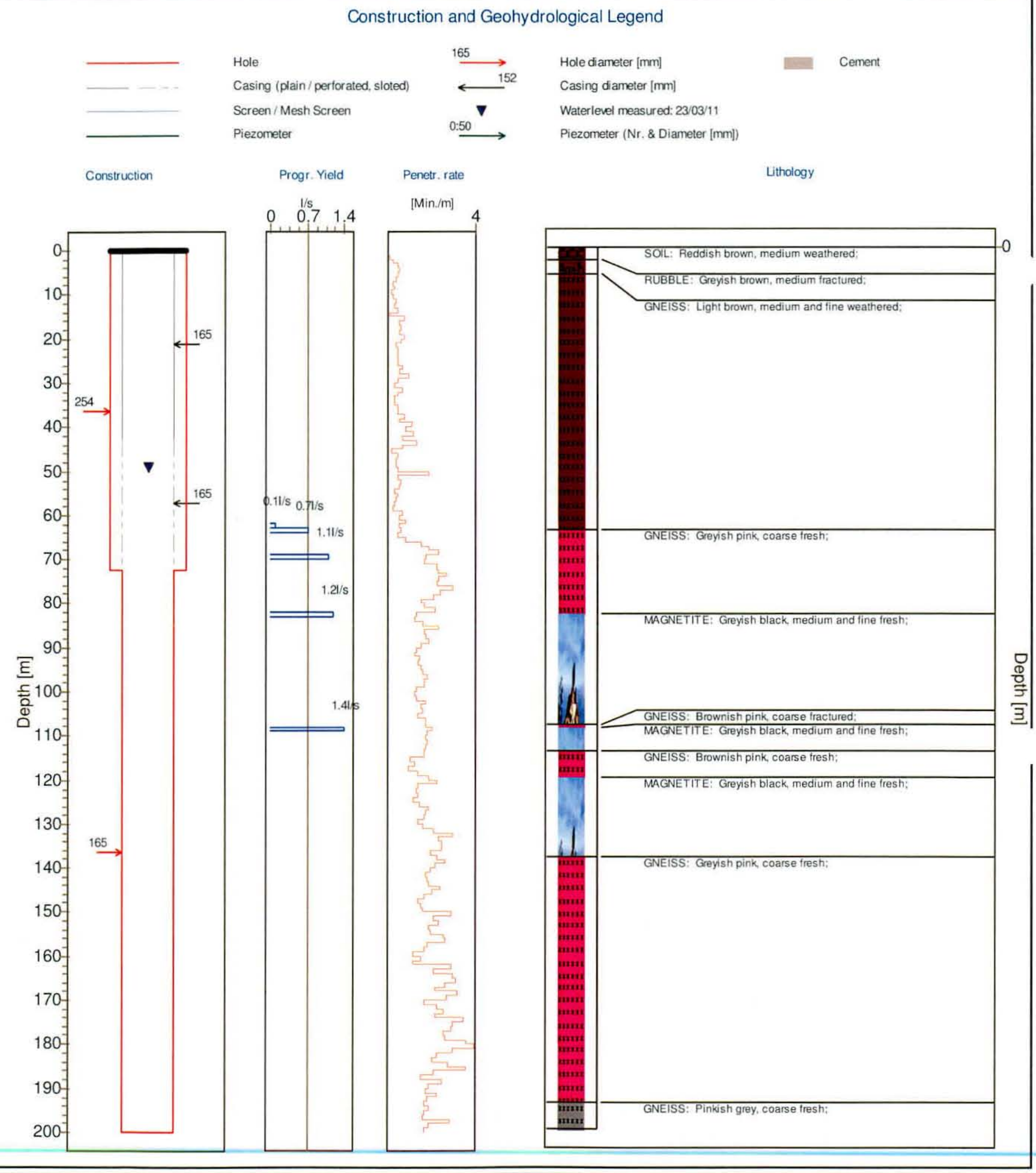
BASIC SITE INFORMATION: ***Site Identifier:*** 2328AAV0002 ***Number:*** H03-3797 ***Site type:*** Borehole

Distr./Farm No.: LPLR111 ***Site Name/Des.:*** MOONLIGHT PTN. MARNITZ

Region Type: District Council ***Region Descr.:*** WATERBERG/LEPHALALE

Latitude [°]:	23.238805	***Reg./BB.:***	TMMWG01	***Topo-set.:***	Flat surface, plain	***Depth [m]:***	119.72
Longitude [°]:	28.221917	***G-Nr.:***		***Site status:***	Unused	***Col. ht. [m]:***	
Altitude [m]:	976.00			***Site purp.:***	Exploration	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 10 units			***Use applic.:***	Domestic - all purposes	***Drain. reg.:***	A50H
Coord. meth.:	Interpolated from map			***Equipment:***	No equipment	***Rep. inst.:***	VSA

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), WGS 1984



COMMENT:

Borehole Construction and Geological Log

Date compiled: 2011/05/09

BASIC SITE INFORMATION: *Site Identifier:* 2328AAV0003 *Number:* H03-3839 *Site type:* Borehole

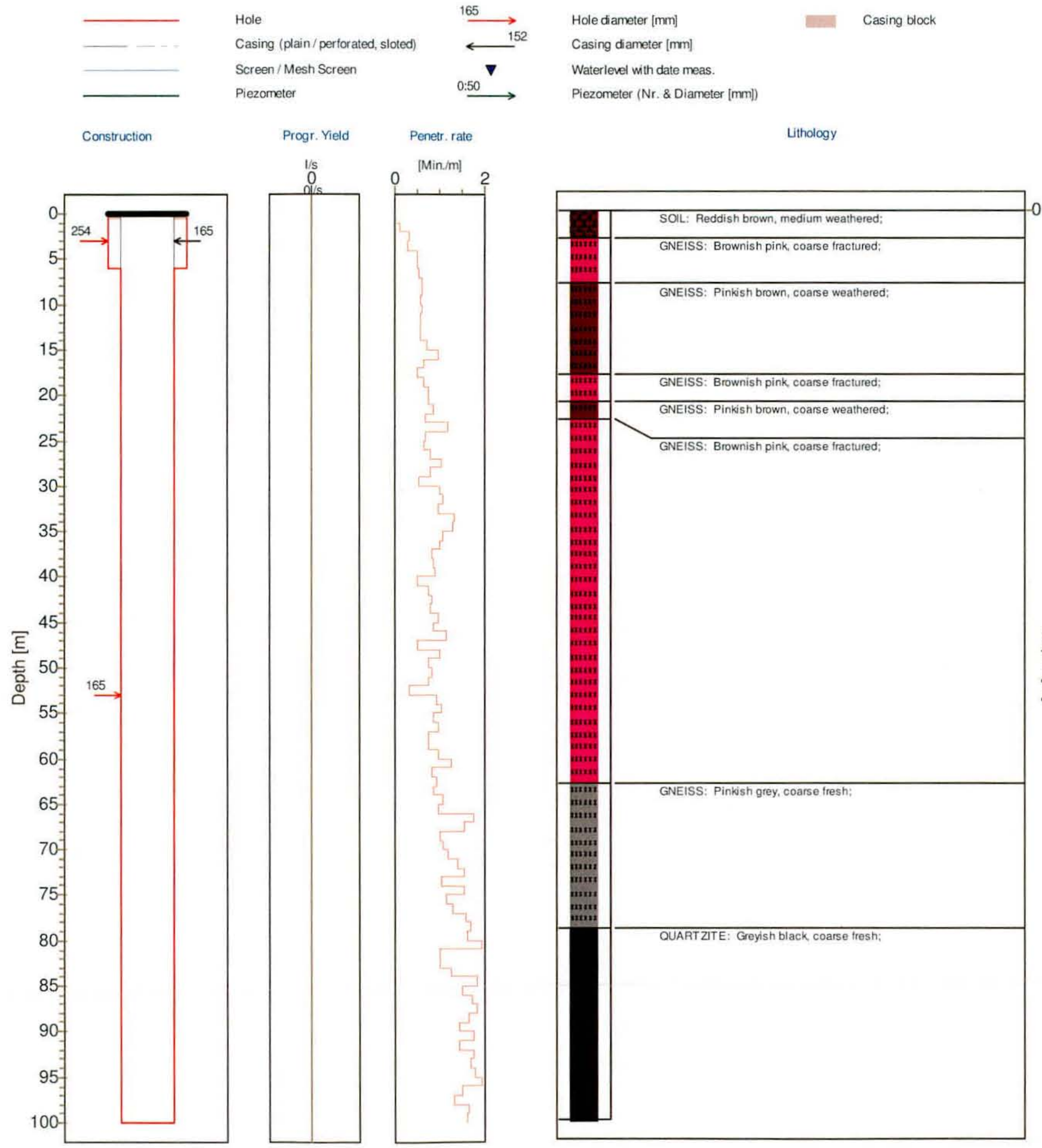
Distr./Farm No.: LPLR111 *Site Name/Des.:* MOONLIGHT PTN. MARNITZ

Region Type: District Council *Region Descr.:* WATERBERG/LEPHALALE

Latitude [°]:	23.247556
Longitude [°]:	28.231444
Altitude [m]:	965.00
Reg./BB.:	TMMWG02
G-Nr.:	
Coord. acc.:	Accurate to within 10 units
Coord. meth.:	Interpolated from map
Topo-set.:	Flat surface, plain
Site status:	Unused
Site purp.:	Exploration
Use applic.:	Domestic - all purposes
Equipment:	No equipment
Depth [m]:	100.00
Col. ht. [m]:	
Diam. [mm]:	165
Drain. reg.:	A50H
Rep. inst.:	VSA

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), WGS 1984

Construction and Geohydrological Legend



COMMENT:

Borehole Construction and Geological Log

Date compiled: 2011/04/07

BASIC SITE INFORMATION: ***Site Identifier:*** 2328AAV0004 ***Number:*** H03-3840 ***Site type:*** Borehole

Distr./Farm No.: LPLR111 ***Site Name/Des.:*** MOONLIGHT PTN. MARNITZ

Region Type: District Council ***Region Descr.:*** WATERBERG/LEPHAPALE

Latitude [°]:	23.225250	***Reg./BB.:***	TMMWG03	***Topo-set.:***	Flat surface, plain	***Depth [m]:***	100.00
Longitude [°]:	28.218556	***G-Nr.:***		***Site status:***	Unused	***Col. ht. [m]:***	0
Altitude [m]:	970.00			***Site purp.:***	Exploration	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 10 units			***Use applic.:***	Domestic - all purposes	***Drain. reg.:***	A50H
Coord. meth.:	Interpolated from map			***Equipment:***	No equipment	***Rep. inst.:***	VSA

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), WGS 1984

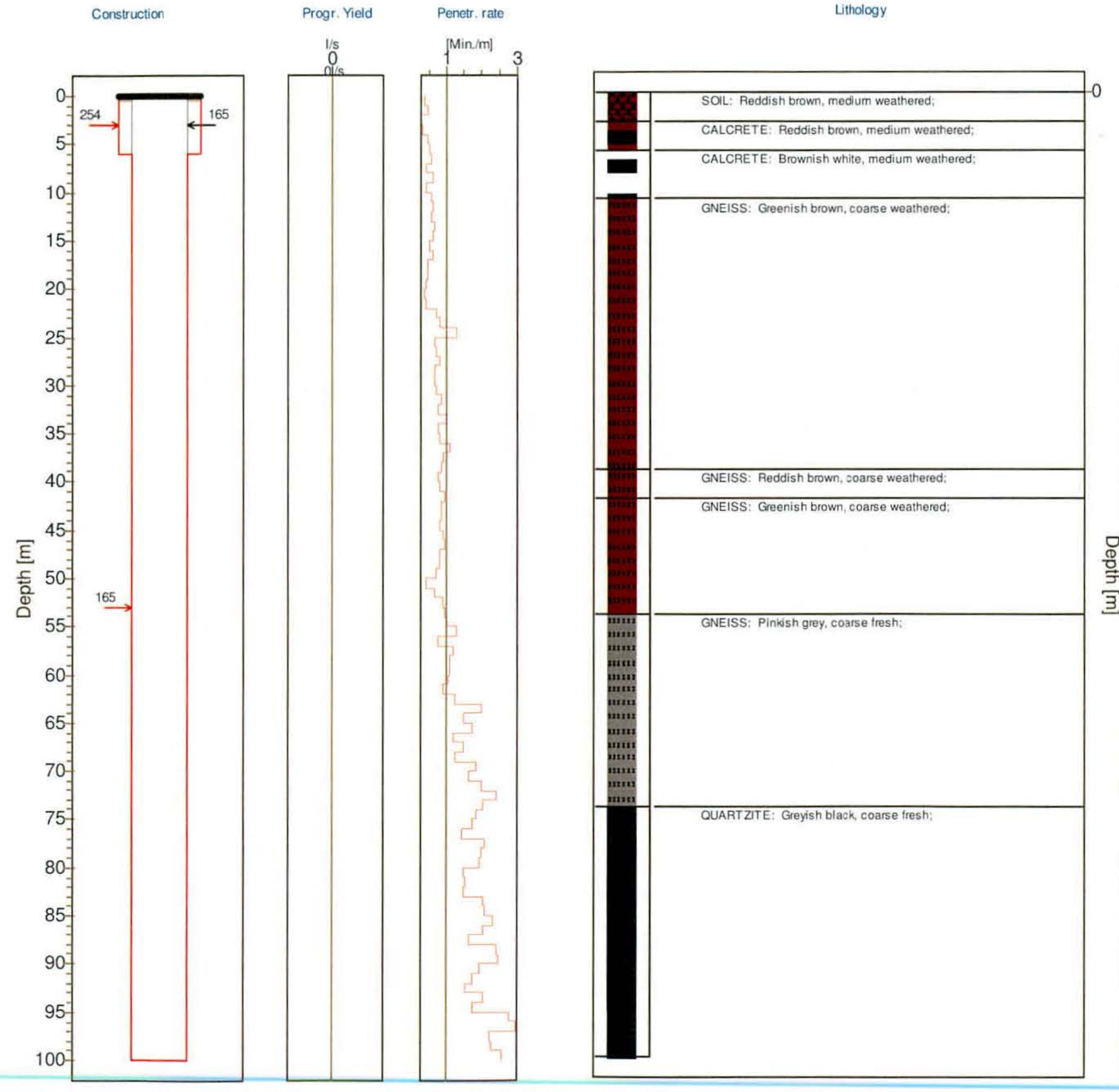
Construction and Geohydrological Legend

Hole — 165 Hole diameter [mm] — Casing block

Casing (plain / perforated, sloted) — 152 Casing diameter [mm]

Screen / Mesh Screen — Waterlevel with date meas.

Piezometer — 0:50 Piezometer (Nr. & Diameter [mm])



COMMENT:

Borehole Construction and Geological Log

Date compiled: 2011/04/07

BASIC SITE INFORMATION: ***Site Identifier:*** 2328AAV0005 ***Number:*** H03-3841 ***Site type:*** Borehole

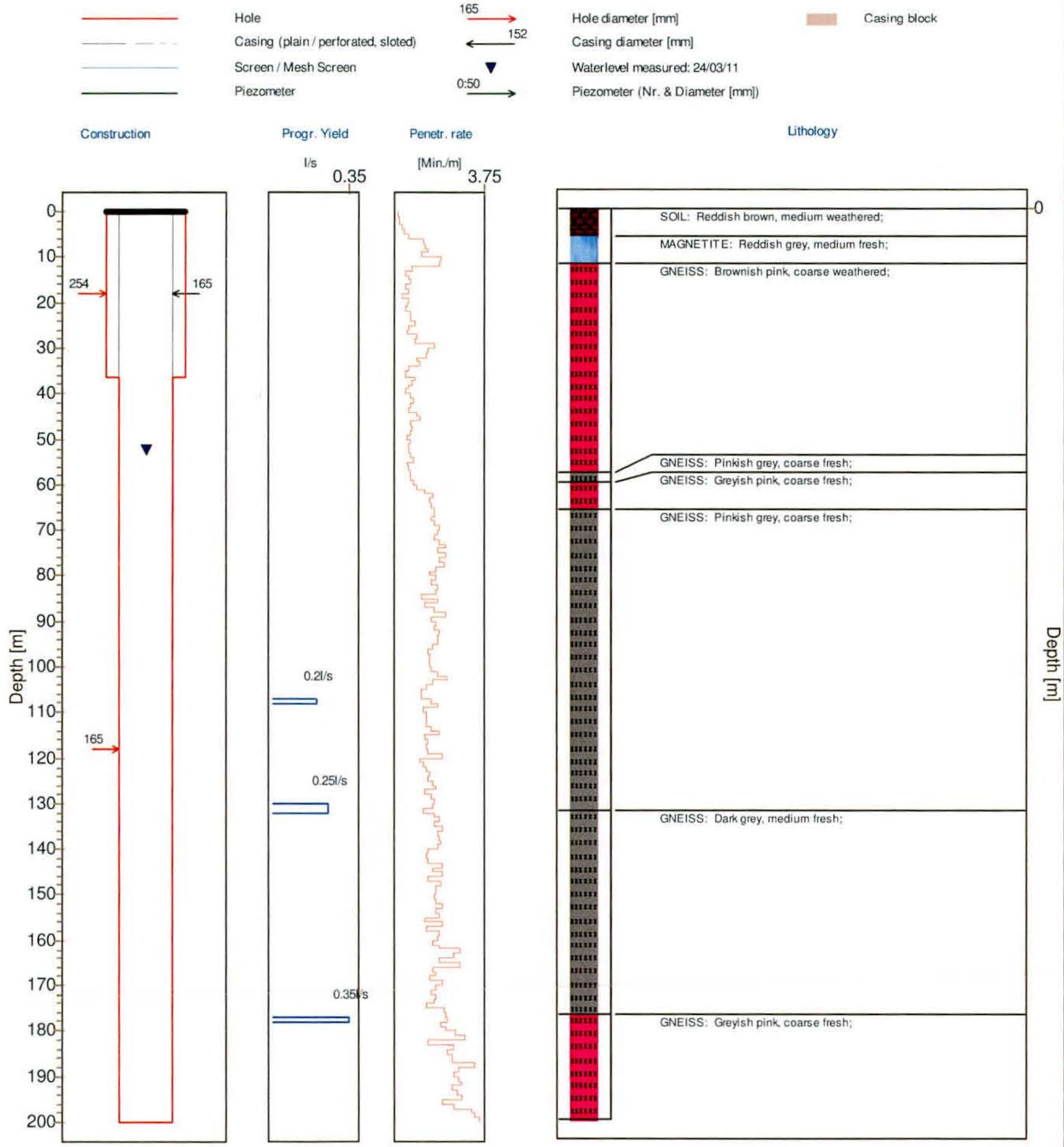
Distr./Farm No.: LPLR111 ***Site Name/Des.:*** MOONLIGHT PTN. MARNITZ

Region Type: District Council ***Region Descr.:*** WATERBERG/LEPHALALE

Latitude [°]:	23.248805	***Reg./BB.:*** TMMWG04		***Topo-set.:***	Flat surface, plain	***Depth [m]:***	195.96
Longitude [°]:	28.224056	***G-Nr.:***		***Site status:***	Unused	***Col. ht. [m]:***	
Altitude [m]:	956.00			***Site purp.:***	Exploration	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 10 units			***Use applic.:***	Domestic - all purposes	***Drain. reg.:***	A50H
Coord. meth.:	Interpolated from map			***Equipment:***	No equipment	***Rep. inst.:***	VSA

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), WGS 1984

Construction and Geohydrological Legend



COMMENT:

Borehole Construction and Geological Log Date compiled: 2011/05/09

BASIC SITE INFORMATION: ***Site Identifier:*** 2328ACV0006 ***Number:*** H03-3865 ***Site type:*** Borehole

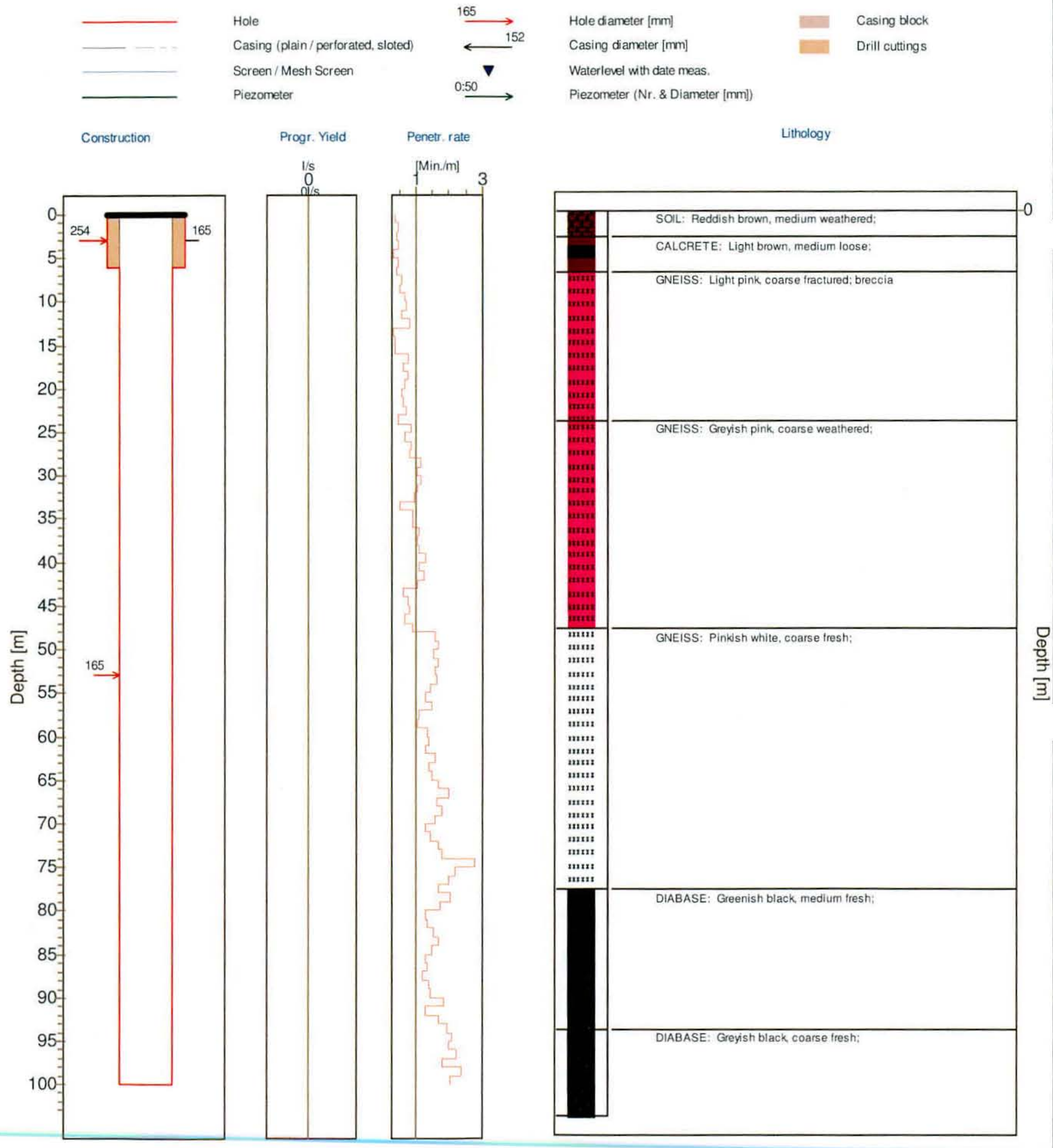
Distr./Farm No.: LPLR111 ***Site Name/Des.:*** MOONLIGHT PTN. MOONLIGHT

Region Type: District Council ***Region Descr.:*** WATERBERG/LEPHALALE

Latitude [°]:	23.262410	***Reg./BB.:*** TMMWG05		***Topo-set.:***	Flat surface, plain	***Depth [m]:***	100.00
Longitude [°]:	28.206430	***G-Nr.:***		***Site status:***	Unused	***Col. ht. [m]:***	0.45
Altitude [m]:	955.00			***Site purp.:***	Exploration	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 10 units			***Use applic.:***	Domestic - all purposes	***Drain. reg.:***	
Coord. meth.:	Interpolated from map			***Equipment:***	No equipment	***Rep. inst.:***	VSA

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), WGS 1984

Construction and Geohydrological Legend



COMMENT:

Borehole Construction and Geological Log

Date compiled: 2011/05/09

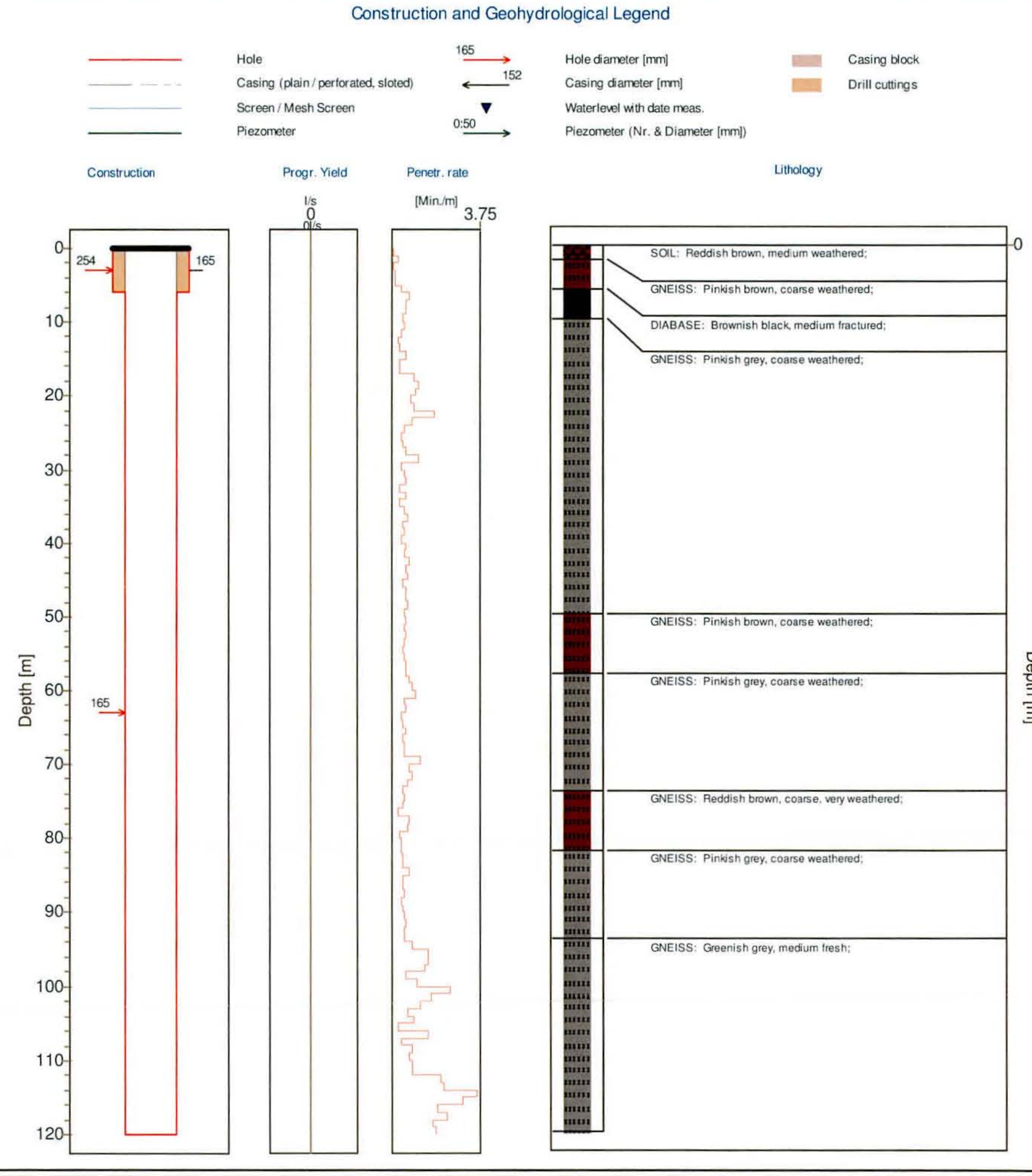
BASIC SITE INFORMATION: ***Site Identifier:*** 2328ACV0005 ***Number:*** H03-3864 ***Site type:*** Borehole

Distr./Farm No.: LPLR112 ***Site Name/Des.:*** JULIETTA PTN. MOONLIGHT

Region Type: District Council ***Region Descr.:*** WATERBERG/LEPHALALE

Latitude [°]:	23.259280	***Reg./BB.:***	TMMWG06	***Topo-set.:***	Flat surface, plain	***Depth [m]:***	120.00
Longitude [°]:	28.189150	***G-Nr.:***		***Site status:***	Unused	***Col. ht. [m]:***	0.50
Altitude [m]:	965.00			***Site purp.:***	Exploration	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 10 units			***Use applic.:***	Domestic - all purposes	***Drain. reg.:***	
Coord. meth.:	Interpolated from map			***Equipment:***	No equipment	***Rep. inst.:***	VSA

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), WGS 1984



COMMENT:

Borehole Construction and Geological Log

Date compiled: 2011/05/09

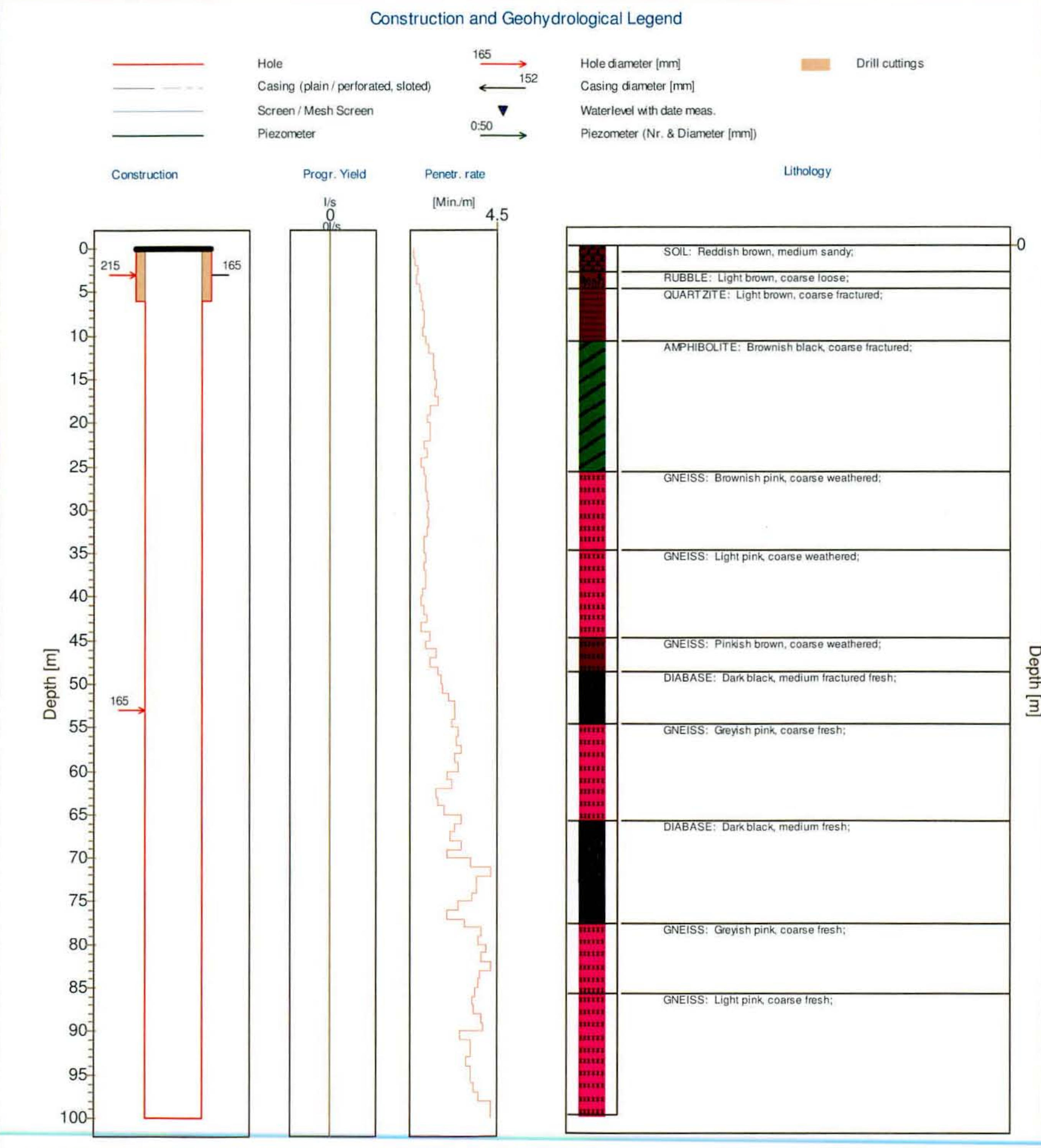
BASIC SITE INFORMATION: ***Site Identifier:*** 2328AAV0012 ***Number:*** H03-3863 ***Site type:*** Borehole

Distr./Farm No.: LPLR076 ***Site Name/Des.:*** GOUDA FONTEIN PTN. MOONLIGHT

Region Type: District Council ***Region Descr.:*** WATERBERG/LEPHALALE

Latitude [°]: 23.216380	***Reg./BB.:*** TMMWG07	***Topo-set.:*** Flat surface, plain	***Depth [m]:*** 100.00
Longitude [°]: 28.202750	***G-Nr.:***	***Site status:*** Unused	***Col. ht. [m]:*** 0.50
Altitude [m]: 968.00		***Site purp.:*** Exploration	***Diam. [mm]:*** 165
Coord. acc.: Accurate to within 10 units		***Use applic.:*** Agricultural and domestic	***Drain. reg.:***
Coord. meth.: Global Positioning System		***Equipment:*** No information	***Rep. inst.:*** VSA

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), WGS 1984



COMMENT:

Borehole Construction and Geological Log

Date compiled: 2011/05/09

BASIC SITE INFORMATION: *Site Identifier:* 2328AAV0011 *Number:* H03-3862 *Site type:* Borehole

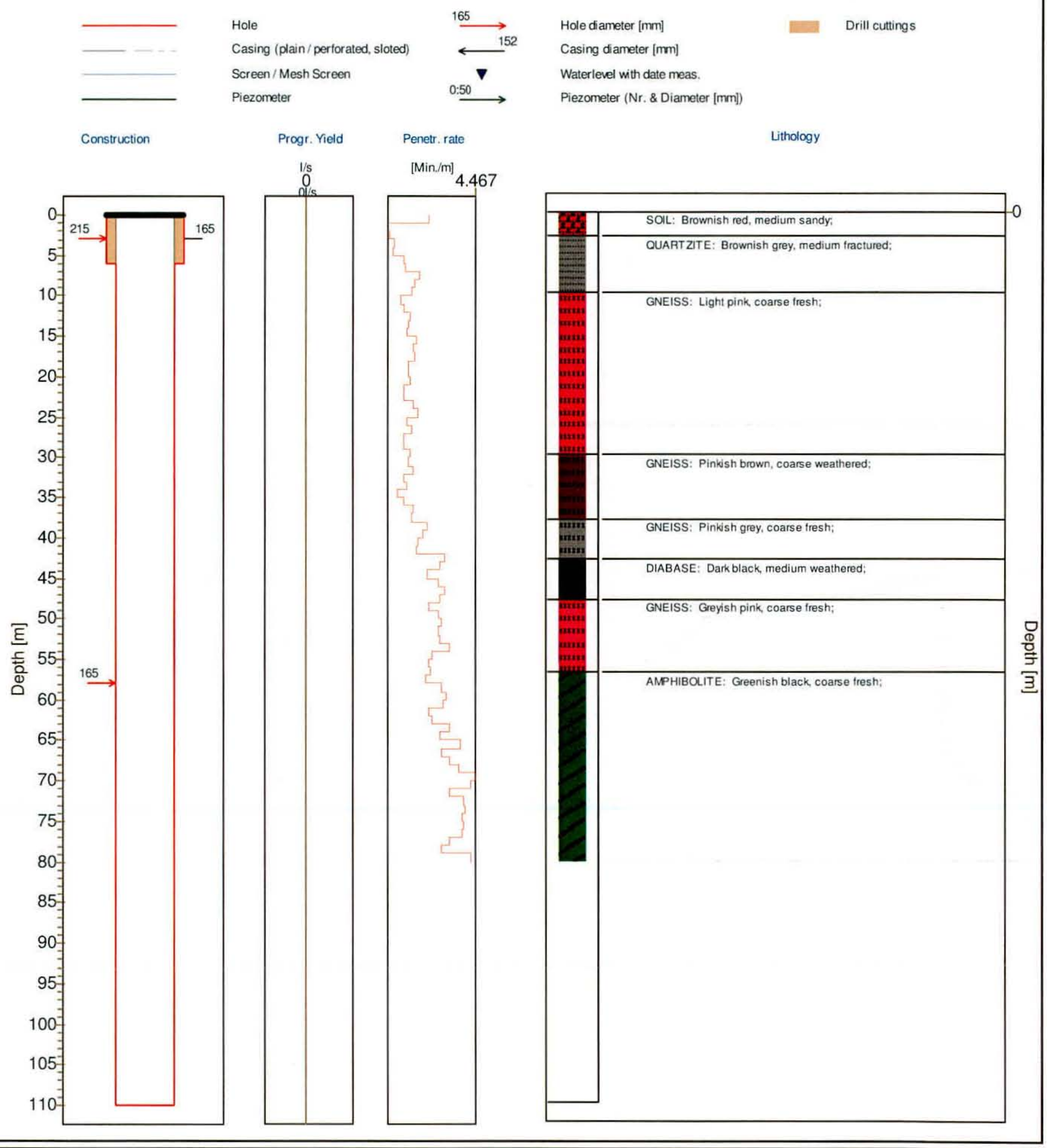
Distr./Farm No.: LPLR076 *Site Name/Des.:* GOUDA FONTEIN PTN. MOONLIGHT

Region Type: District Council *Region Descr.:* WATERBERG/LEPHALALE

Latitude [°]:	23.217910	*Reg./BB.:*	TMMWG08	*Topo-set.:*	Flat surface, plain	*Depth [m]:*	80.00
Longitude [°]:	28.187960	*G-Nr.:*		*Site status:*	Unused	*Col. ht. [m]:*	0.50
Altitude [m]:	950.00			*Site purp.:*	Exploration	*Diam. [mm]:*	165
Coord. acc.:	Accurate to within 100 units			*Use applic.:*	Agricultural and domestic	*Drain. reg.:*	
Coord. meth.:	Global Positioning System			*Equipment:*	No information	*Rep. inst.:*	VSA

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), WGS 1984

Construction and Geohydrological Legend



COMMENT:

Borehole Construction and Geological Log

Date compiled: 2011/05/09

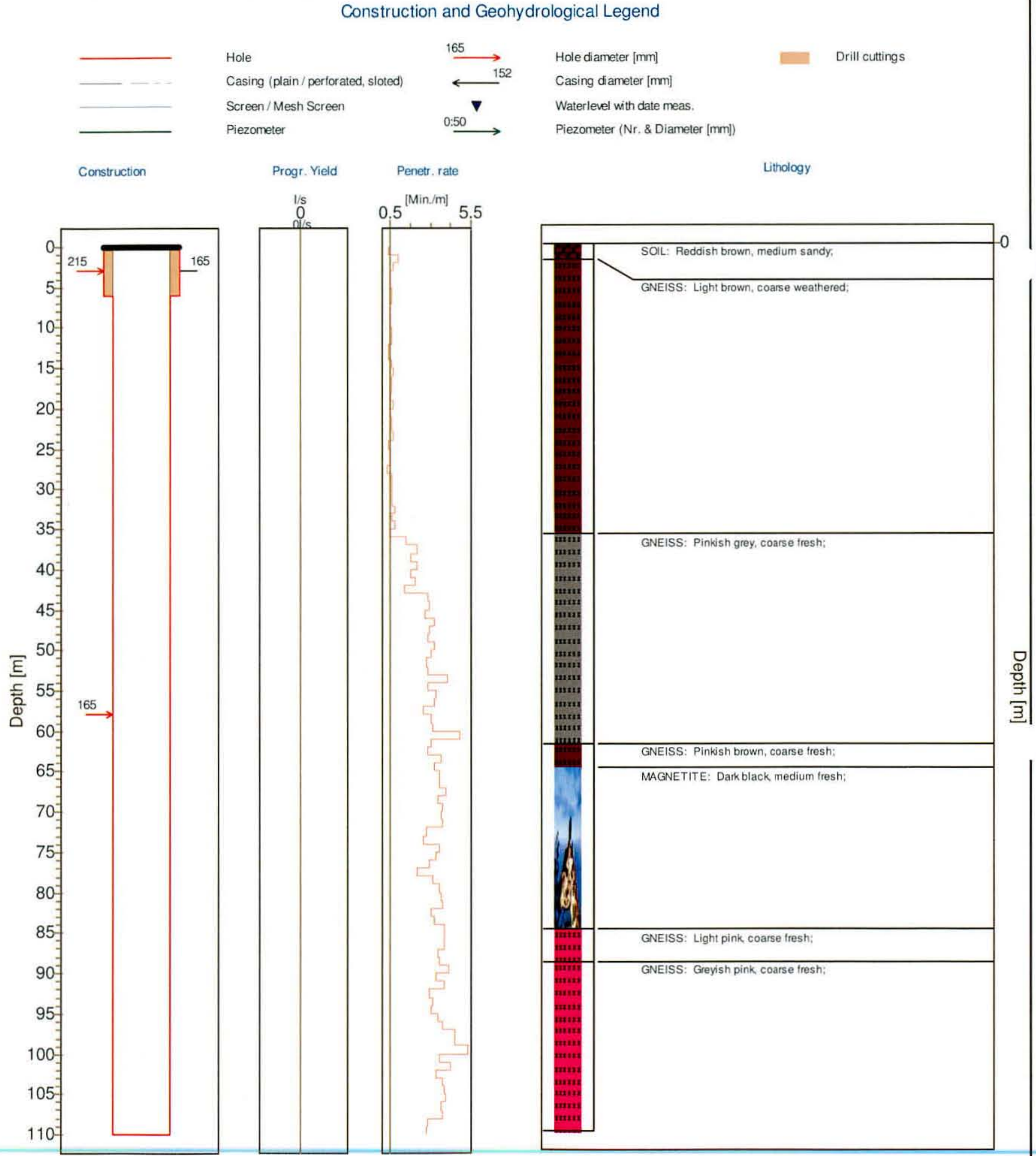
BASIC SITE INFORMATION: ***Site Identifier:*** 2328AAV0010 ***Number:*** H03-3861 ***Site type:*** Borehole

Distr./Farm No.: LPLR112 ***Site Name/Des.:*** JULIETTA PTN. MOONLIGHT

Region Type: District Council ***Region Descr.:*** WATERBERG/LEPHALALE

Latitude [°]: 23.241830	***Reg./BB.:*** TMMWG09	***Topo-set.:*** Flat surface, plain	***Depth [m]:*** 110.00
Longitude [°]: 28.172240	***G-Nr.:***	***Site status:*** Unused	***Col. ht. [m]:*** 0.50
Altitude [m]: 945.00		***Site purp.:*** Production (water supply)	***Diam. [mm]:*** 165
Coord. acc.: Accurate to within 100 units		***Use applic.:*** Agricultural and domestic	***Drain. reg.:***
Coord. meth.: Global Positioning System		***Equipment:*** No information	***Rep. inst.:*** VSA

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), WGS 1984



COMMENT:

Borehole Construction and Geological Log

Date compiled: 2011/05/09

BASIC SITE INFORMATION: ***Site Identifier:*** 2328AAV0009 ***Number:*** H03-3860 ***Site type:*** Borehole

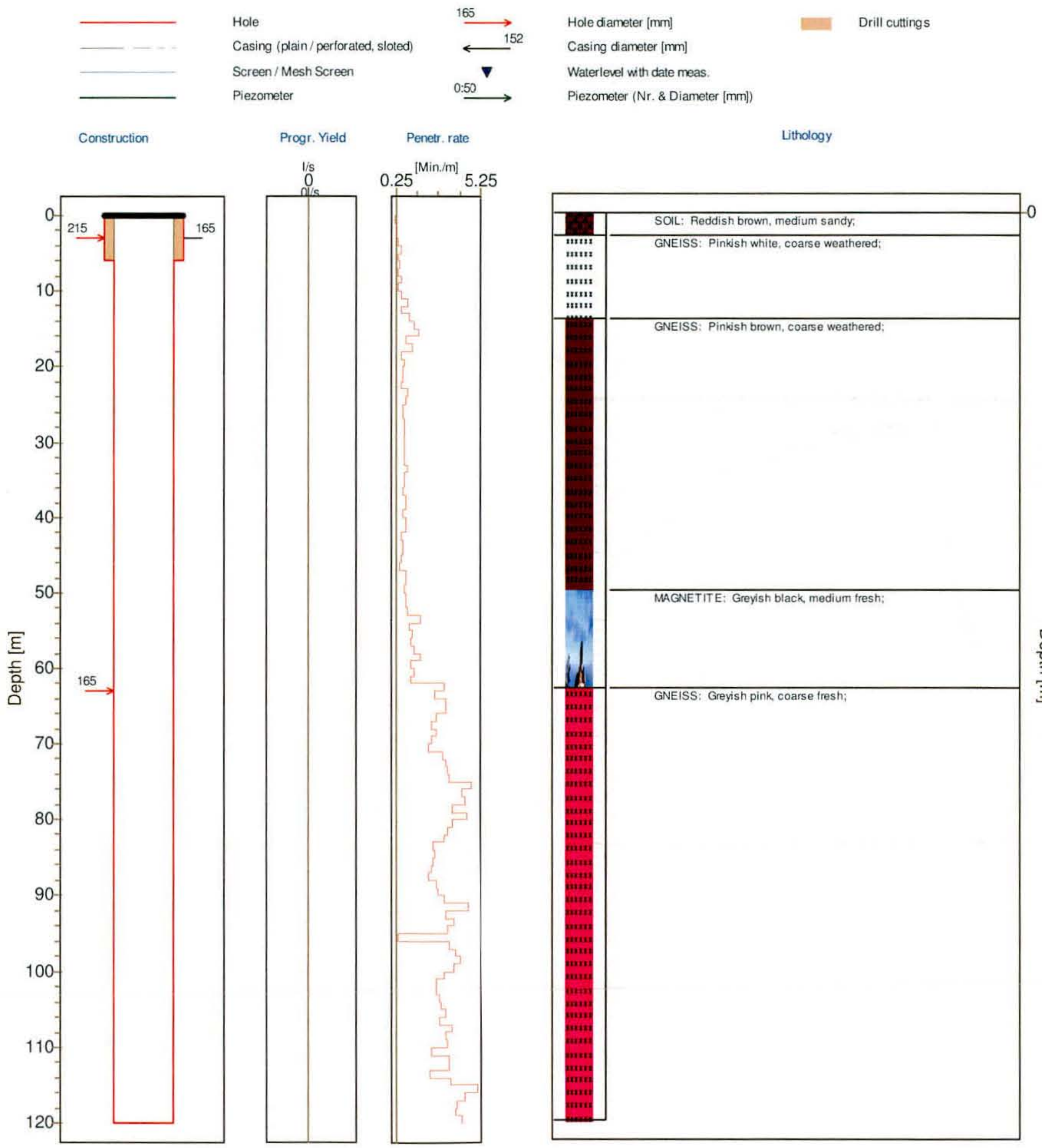
Distr./Farm No.: LPLR112 ***Site Name/Des.:*** JULIETTA PTN. MOONLIGHT

Region Type: District Council ***Region Descr.:*** WATERBERG/LEPHALALE

Latitude [°]:	23.229710	***Reg./BB.:***	TMMWG10	***Topo-set.:***	Flat surface, plain	***Depth [m]:***	120.00
Longitude [°]:	28.202630	***G-Nr.:***		***Site status:***	Unused	***Col. ht. [m]:***	0.50
Altitude [m]:	970.00			***Site purp.:***	Production (water supply)	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 100 units			***Use applic.:***	Agricultural and domestic	***Drain. reg.:***	
Coord. meth.:	Global Positioning System			***Equipment:***	No information	***Rep. inst.:***	VSA

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), WGS 1984

Construction and Geohydrological Legend



COMMENT:

Borehole Construction and Geological Log

Date compiled: 2011/05/09

BASIC SITE INFORMATION: ***Site Identifier:*** 2328AAV0008 ***Number:*** H03-3859 ***Site type:*** Borehole

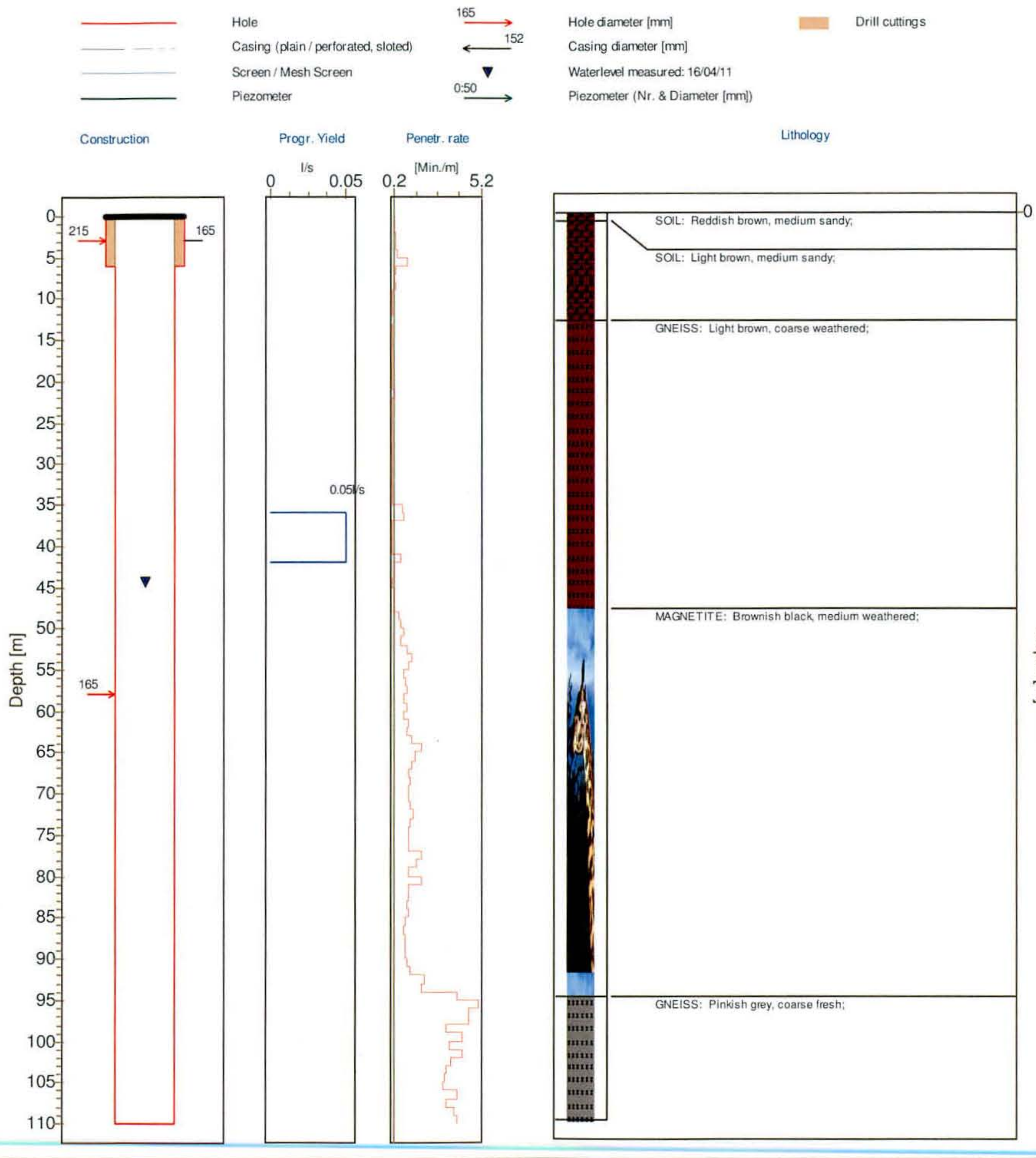
Distr./Farm No.: LPLR111 ***Site Name/Des.:*** MOONLIGHT PTN. MOONLIGHT

Region Type: District Council ***Region Descr.:*** WATERBERG/LEPHALALE

Latitude [°]:	23.238770	***Reg./BB.:*** TMMWG11	***Topo-set.:*** Flat surface, plain	***Depth [m]:***	109.37
Longitude [°]:	28.220040	***G-Nr.:***	***Site status:*** Unused	***Col. ht. [m]:***	0.05
Altitude [m]:	975.00		***Site purp.:*** Production (water supply)	***Diam. [mm]:***	165
Coord. acc.:	Accurate to within 10 units		***Use applic.:*** Agricultural and domestic	***Drain. reg.:***	
Coord. meth.:	Global Positioning System		***Equipment:*** No equipment	***Rep. inst.:***	VSA

Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), WGS 1984

Construction and Geohydrological Legend



COMMENT:

Borehole Construction and Geological Log

Date compiled: 2011/05/09

BASIC SITE INFORMATION: *Site Identifier:* 2328AAV0014 *Number:* H03-3866 *Site type:* Borehole

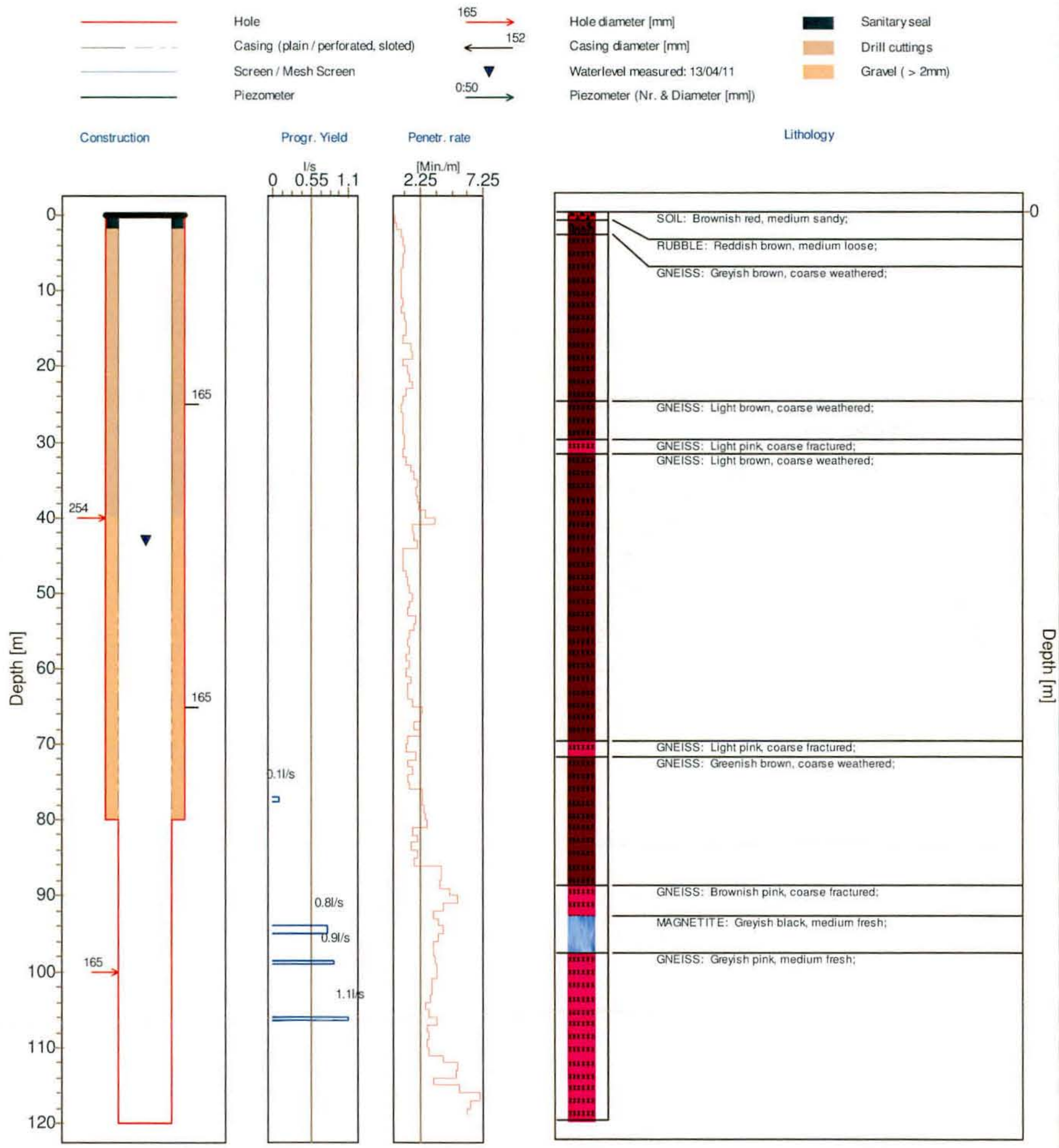
Distr./Farm No.: LPLR111 *Site Name/Des.:* MOONLGHT PTN. MOONLIGHT

Region Type: District Council *Region Descr.:* WATERBERG/LEPHALALE

Latitude [°]: 23.237880	*Reg./BB.:* TMMWG12	*Topo-set.:* Flat surface, plain	*Depth [m]:* 119.34
Longitude [°]: 28.219980	*G-Nr.:*	*Site status:* Unused	*Col. ht. [m]:*
Altitude [m]: 975.00		*Site purp.:* Production (water supply)	*Diam. [mm]:* 180
Coord. acc.: Accurate to within 10 units		*Use applic.:* Domestic - all purposes	*Drain. reg.:*
Coord. meth.: Interpolated from map		*Equipment:* No equipment	*Rep. inst.:* VSA

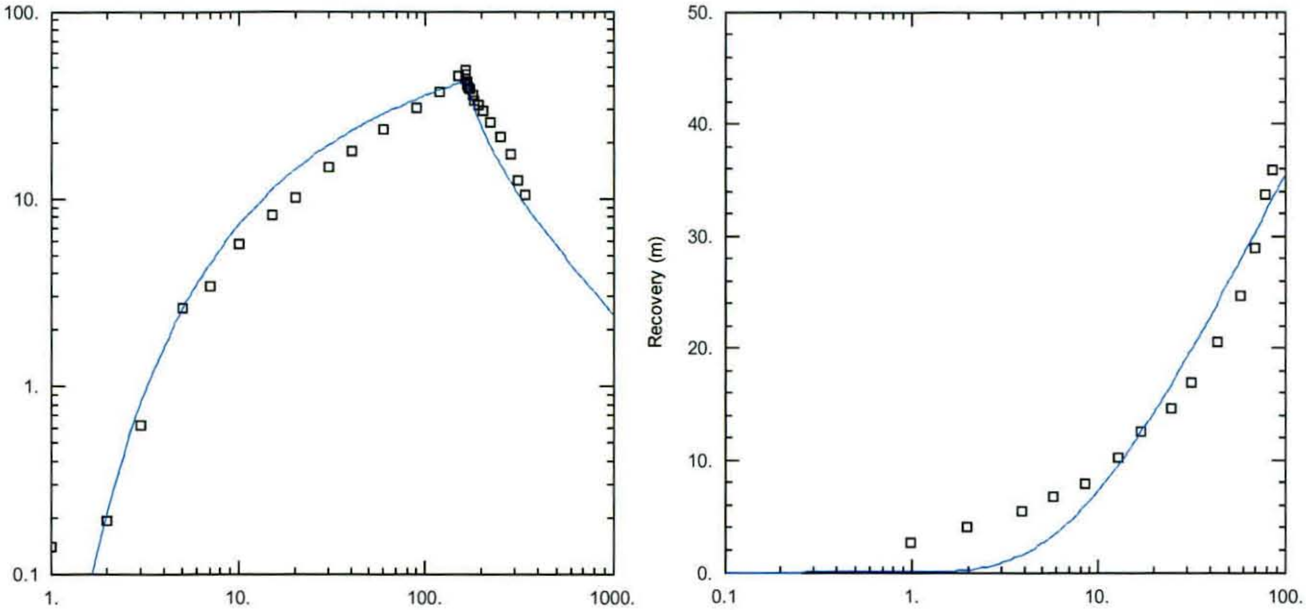
Coordinate System: Geographic Decimal Degrees (Longitude/Latitude), WGS 1984

Construction and Geohydrological Legend

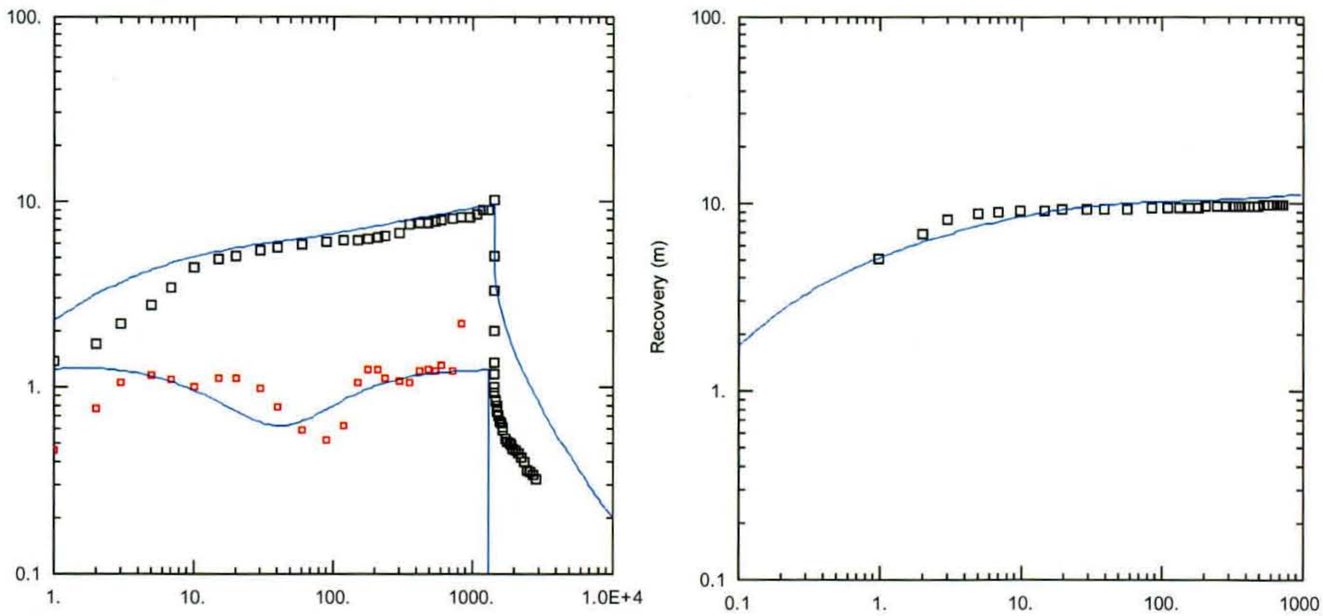


COMMENT:

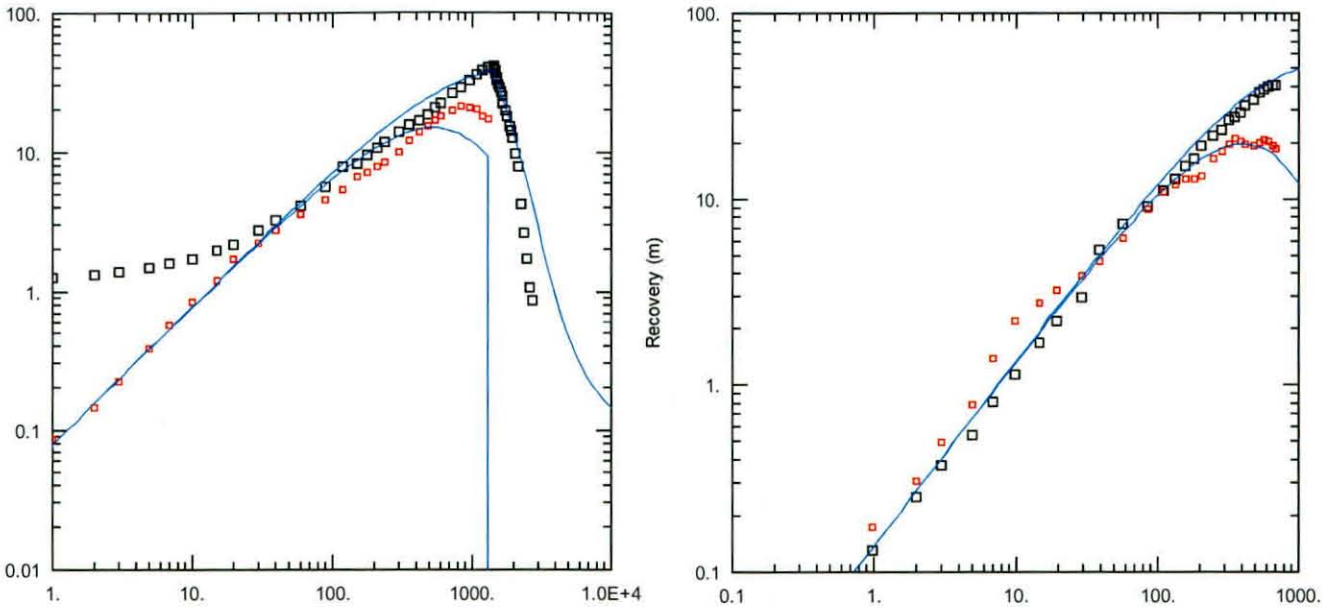
APPENDIX D: PUMPING TEST ANALYSIS PLOTS



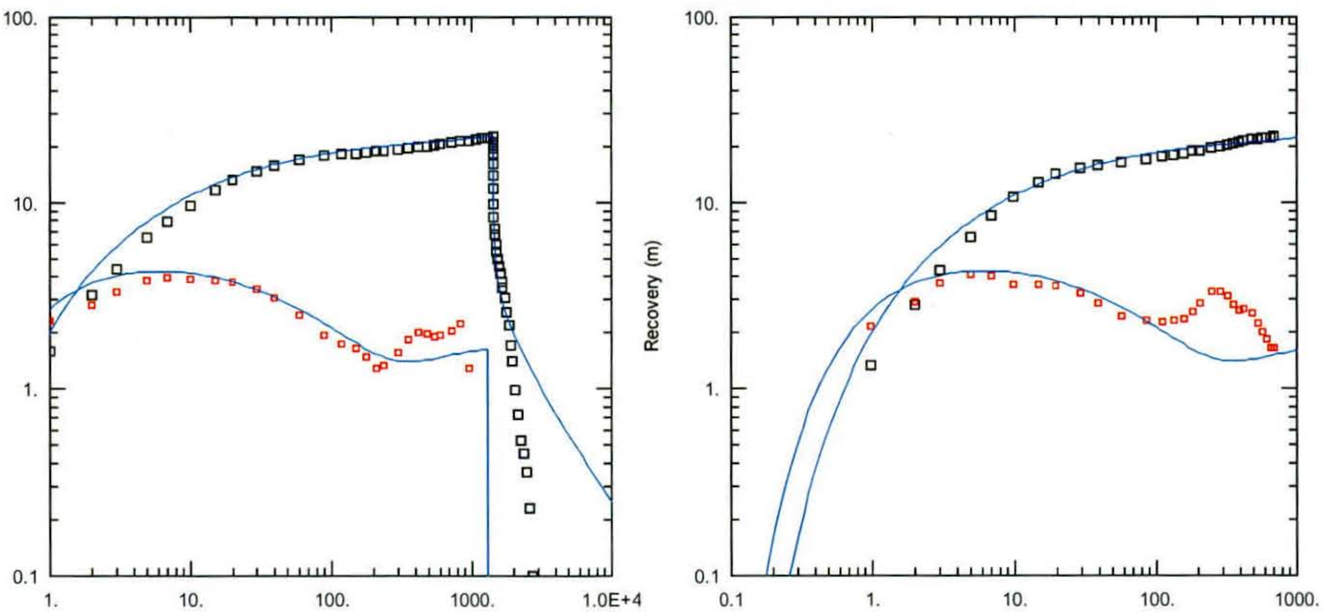
Diagnostic plots (log-log) and Agarwal (recovery plot) of the constant discharge test of borehole **TM-MWG04** fitted with a Neuman (unconfined) solution.



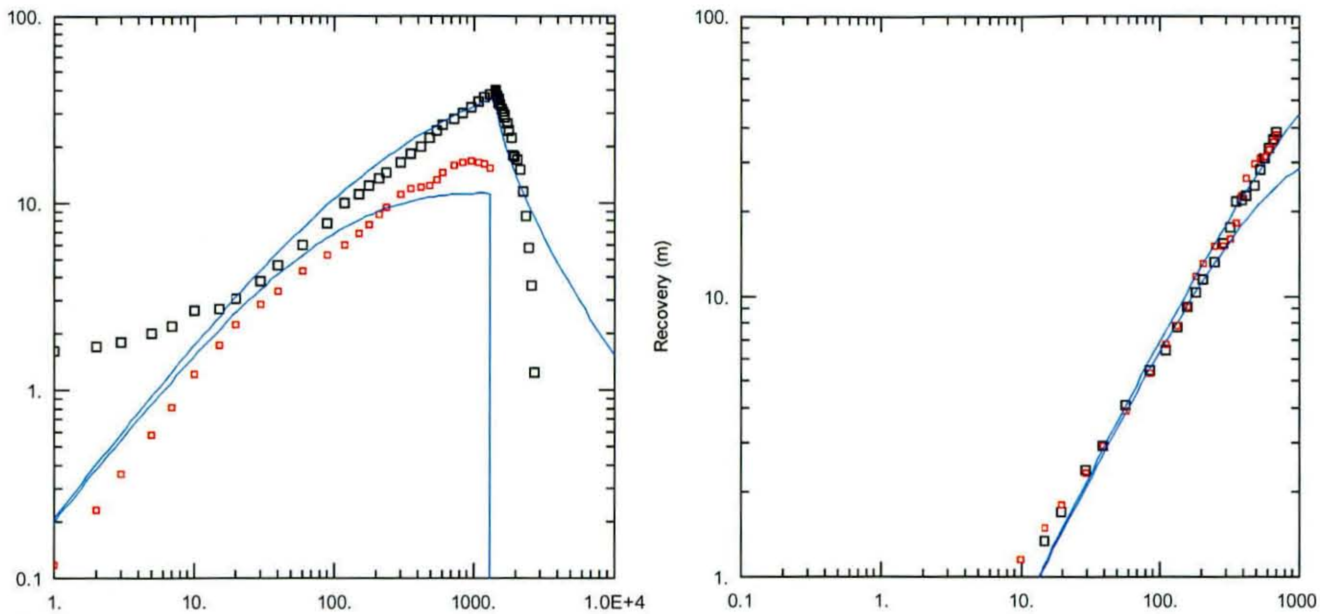
Diagnostic plots (log-log) and Agarwal (recovery plot) of the constant discharge test of borehole **TM-MWG01** fitted with a Neuman (unconfined) solution.



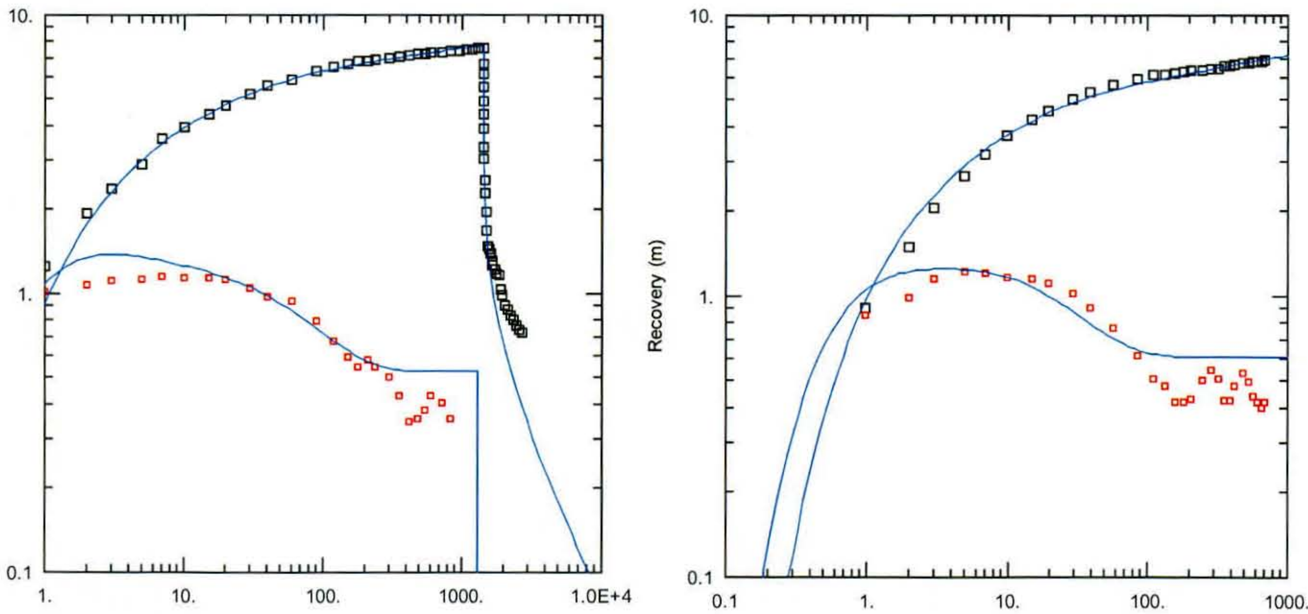
Diagnostic plots (log-log) and Agarwal (recovery plot) of the constant discharge test of borehole **TM-MWG11** fitted with a Moench (no flow leaky) solution.



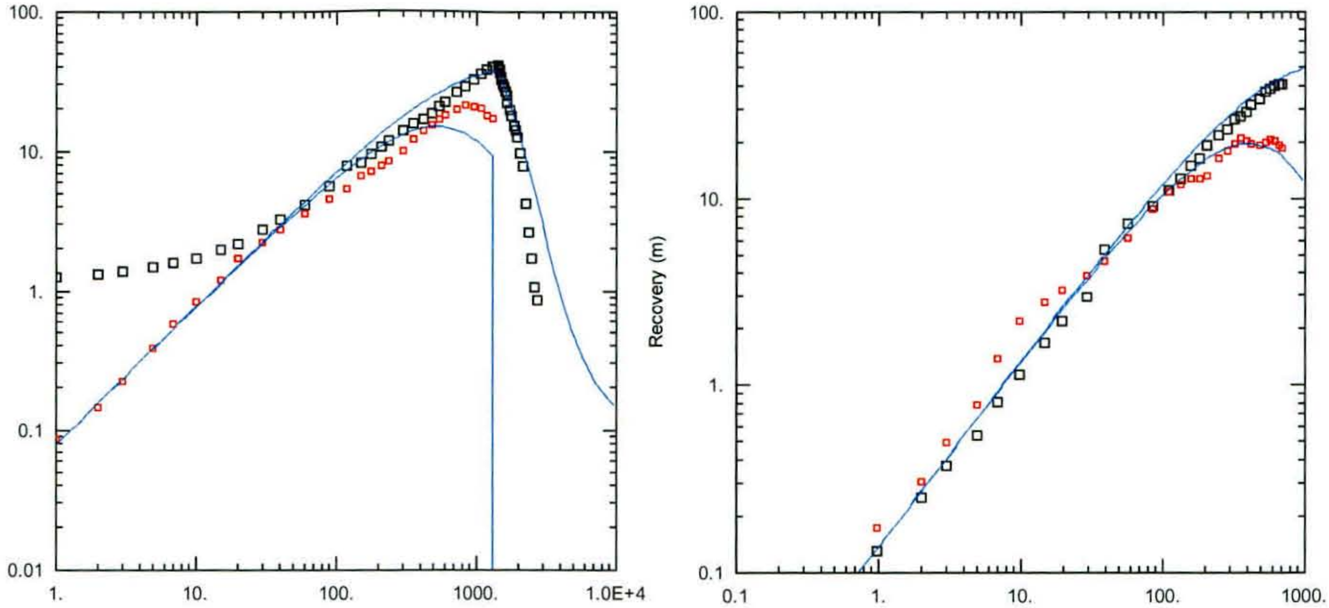
Diagnostic plots (log-log) and Agarwal (recovery plot) of the constant discharge test of borehole **TM-MWG12** fitted with a Neuman (unconfined) solution.



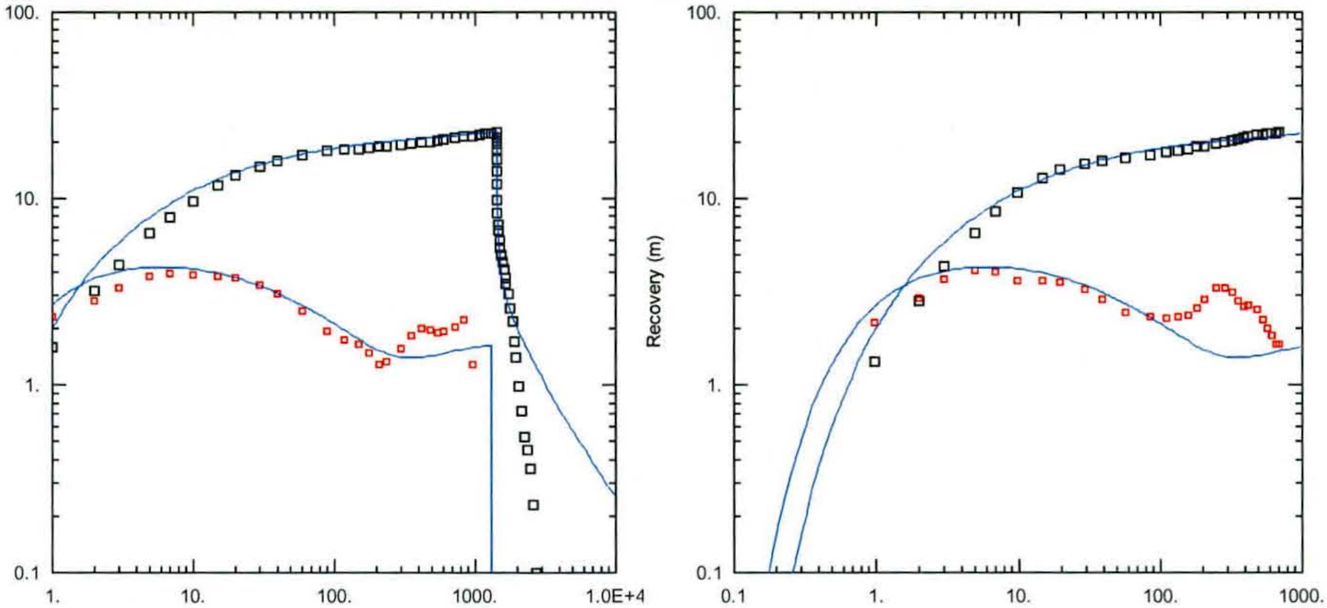
Diagnostic plots (log-log) and Agarwal (recovery plot) of the constant discharge test of borehole **BH39** fitted with a Moench (no flow leaky) solution.



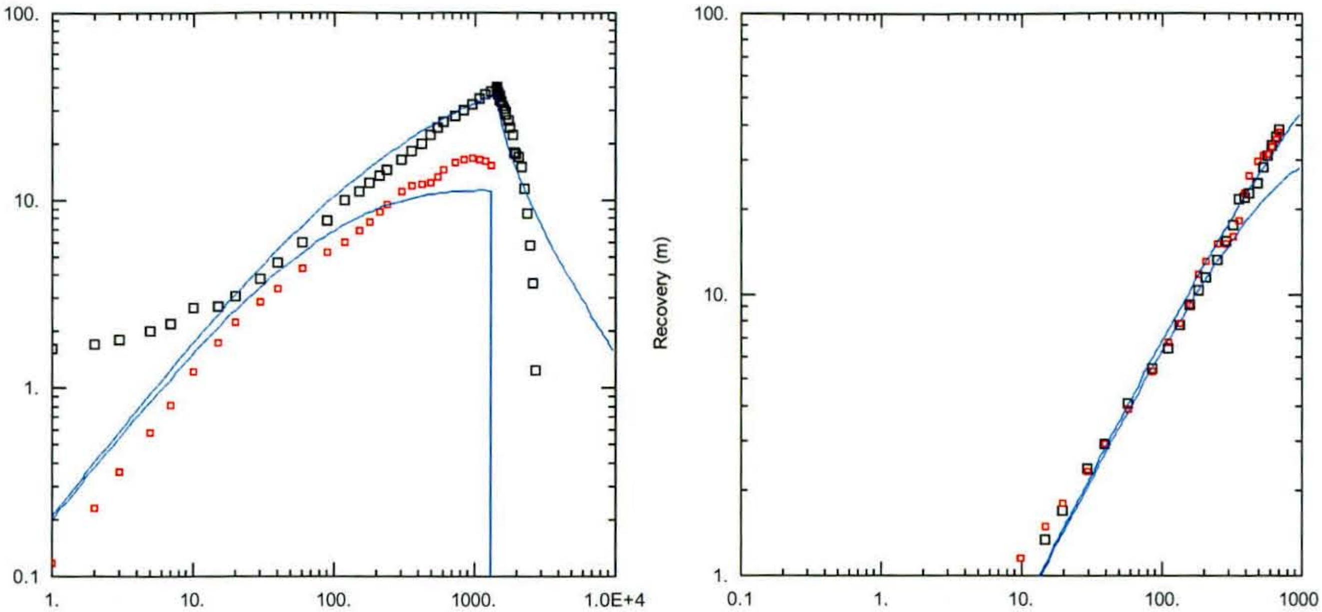
Diagnostic plots (log-log) and Agarwal (recovery plot) of the constant discharge test of borehole **BH4** fitted with a Moench (no flow leaky) solution.



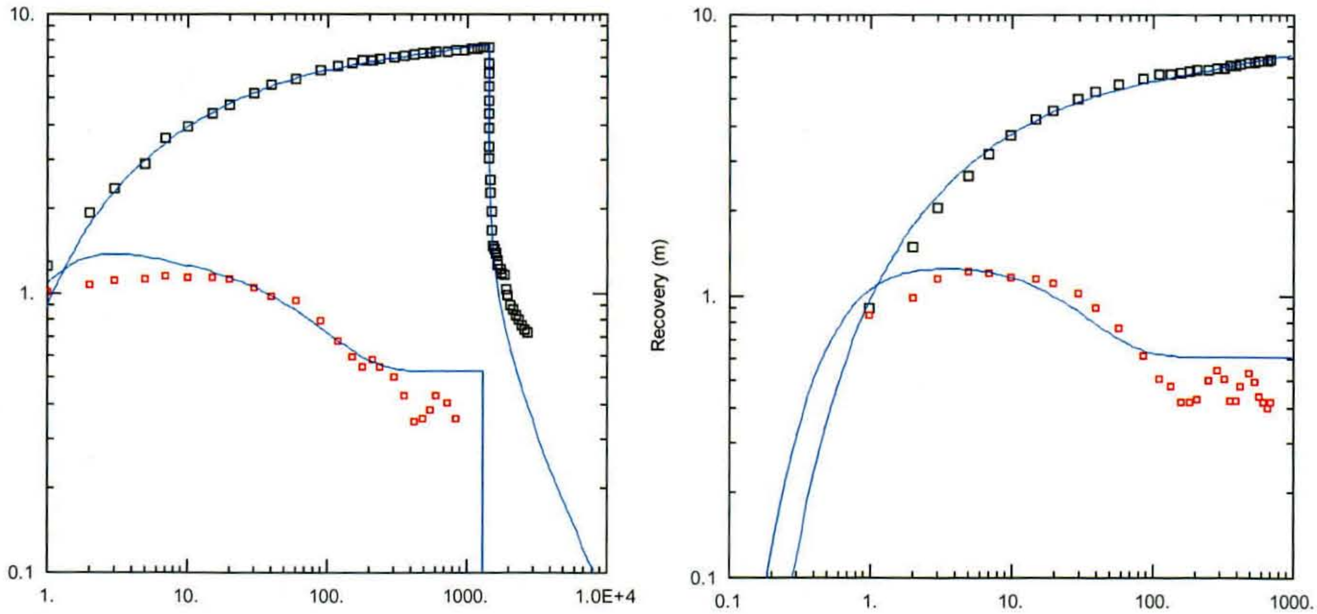
Diagnostic plots (log-log) and Agarwal (recovery plot) of the constant discharge test of borehole **TM-MWG11** fitted with a Moench (no flow leaky) solution.



Diagnostic plots (log-log) and Agarwal (recovery plot) of the constant discharge test of borehole **TM-MWG12** fitted with a Neuman (unconfined) solution.



Diagnostic plots (log-log) and Agarwal (recovery plot) of the constant discharge test of borehole **BH39** fitted with a Moench (no flow leaky) solution.



Diagnostic plots (log-log) and Agarwal (recovery plot) of the constant discharge test of borehole **BH4** fitted with a Moench (no flow leaky) solution.

Metago Environmental Engineers (Pty) Ltd
Consulting Engineers and Scientists

RECORD OF REPORT DISTRIBUTION

Project Number:	Proj. No. ET020-05
Title:	Hydrogeological Investigation and Impact Assessment for the Proposed Moonlight Iron Ore Mine
Report Number:	001/0132
Proponent:	Turquoise Moon Trading 157 (PTY) Ltd

Name	Entity	Copy No.	Date issued	Issuer
Alex Pheiffer	Metago Environemntal Engineers	1	1 June 2011	M Holland

APPENDIX L: AIR QUALITY STUDY

Specialist report prepared by Airshed Planning Professionals, June 2011

Project done on behalf of

Metago Environmental Engineers (Pty) Ltd

AIR QUALITY IMPACT ASSESSMENT FOR THE PROPOSED TURQUOISE MOON IRON ORE MINE, LIMPOPO PROVINCE

Report No.: APP/10/MEE-14 Rev 3

DATE: June 2011

H Liebenberg-Enslin

N Grobler

Airshed Planning Professionals (Pty) Ltd

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Halfway House
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Tel : +27 (0)11 805 1940
Fax : +27 (0)11 805 7010
e-mail : mail@airshed.co.za

REPORT DETAILS

Reference	APP/10/MEE-14
Status	Report, Revision 3
Report Title	Air Quality Impact Assessment for the proposed Turquoise Moon Mine, Limpopo Province
Date	June 2011
Client	Metago Environmental Engineers (PTY) Ltd
Prepared by	Hanlie Liebenberg-Enslin, MSc (University of Johannesburg) Nick Grobler, BSc.ChemEng (University of Pretoria)
Notice	Airshed Planning Professionals (Pty) Ltd is a consulting company located in Midrand, South Africa, specialising in all aspects of air quality, ranging from nearby neighbourhood concerns to regional air pollution impacts. The company originated in 1990 as Environmental Management Services, which amalgamated with its sister company, Matrix Environmental Consultants, in 2003.
Declaration	Airshed is an independent consulting firm with no interest in the project other than to fulfil the contract between the client and the consultant for delivery of specialised services as stipulated in the terms of reference.
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Acknowledgements	The authors would like to express their appreciation for the discussions and technical input from Alex Pheiffer from Metago.

Executive Summary

Airshed Planning Professionals (Pty) Ltd (Airshed) was appointed by Metago Environmental Engineers (Pty) Ltd (Metago) to conduct an air quality impact assessment for the proposed Turquoise Moon Mining Project as part of an Environmental Impact Assessment (EIA).

Turquoise Moon Iron Ore Mine Project (Turquoise Moon) is located in the north-western part of the Limpopo Province, approximately 30 km from the Botswana border. The proposed project will be an opencast iron ore mine including drilling and blasting activities, loading, hauling and off-loading of ore and waste rock, crushing and screening and a processing plant. There will be one tailings storage facility (TSF) and two waste rock dumps (WRDs) at the mine, linked to the open pit via unpaved haul roads. The mine access road, linking with the N11 between Mokopane and the Botswana border, will be unpaved.

The nearest towns to the proposed mine are Lephalale, approximately 70 km to the southwest and Mokopane, 140 km to the southeast.

Project Scope

The scope of the study includes a baseline characterisation and an impact assessment.

The baseline characterisation is limited to the assessment of meteorological data to determine the dispersion potential of the site since no existing ambient or dust fall data for the region exist. Ambient baseline monitoring for a period of at least one year is required to account for seasonal variation. The Waterberg Air Quality Management Plan compiled in 2009 primarily focussed on the Lephalale region and is not regarded representative of the area around Turquoise Moon. As a District, the Waterberg Municipality is ranked potentially poor by the Department of Environmental Affairs (DEA) meaning the potential exist for exceedances of the National Ambient Air Quality Standards (NAAQSs).

There is no on-site weather station and meteorological data for a location at the site were obtained from the South African Weather Services Unified Model Data for one year (2009). This was used as input to the dispersion model.

Particulates represent the main pollutant of concern when assessing open cast mining operations. Particulates are divided into different particle size categories with Total Suspended Particulates (TSP) associated with nuisance impacts and the finer fractions of PM_{10} (particulates with a diameter less than 10 μm) and $PM_{2.5}$ (diameter less than 2.5 μm) linked with potential health impacts. PM_{10} is primarily associated with mechanically generated dust whereas $PM_{2.5}$ is associated with combustion sources. Gaseous pollutants (such as sulphur dioxide, oxides of nitrogen, carbon monoxide, etc.) are derived from vehicle exhausts but regarded as negligible in comparison to particulate emissions and are therefore omitted from the assessment.

The impact assessment includes the qualitative assessment of construction activities, closure and post closure phases as well as the quantitative assessment of the operational phase.

Construction operations will include a series of different activities such as land clearing, topsoil removal, road grading, material loading and hauling, stockpiling, etc., each with its own duration and potential for dust generation. Due to the lack of a detailed construction activity plan, an area wide emission factor was applied to estimate the total TSP emissions that will derive for the 24 month period. This is regarded a conservative approach assuming all construction activities will occur simultaneously and over the entire area. The potential for impact is qualitatively assessed.

The operational phase includes the identification and quantification of all dust generating sources at the proposed mine. A comprehensive emissions inventory was compiled based on the mine layout plan and mining rates as supplied. A total of 6.5 million tons per annum of ore and a similar amount of waste material will be mined per year. The Life of Mine is estimated at 30 years and operations will be for 24 hours per day, seven days per week. In the quantification of fugitive dust emissions, emission factors were used linking the quantity of a pollutant to the activity associated with the release of that pollutant. Use was made of the comprehensive set of emission factors published by the US Environmental Protection Agency (US.EPA) in its AP-42 document compilation of Air Pollution Emission Factors and the Australian National Pollution Inventory (NPI) documents. The two scenarios assessed include unmitigated; assuming no dust control measures to be in place and mitigated. The latter assumes water sprays will be applied to the crushing and screening operations resulting in 60% control efficiency and on the roads resulting in 75% control efficiency.

Dispersion modelling is used to simulate the potential for impacts on the surrounding environment and human health. Dispersion models don't contain all the features of a real system but hold the feature of interest for management issues or scientific problems to be solved. The US.EPA regulatory AERMOD model was used to simulate highest daily and annual average ground level concentrations (GLCs). AERMOD is a Gaussian plume model with an uncertainty range of between -50% to 200%. An area of 20 km by 20 km was included in the model with the mine in the centre of the modelling domain.

The averaging periods were selected to facilitate the comparison of predicted pollutant concentrations/ deposition with relevant National Ambient Air Quality Standards (NAAQS) and SANS Dust Fallout limits, respectively. According to the Air Quality Act of 2004, ambient air quality standards apply to areas where the general public has access i.e. outside the mine boundary. Nearby farm houses and homesteads were included as sensitive receptors in addition to assessing the impacts at the mine boundary.

According to the closure plan, the TSF side walls will be rock gladded with paddocks of vegetation and pools established on-top. This will reduce the potential for wind erosion.

In interpreting the study findings it is important to note the limitation and assumptions on which the assessment was based. A list of these uncertainties is provided in the report.

Conclusions

Emissions - From the emissions quantification, windblown dust from the two WRDs and the TSF are the main contributing sources to both PM_{10} (60%) and TSP (48%) emissions for the unmitigated scenario. Dust emanating from unpaved haul roads and the access road is the second most significant source group contributing 24% to PM_{10} and 37% to TSP. Crushing and screening, third on the list, adds 9% and 10% to PM_{10} and TSP, respectively. With mitigation in place, the overall emissions will reduce by 24% and 33% for PM_{10} and TSP, respectively.

PM_{10} Ground Level Concentrations for the three mining phases were as follows:

- Construction operations – calculations indicate that the main dust generating activities will generate 751.30 tons of TSP per month. This is 1.3 times that of the annual tonnages for TSP produced by the operational phase. It is however unlikely that the construction operations would result in higher impacts than the operational phase given that construction will occur in a stepped approach and not simultaneously.

- Operational phase - PM_{10} daily impacts are significant in close proximity to the mine when no mitigation is applied. Predictions indicate that the NAAQ limit of 75 µg/m³ will be exceeded for more than 4 days per year implicating non-compliance with the AQA. The impact area stretches approximately 3 km to the east and south of the mine boundary and includes two farm dwellings. The annual NAAQS is not exceeded. The main contributing sources to predicted GLCs are unpaved roads, materials handling (specifically crushing and screening) and windblown dust from the WRDs and TSF. With mitigation in place, the predicted impacts will comply with the NAAQSs.

- Closure and Post-closure - The potential for impacts during the closure phase will be dependent on the extent of demolition and rehabilitation efforts. The proposed rehabilitation option will reduce the potential for windblown dust significantly.

Dust fallout rates for the operational phase were as follows:

- Predictions indicate high dust fallout rates (>600 mg/m²/day) on-site, close to the dust generating sources. Dust fallout rates off-site are well below the residential limit of 600 mg/m²/day. Predicted off-site dust fall is also below the European limit for vegetation impacts of 400 mg/m²/day. With mitigation in place, these impacts will reduce to an even smaller area.

Recommendations

From the impact assessment it is evident that the main sources of particulate matter at the proposed Turquoise Moon mine are the unpaved roads, windblown dust from the WRDs and TSF and crushing and screening operations. The following recommendations are made based on these findings.

Recommendation 1 – The mine layout plan provided indicate the majority of dust generating sources centralised within a specific boundary. Adherence to this plan will limit the potential for off-site impacts. Drastic changes to the proposed plan will have adverse effects on the off-site PM_{10} concentrations and dust fallout rates.

Recommendation 2 - Vehicle entrained dust from unpaved road surfaces will result in high impacts near the roads and off-site. The mine plan indicates the use of water trucks for road dust suppression. An estimated 75% control efficiency is required to ensure a significant reduction in ground level concentrations from these roads. This will require 0.17 $l/m^2/hour$ when no annual rainfall is accounted for. Calculations were based on the hourly average truck activity. Chemical surfactants such as Dust-a-Side could also be considered for the access road. Chemical suppressants could achieve control efficiencies of 80% to 90% through effective application.

Recommendation 3 - Materials handling operations including crushing and screening of ore are significant sources of dust emissions. Enclosure of crushing operations is very effective in reducing dust, resulting in 75% control efficiency (CE) due to telescopic chutes with water sprays. Enclosure of storage piles where tipping occurs can achieve 99% CE. In addition, chemical suppressants or water sprays will assist in the reduction of the cumulative dust impacts. Water sprays can have up to 50% control efficiency and hoods with scrubbers up to 75%. In addition, enclosed scrubbers and screens could have a 100% control efficiency. It is recommended that control efficiencies of 60% should be achieved to ensure a significant reduction in off-site impacts.

Recommendation 4 – Windblown dust from the WRDs and TSF is a significant source of particulate emissions when it occurs. With no controls on the slopes and on the surfaces of these dumps and piles, high impacts can be experienced off-site. Wind erosion is governed by particle size distribution, binding forces between particles and roughness elements on the surface. It is understood that WRDs comprises various particle sizes, from ultrafine to large boulders. The latter acting both as a screen against the force of the wind and reducing the wind speed over the dump surface, thereby limiting the potential for erosion. The TSF, on the other hand, comprises of very fine particles prone to wind erosion. The wet surface will reduce the potential for windblown dust but the side walls remain a potential source if not mitigated. It is recommended that the walls of TSF be vegetated or rock gladded up to 1 m from the top throughout the life of mine to ensure an increase in both binding agents and roughness elements. It is possible that the surface of TSF, as at other iron ore mines, will harden if undisturbed and reduce the potential for dust generation. This should be verified once the mine is operational. The cover or natural binding should be of such a nature to ensure at least 60% control efficiency.

Monitoring

A dust fallout network comprising of eight single dust fallout buckets following the American Society for Testing and Materials standard method for collection and analysis of dust fall (ASTM D1739-98) should be installed. The bucket locations are indicated on a map and located either up or down wind from the wind dependent sources and close to the access road, the haul road and the crusher. In addition, it is recommended that a PM_{10} sampler be installed at the nearest sensitive receptor (farmhouse) to provide daily average data especially before the mine commences and continuing afterwards.

The main objective of the dust fallout network is to ensure the following:

- dust fallout in the immediate vicinity of the road perimeter to be less than 1 200 $mg/m^2/day$ and less than 600 $mg/m^2/day$ at the mine boundary.
- dust fallout in the immediate vicinity of the open pit should be below 1 200 $mg/m^2/day$.
- dust fallout levels should not exceed 600 $mg/m^2/day$ outside the mine boundary or at any sensitive receptor.
- PM_{10} GLCs should not exceed the NAAQS at the nearest sensitive receptor (less than 40 $\mu g/m^3$ over an annual average and not exceeding the daily limit of 75 $\mu g/m^3$ more than four times per calendar year).

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Airshed	Airshed Planning Professionals (Pty) Ltd
amsl	above mean sea level
ASTM	American Society for Testing And Materials
DEA	The South African Department of Environmental Affairs
TSF	Tailings Storage Facility
g	gram
GLC	Ground Level Concentration
I&AP	Interested and Affected Party
k	kilo
l	Litre
LOF	Life of Mine
m	metre
M	million
m^3	Cubic metre
NAAQS	National Ambient Air Quality Standards
NEMAQA	South Africa National Environment Management Air Quality Act (No. 39 of 2004)
NPI	National Pollutant Inventory (Australia)
PM_{10}	Particulate Matter with an aerodynamic diameter of less than 10μ
$PM_{2.5}$	Particulate Matter with an aerodynamic diameter of less than 2.5μ
ROM	Run of Mine
SA	South Africa
SABS	South African Bureau of Standards
SANS	South African National Standards
SAWS	South African Weather Services
tpa	Tonnes per annum
tpd	Tonnes per day
TSP	Total Suspended Particles
UMD	Unified Model Data
US	United States
μ	Microns
μg	Micrograms
US-EPA	United States Environmental Protection Agency
WB	The World Bank
WHO	The World Health Organisation
WRD	Waste Rock Dump