CITY OF TSHWANE METROPOLITAN MUNICIPALITY

BASIC ASSESMENT:

HYDROGEOLOGICAL INVESTIGATION
AT THE
HATHERLY CEMETERY

APRIL 2015

DOCUMENT NUMBER

111404	**HAT**	**2015**

Compiled by

aurecon

Project Title: Hydrogeological Investigation at the Hatherly Cemetery

Location: Mamelodi, Gauteng Province

Co-ordinates (WGS84):
S 25.74394^0
E 28.41133^0

Prepared for:
Environmental Management Services
04th Floor East
Old Mercedes Benz Building
11 Francis Baard Street
Pretoria
PO Box 1454
Pretoria 0001

Contact person: Ms Rudzani Mukheli

Compiled by:
Aurecon
Lynnwood Bridge Office Park
4 Daventry Street
Lynwood Manor
0081

Contact Person:
Louis Stroebel
Tel No: 012 427 3151

Project team:

L Stroebel	Geohydrologist
M Terblanche	Geotechnician

Signed on behalf of Aurecon:

L Stroebel

TABLE OF CONTENTS

EXECUTIVE SUMMARY .... **III**
1 INTRODUCTION .... ERROR! BOOKMARK NOT DEFINED.
2 METHODOLOGY **1**
2.1 DESK STUDY 1
2.2 SITE VISIT 1
2.3 HYDROCENSUS 1
2.4 GEOPHYSICAL SURVEY 1
2.5 BOREHOLE DRILLING 1
2.6 HYDRAULIC TESTING 2
2.7 GROUNDWATER SAMPLING 2
2.8 REPORTING 2
3 AVAILABLE INFORMATION **2**
4 PHYSIOGRAPHY **2**
4.1 SITE LOCATION 2
4.2 TOPOGRAPHY & DRAINAGE 2
4.3 GEOLOGY & HYDROGEOLOGY 2
5 GROUNDWATER USE **3**
6 GEOPHYSICAL SURVEY **4**
6.1 MAGNETIC TECHNIQUE 4
6.2 ELECTRO MAGNETIC TECHNIQUE 4
6.3 DISCUSSION OF RESULTS 5
7 BOREHOLE DRILLING **5**
8 HYDRAULIC TESTING **6**
9 GROUNDWATER CHEMISTRY **8**
10 MONITORING PROGRAM **12**
11 CONCLUSIONS & RECOMMENDATIONS **14**

LIST OF TABLES

Table 1. Details of boreholes identified during hydrocensus 3
Table 2. Coordinates of the geophysical traverses and drilling targets 5
Table 3. Details of the monitoring boreholes drilled at Hatherly Cemetery 6
Table 4. Calculated hydraulic conductivity as derived from the slug test data 6
Table 5. Chemical parameters compared to SANS 241-1:2011 (edition 1) drinking water standards 8
Table 6. Monitoring boreholes to be included into the monitoring program 12
Table 7. Proposed monitoring requirements 13

LIST OF FIGURES

Figure 1. Borehole HA-BH3 6

LIST OF APPENDICES

Appendix A: Maps

Appendix B: Geophysical Profiles

Appendix C: Borehole Logs

Appendix D: Slug Test Analysis

Appendix E: Laboratory Reports

EXECUTIVE SUMMARY

The *Environmental & Advisory Unit of Aurecon SA (Pty Ltd)* was appointed by the City of Tshwane Metropolitan Municipality to conduct a Basic Assesment for the Hatherly Cemetery. A hydrogeological investigation was conducted as part of Assesment requirements.

The investigation consisted of the following:

1. *Desk study & Hydrocensus.*
2. *Borehole siting by means of a ground geophysical survey.*
3. *Appointment of a drilling contractor and supervising the drilling of a monitoring borehole.*
4. *Hydraulic testing & chemical analysis of the newly drilled borehole.*
5. *Report on the findings of the investigation.*

Based on the existing data and newly acquired data, the following can be concluded:

- The cemetery is underlain by partly carbonaceous shale of the Silverton Formation, Pretoria Group (Valian Era). Part of the site is underlain by a diabase sill that was intruded into the shale sequence. This was confirmed during drilling.
- According to the 1:500 000 geohydrological map, the groundwater yield potential is classed as good on the basis that 40% of boreholes on record produce more than 2l/s and 22% produce more than 5l/s. No major water strikes were however intercepted in the newly drilled borehole. The boreholes identified during the hydrocensus do however have usable yields, although the yields are unknown.
- The groundwater rest level occurs between 10 and 25m below surface and this was confirmed by the measured water level of 22.97mbgl.
- A total of 3 magnetic and electromagnetic traverses were performed with a total length of 420m, 200m and 150m each, respectively. An anomaly was detected at 370m on traverse 1 and the monitoring borehole was drilled at this location. No anomalies were detected on the remaining traverses.
- It can be assumed that the regional groundwater flow direction will emulate to local topography. Groundwater flow will thus be in a north easterly and south westerly direction. Calculations from the hydraulic testing showed that pollutants from the cemetery would thus migrate at an estimated rate of ~1.6×10^{-5} m/d towards the Edendalspruit.
- The hydrocensus revealed the existence of two boreholes. The boreholes are equipped with submersible pumps, belong to Hatherly Cemetery and are used for domestic purposes by its staff and visitors to the cemetery.
- Pumped groundwater samples were collected for chemical analysis from boreholes identified during the hydrocensus, while a bailed sampled was collected from the newly drilled borehole. All of the boreholes reported water quality within the Standard Limits of the SANS 241-1 standard and it can be assumed that these boreholes have not been impacted upon by the operations at the cemetery.
- Based on the aquifer classification it can be concluded that the aquifer system in the study area is a “Sole Aquifer System”. Groundwater is the sole water supply in the area. The aquifer is important for supplying baseflow to the Edendalspruit.

- Vulnerability Classification yields a Groundwater Quality Management Index of 6 for the study area, indicating that high level groundwater protection may be required.

Based on the above conclusions, the following recommendations are made:

- A groundwater monitoring program should be implemented to monitor the impact of the cemetery on the hydrogeological environment. Should it become evident from the monitoring program that pollution of the groundwater occurs, corrective and remedial actions should be implemented, especially due to the fact that groundwater is being used for drinking purposes at the cemetery.

1 INTRODUCTION

The Environmental & Advisory Unit of Aurecon SA (Pty Ltd) was appointed by the City of Tshwane Metropolitan Municipality to conduct a Basic Assesment for the Hatherly Cemetery. A hydrogeological investigation was conducted as part of Assesment requirements.

The investigation consisted of the following:

1. Desk study & Hydrocensus.
2. Borehole siting by means of a ground geophysical survey.
3. Appointment of a drilling contractor and supervising the drilling of a monitoring borehole.
4. Hydraulic testing & chemical analysis of the newly drilled borehole.
5. Report on the findings of the investigation.

This report is not intended to be an exhaustive description of the investigation at Hatherly Cemetery, but rather as a specialist hydrogeological study to evaluate the overall hydrogeological character of the site, as well as recommendations on a groundwater monitoring program.

2 METHODOLOGY

The work completed for the purposes of compiling a hydrogeological report comprised the following:

2.1 Desk Study

The collating of all existing published data. Aerial photos and geological maps were studied to identify possible structural features. This data was used to familiarise ourselves with the site conditions and project objectives. Target areas for the geophysical traverses were identified.

2.2 Site Visit

A site visit was conducted to familiarise ourselves with the site and to evaluate the geology, hydrogeology and potential receptors of pollution emanating from the cemetery.

2.3 Hydrocensus

A hydrocensus was carried out on the property of the cemetery as well as the adjacent area to identify legitimate groundwater users, the groundwater potential and quality. Where possible, groundwater levels were also measured to assist in the understanding of groundwater flow at the site.

2.4 Geophysical Survey

A geophysical survey was performed in pre-determined areas of the site to identify possible dykes, faults and/or fracture zones which may act as groundwater flow barriers or preferential pathways. The Electro-magnetic and Magnetic methods were used in the survey. The data was used to assist in the placement of the monitoring borehole.

2.5 Borehole Drilling

After interpretation of the geophysical data, a drilling target was selected. The borehole was drilled using an air percussion rig and the borehole will act a fourfold purpose: (1) verification of the geology; (2) determine aquifer parameters through hydraulic testing; (3) determine groundwater quality and (4) serve as a future monitoring borehole.

2.6 Hydraulic Testing

Hydraulic testing of the newly drilled borehole was done to determine aquifer parameters (hydraulic conductivity) which will give an indication of the rate at which groundwater flows in the investigated area. Falling head tests (“slug tests”) were carried out.

2.7 Groundwater Sampling

Groundwater samples were collected for a major inorganic analysis in the newly drilled borehole, as well as boreholes identified during the hydrocensus.

2.8 Reporting

Upon completion of the desk study and field work, a document was compiled summarising the findings of the investigation.

3 AVAILABLE INFORMATION

The following information was available and was used in the investigation:

- 1:50 000 Geological Map (2528CB Silverton).
- 1:500 000 Hydrogeological Map (Johannesburg 2526)
- An Explanation of the 1:500 000 General Hydrogeological Map – Johannesburg 2526. HC Barnard, October 2000.

4 PHYSIOGRAPHY

4.1 Site Location

The site is located in the suburb of Mamelodi in the east of Pretoria. It is accessible from Solomon Mahlangu Road (M21) via Mkatshlua Street (Map 1, Appendix A). The adjacent land-use mainly comprise of a number of smallholdings where small scale agricultural activities are practised as well as a solid waste refuse site belonging to the City of Tshwane Municipality.

4.2 Topography & Drainage

The cemetery is located on a watershed and slopes towards the north eastern direction as well as the south western direction. The north eastern part of the site has a gradient of 1% and is drained by a tributary of the Edendalspruit, which flows into the Roodeplaat Dam. The south western part of the site has a gradient of 1% and is drained by tributaries of the Pienaars River, also flowing into the Roodeplaat Dam.

4.3 Geology & Hydrogeology

According to the published 1:50 000 geological map (2528CB Silverton) the cemetery is underlain by partly carbonaceous shale of the Silverton Formation, Pretoria Group (Valian Era) (Map 2, Appendix A). Part of the site is underlain by a diabase sill that was intruded into the shale sequence. The contact zones of the sill are usually fractured and this may act as a preferential pathway for groundwater flow.

According to Barnard (2000), groundwater occurrence favours weathered shale, brecciated or jointed zones and especially the contact zones between intrusive diabase sheets and the shale. The groundwater yield potential is classed as good on the basis that 40% of boreholes on record produce more than 2l/s and 22% produce more than 5l/s. Higher yielding boreholes most often occur in association with the surface water drainage systems of the broad valley bottoms.

The general suitability of the groundwater for any use is indicated by the average EC value of 58 mS/m and a mean pH value of 7.6.

The groundwater rest level occurs between 10 and 25m below surface and this was confirmed by the measured water level of 22.97mbgl.

It can be assumed that the regional groundwater flow direction will emulate to local topography. Groundwater flow will thus be in a north easterly and south westerly direction.

5 GROUNDWATER USE

A hydrocensus was carried out on the 11th of March 2015 on the property of the cemetery as well as the adjacent area to identify legitimate groundwater users, the groundwater potential and quality. The hydrocensus extended to a distance of ~1km from the cemetery, except where a river or a surface water body exists. The hydrocensus did not extend past such a feature as surface water bodies are usually hydraulically connected to an aquifer, acts as a constant-head boundary and a groundwater pollution plume would theoretically not extend past a constant head boundary.

Two boreholes were found and both are equipped with submersible pumps. These boreholes belong to the Hatherly Cemetery and are used for domestic purposes by its staff.

A pumped water sample was collected from the 2 boreholes and submitted to Aquatico Scientific (SANAS accredited laboratory) for a major cation/anion analysis. The sample was a blend of each of the boreholes due to the fact that both boreholes pump into the same reservoir sytem. The results of the water quality are discussed in detail in section 9.

The location of the boreholes is indicated in Map 3, Appendix A. Table 1 summarises the details of the boreholes identified during the hydrocensus.

Table 1. Details of boreholes identified during hydrocensus

BH nr.	Coordinates (WGS84)	Owner/Contact details	Static water level (#mbgl)	Estimated Yield (liters/hour)	User application
HA-BH1	S 25.74334° E 28.41220°	Hatherly Cemetery 072 368 0793	~	1500	Domestic
HA-BH2	S 25.74280° E 28.41277°	Hatherly Cemetery 072 368 0793	~	1500	Domestic

#mbgl - meters below ground level

6 GEOPHYSICAL SURVEY

A diabase sill underlying a portion of the site was identified on the regional geological map. However, geological maps are not intended to delineate structures on small scale, and thus geophysical methods had to be used to identify such structures, if present.

The objective of the field survey was to investigate possible geological lineaments or weathering to determine the location of possible water bearing structures which could act as preferred groundwater pathways. The ground geophysical survey would also aid to select suitable targets for the placement of the downstream monitoring borehole.

6.1 Magnetic technique

The earth's magnetic field, from an exploration geophysicist's perspective, consists of three parts:

- the main field (internal origin)
- a small field with external origin
- spatial variations of the main field which are caused by local magnetic anomalies in the near-surface crust of the earth.

The main field varies relatively slowly and can be shown to have an internal origin using spherical harmonic analysis. The present theory is that the source of this field is convection currents of conducting material circulating in the liquid outer core. The field closely represents that of a bar magnet with the two poles being closely to, but not exactly on, the geographical north and south poles of the earth. This field contributes to more than 99% of the total magnetic field.

The relatively small external field is caused by electric currents in the ionized layers of the upper atmosphere. Time variations of this part are much more rapid than for the main field. Variations are caused by solar lunar variations as well as magnetic storms which correlate with sunspot activity.

Local changes in the main field result from variations in the magnetic mineral content of near-surface rocks often indicating the presence of dykes and/or faults/shear zones. These anomalies do not persist over great distances and are the main targets of the groundwater explorationist.

The magnetometer used for the ground geophysics in this study is a proton-precession magnetometer. This instrument depends on the measurement of the free-precession frequency of protons that have been polarised in a direction approximately normal to the direction of the earth's field. Only the total field intensity (F) can be measured and the sensitivity is approximately 1 nT. The field procedure consists of taking a measurement at equal intervals along a profile. The values are presented as profile plots of amplitude versus distance. The shape of the magnetic profile is a function of the geometrical shape of the causative body, the direction of the profile, the inclination and declination of the main magnetic field at that position and whether or not the body has remnant magnetization.

6.2 Electro Magnetic technique

Electro-magnetic systems are based on the principles that all electrical currents have magnetic field associated with them and that all time varying magnetic fields will induce current in a conductor. A time varying magnetic field is generated by driving an alternating current through a wire loop. If any conductive material is present in the associated magnetic field, currents normal to the direction of the magnetic field will be induced in the conductor. These induced currents, in turn, create their own associated magnetic fields that, together with the primary field associated with the original transmitter, forms part of the total magnetic field. This resultant magnetic field is then measured in terms of the voltage induced in the receiver loop.

The EM-34 used during this study is a moving source (transmitter) – moving receiver type instrument. It consists of a transmitter coil and receiver coil, both small enough to be handled by a two man team. It has three standard coil separations, 10m, 20m, and 40m, corresponding to three different frequencies and different depths of investigation.

Two measurements (horizontal & vertical coil configuration) are taken at each point along a profile and presented as profile plots of amplitude versus distance. Dykes and/or faults/shear zones form anomalies which can be interpreted to yield conductance, depth and dip.

The EM-34 system allows easy and rapid measurements, is sensitive to changes in conductivities in the order of 5 or 10 % and the data can be interpreted fast and accurately.

6.3 Discussion of Results

A total of 3 magnetic and electromagnetic traverses were performed with a total length of 420m, 200m and 150m each, respectively. An anomaly was detected at 370m on traverse 1 and the monitoring borehole was drilled at this location. No anomalies were detected on the remaining traverses. Coordinates of the geophysical traverses and position of the drilling target are presented in Table 2. The geophysical profiles are presented in Appendix B.

Table 2. Coordinates of the geophysical traverses and drilling targets

Traverse nr.	Start Coordinates (WGS84)	End Coordinates (WGS84)	Drilling Target (Borehole nr)
HA-T1	S 25.74423° E 28.41375°	S 25.74593° E 28.41026°	370m (HA-BH3)
HA-T2	S 25.74592 ° E 28.41064 °	S 25.74558 ° E 28.40876 °	No target
HA-T3	S 25.74648 ° E 28.40957 °	S 25.74706 ° E 28.40823 °	No target

7 BOREHOLE DRILLING

One downstream monitoring borehole was drilled on the 4th of March 2015. The borehole was drilled down to a depth of 30m and delivered with 125 mm PVC casing, gravel pack, bentonite seal, concrete plinth, marker plate and lockable cap (Figure 1). Solid casing was installed in the upper 3m, together with a bentonite sanitary seal. Perforated (slotted) casing and a gravel pack was installed in the remainder of the borehole in order to allow seepage into the borehole.

Drilling of the boreholes was supervised by a qualified geotechnician/hydrogeologist and necessary information (geological profile, weathered zones, water strikes, borehole depth, casing installation, etc.) was recorded. The location of the monitoring boreholes is presented in Map 3 in Appendix A.

Details of the boreholes are presented in Table 3 and borehole and construction logs in Appendix C. Drilling verified the presence of a diabase intrusion as noted during the desk study.

Table 3. Details of the monitoring borehole drilled at Hatherly Cemetery

BH nr.	Coordinates (WGS84)	Depth (m)	Static water level (mbgl)	Water Strikes	Blow Yield (l/hour)
HA-BH3	S 25.74584^{o} E 28.41054^{o}	30	22.97	~	Dry

Figure 1. Borehole HA-BH3

8 HYDRAULIC TESTING

A falling head test ("slug test") was carried out on the newly drilled borehole. The test involves continues measuring of the water level response in a borehole to the rapid displacement of water therein. This displacement or rise in water level is caused as a result from the introduction of a slug below the rest water level. The "slug test" was carried out using a "Solinst Levelogger" recording water levels at very short intervals (3 seconds). Data acquired from the "slug tests" was used to calculate the hydraulic conductivity (K) used in the calculation of the flow velocity of groundwater on-site. Hydraulic conductivity provides an indication of the ease with which water moves through the subsurface and is used to calculate rates of groundwater movement.

The slug test analysis is presented in Appendix D and the results of the analysis are shown in Table 4.

Table 4. Calculated hydraulic conductivity as derived from the slug test data

BH nr.	K (m/d)
HA-BH2	3.97×10^{-4}

Hydraulic conductivity (K) measured in m/d can be defined as: *“the volume of a fluid passing through a porous medium in a unit time under a specific hydraulic gradient and moving through a unit area perpendicular to the flow direction.”* Darcy’s flow equation was used to calculate the groundwater flow velocity on-site. Darcy’s Law states that the rate of flow through a porous medium is proportional to the loss of head, and inversely proportional to the length of the flow path. Alternatively Darcy’s Law can be rewritten to be defined by the following equation:

$V = (K\ i)/n_e$

Where:

V = Flow velocity

K = Hydraulic Conductivity

i = Groundwater gradient/surface slope

n_e = Effective porosity

Applying the values calculated for the site and using a porosity of 25% (0.25), the groundwater flow velocity on-site was calculated to be:

$V = (0.0004 \times 0.01)/0.25$

$= 1.6 \times 10^{-5}$ m/d

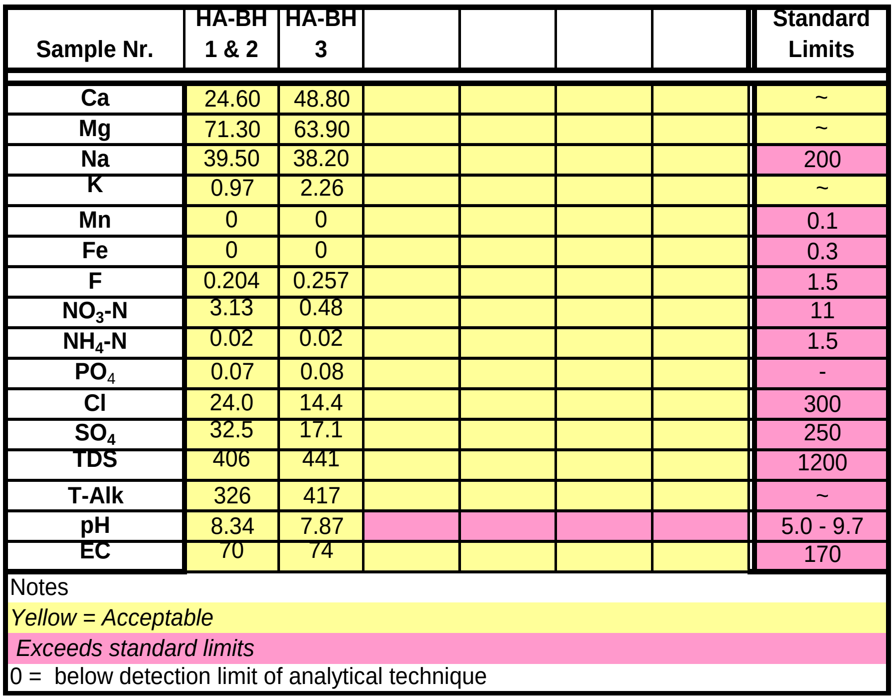
Based on Darcy’s flow equation potential pollutants originating from the cemetery and seeping to the groundwater would thus migrate at an estimated rate of $\sim 1.6 \times 10^{-5}$ m/d towards the Edendalspruit.

9 GROUNDWATER CHEMISTRY

Pumped groundwater samples were collected for chemical analysis from boreholes identified during the hydrocensus, while a bailed sample was taken from the newly drilled borehole on the 11th of March 2015. The groundwater samples were submitted to an accredited laboratory (*Aquatico Scientific in Pretoria*) for a major cation/anion analysis, as well as selected trace metals. The laboratory reports are attached in Appendix E.

The analytical results were compared with the SABS drinking water standards (SANS 241-1:2011, edition 1) (Table 5). Water is classified unfit for human consumption if the Standard Limits are exceeded.

Table 5. Chemical parameters compared to SANS 241-1:2011 (edition 1) drinking water standards



Sample Nr.	HA-BH 1 & 2	HA-BH 3					Standard Limits
Ca	24.60	48.80					~
Mg	71.30	63.90					~
Na	39.50	38.20					200
K	0.97	2.26					~
Mn	0	0					0.1
Fe	0	0					0.3
F	0.204	0.257					1.5
NO_3-N	3.13	0.48					11
NH_4-N	0.02	0.02					1.5
PO_4	0.07	0.08					-
Cl	24.0	14.4					300
SO_4	32.5	17.1					250
TDS	406	441					1200
T-Alk	326	417					~
pH	8.34	7.87					5.0 - 9.7
EC	70	74					170

Notes

Yellow = Acceptable

Exceeds standard limits

0 = below detection limit of analytical technique

EC measurements in mS/m, other parameters in mg/ℓ

From Table 5 it can be concluded that the water quality in all of the boreholes at the Hatherley cemetery fall within the Standard Drinking Water Limits.

Based on the analytical result, it can be concluded that the operation of the cemetery has not had an impact on the investigated boreholes to date.

10 AQUIFER CLASSIFICATION

The aquifer(s) underlying the project area were classified in accordance *with "A South African Aquifer System Management Classification, December 1995."*

Classification has been done in accordance with the following definitions for Aquifer System Management Classes:

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

Based on information collected during the hydrocensus it can be concluded that aquifer system in the study area can be classified as a "Sole Aquifer System". Groundwater is the sole water supply in the area. The aquifer is important for supplying baseflow to the Edendalspruit.

In order to achieve the Groundwater Quality Management Index a points scoring system as presented in Table 6, Table 7 and Table 8 was used.

Table 6. Ratings for the Aquifer System Management and Second Variable Classifications:

Aquifer System Management Classification		
Class	Points	Study area
Sole Source Aquifer System:	6	6
Major Aquifer System:	4	
Minor Aquifer System:	2	
Non-Aquifer System:	0	
Special Aquifer System:	0 – 6	
Second Variable Classification (Weathering/Fracturing)		
Class	Points	Study area
High:	3	
Medium:	2	
Low:	1	1

Table 7. Ratings for the Groundwater Quality Management (GQM) Classification System:

Aquifer System Management Classification		
Class	Points	Study area
Sole Source Aquifer System:	6	6
Major Aquifer System:	4	
Minor Aquifer System:	2	
Non-Aquifer System:	0	
Special Aquifer System:	0 - 6	
Aquifer Vulnerability Classification		
Class	Points	Study area
High:	3	
Medium:	2	
Low:	1	1

The occurring aquifer(s), in terms of the above definitions, is classified as a sole aquifer system.

The vulnerability, or the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer, in terms of the above, is classified as **low**. A relatively deep water table (>22 mbgl at places) and relatively fresh rock underlie the site.

The level of groundwater protection based on the Groundwater Quality Management Classification:

GQM Index = Aquifer System Management x Aquifer Vulnerability

= 6 X 1 = 6

Table 8. GQM index for the study area

GQM Index	Level of Protection	Study Area
<1	Limited	
1 - 3	Low Level	
3 - 6	Medium Level	
6 - 10	High Level	6
>10	Strictly Non-Degradation	

Aquifer Susceptibility

Aquifer susceptibility, a qualitative measure of the relative ease with which a groundwater body can be potentially contaminated by anthropogenic activities and which includes both aquifer vulnerability and the relative importance of the aquifer in terms of its classification, in terms of the above, is classified as **low**.

Aquifer Protection Classification

The ratings for the Aquifer System Management Classification and Aquifer Vulnerability Classification yield a Groundwater Quality Management Index of 6 for the study area, indicating that **high level groundwater protection** may be required.

Due to the high GQM index calculated for this area, a high level of protection is needed to adhere to DWS's water quality objectives. Reasonable and sound groundwater protection measures are recommended to ensure that no cumulative pollution affects the aquifer, even in the long term.

In terms of DWS's overarching water quality management objectives which is (1) protection of human health and (2) the protection of the environment, the significance of this aquifer classification is that if any potential risk exist, measures must be triggered to limit the risk to the environment, which in this case is the (1) protection of the Secondary Underlying Aquifer, (2) the Edendalspruit which drains the subject area and (3) the number of external users of groundwater in the area.

11 MONITORING PROGRAM

A groundwater monitoring network has been developed for the Hatherley Cemetery, incorporating boreholes identified during the hydrocensus and the newly drilled borehole (Table 9). It is important to note that a groundwater-monitoring network should be dynamic. This means that the network should be extended over time to accommodate the migration of contaminants through the aquifer as well as the expansion of infrastructure and/or addition of possible pollution sources.

Table 9. Monitoring boreholes to be included into the monitoring program

Borehole	Objective
HA-BH1	Downstream from the cemetery. Impact Monitoring.
HA-BH2	Downstream from the cemetery. Impact Monitoring.
HA-BH3	Downstream from the cemetery. Impact Monitoring.

Water samples must be taken from all the monitoring boreholes by using approved sampling techniques and adhering to recognised sampling procedures. Table 10 below presents the parameters and frequency that should form part of the groundwater monitoring program. The results should be recorded on a data base and reported annually to the Department of Water and Sanitation.

Table 10. Proposed monitoring requirements

Class	Parameter	Frequency	Motivation
Physical	Static groundwater levels	Monthly	Time dependant data is required to understand the groundwater flow dynamics of the site. An anomaly in static water levels caused by mounding below the drainage field may give early warning to spillages or leakages from lined/unlined facilities.
	Rainfall	Daily	Recharge to the saturated zone is an important parameter in assessing groundwater vulnerability. Time dependant data is required to understand the groundwater flow dynamics of the site.
	Groundwater abstraction rates (if present)	Monthly	Response of groundwater levels to abstraction rates could be useful to calculate aquifer storativity – important for groundwater management. Could also explain anomalous groundwater level measurements.
Chemical	Major chemical parameters: Ca, Mg, Na, K, NO_3, NH_4, SO_4, Cl, Fe, Mn, F, Alkalinity, pH, EC, TDS.	Quarterly (Jan., Apr., Jul., Sept) May be reduced to bi-annual (April & Sept.) as more data becomes available)	Background information is crucial to assess impacts during operation and thereafter. Changes in chemical composition may indicate areas of groundwater contamination and be used as an early warning system to implement management/remedial actions. Legal requirement.
	Minor chemical constituents Cr & Cr^6, Ni, As, Cu, Pb, Cd, Zn Stable isotopes	Ad hoc Basis.	Changes in chemical composition may indicate areas of groundwater contamination and be used as an early warning system to implement management/remedial actions. The monitoring program should allow for research and refinement of the conceptual hydrogeological model. This may, from time to time, require special analyses like stable isotopes.

12 CONCLUSIONS & RECOMMENDATIONS

Based on the existing data and newly acquired data, the following can be concluded:

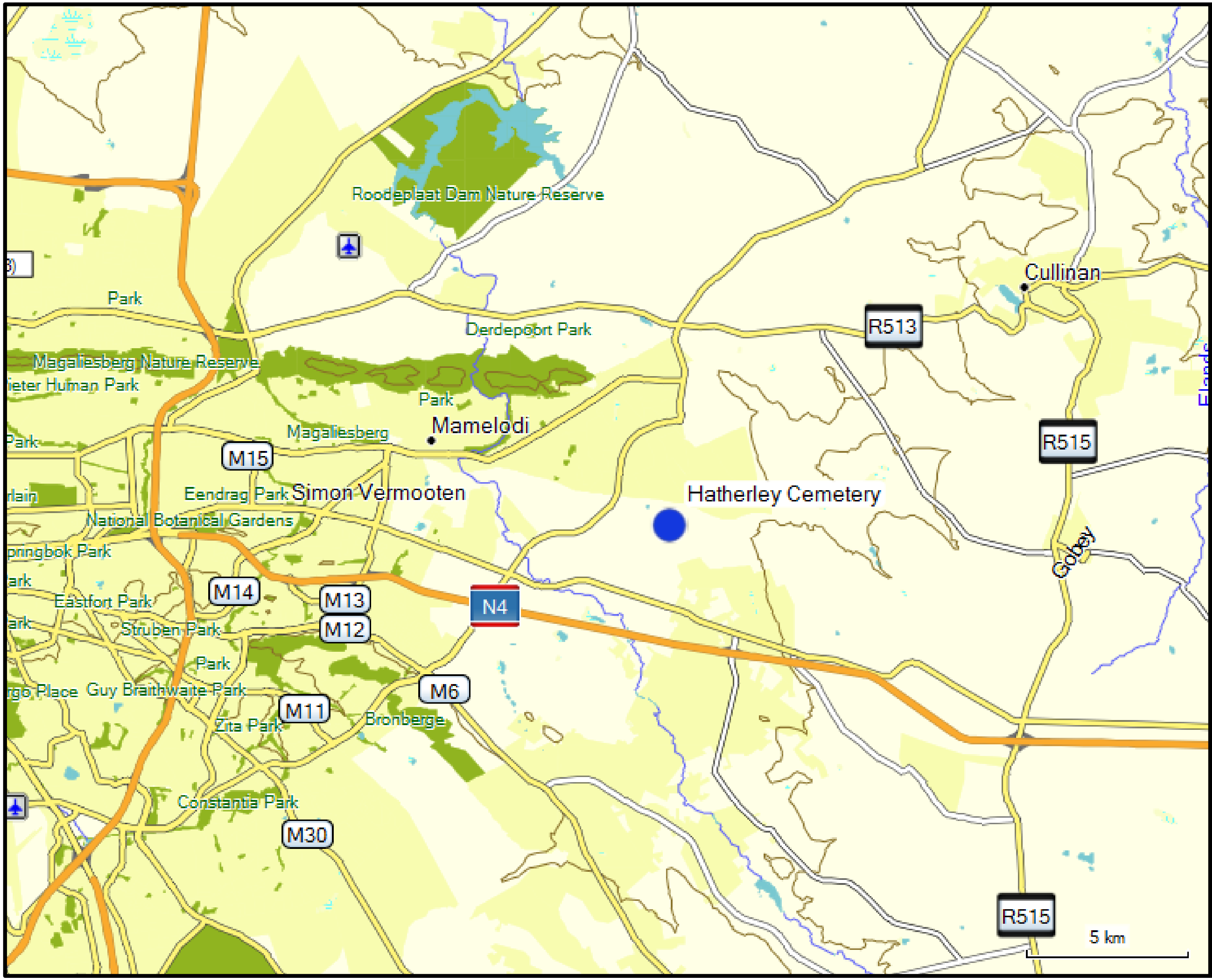
- The cemetery is underlain by partly carbonaceous shale of the Silverton Formation, Pretoria Group (Valian Era). Part of the site is underlain by a diabase sill that was intruded into the shale sequence. This was confirmed during drilling.
- According to the 1:500 000 geohydrological map, the groundwater yield potential is classed as good on the basis that 40% of boreholes on record produce more than 2l/s and 22% produce more than 5l/s. No major water strikes were however intercepted in the newly drilled borehole. The boreholes identified during the hydrocensus do however have usable yields, although the yields are unknown.
- The groundwater rest level occurs between 10 and 25m below surface and this was confirmed by the measured water level of 22.97mbgl.
- A total of 3 magnetic and electromagnetic traverses were performed with a total length of 420m, 200m and 150m each, respectively. An anomaly was detected at 370m on traverse 1 and the monitoring borehole was drilled at this location. No anomalies were detected on the remaining traverses.
- It can be assumed that the regional groundwater flow direction will emulate to local topography. Groundwater flow will thus be in a north easterly and south westerly direction. Calculations from the hydraulic testing showed that pollutants from the cemetery would thus migrate at an estimated rate of $\sim 1.6 \times 10^{-5}$ m/d towards the Edendalspruit.
- The hydrocensus revealed the existence of two boreholes. The boreholes are equipped with submersible pumps, belong to Hatherly Cemetery and are used for domestic purposes by its staff and visitors to the cemtery.
- Pumped groundwater samples were collected for chemical analysis from boreholes identified during the hydrocensus, while a bailed sampled was collected from the newly drilled borehole. All of the boreholes reported water quality within the Standard Limits of the SANS 241-1 standard and it can be assumed that these boreholes have not been impacted upon by the operations at the cemetery.
- Based on the aquifer classification it can be concluded that the aquifer system in the study area is a “Sole Aquifer System”. Groundwater is the sole water supply in the area. The aquifer is important for supplying baseflow to the Edendalspruit.
- Vulnerability Classification yields a Groundwater Quality Management Index of 6 for the study area, indicating that high level groundwater protection may be required.

Based on the above conclusions, the following recommendations are made:

- ➢ A groundwater monitoring program should be implemented to monitor the impact of the cemetery on the hydrogeological environment. Should it become evident from the monitoring program that pollution of the groundwater occurs, corrective and remedial actions should be implemented, especially due to the fact that groundwater is being used for drinking purposes at the cemetery.

APPENDIX A

MAPS



Project Title:

HYDROGEOLOGICAL INVESTIGATION AT THE HATHERLEY CEMETERY

Map Title:

HATHERLEY CEMETERY: Locality Map

Map Number:

Map 1

LEGEND

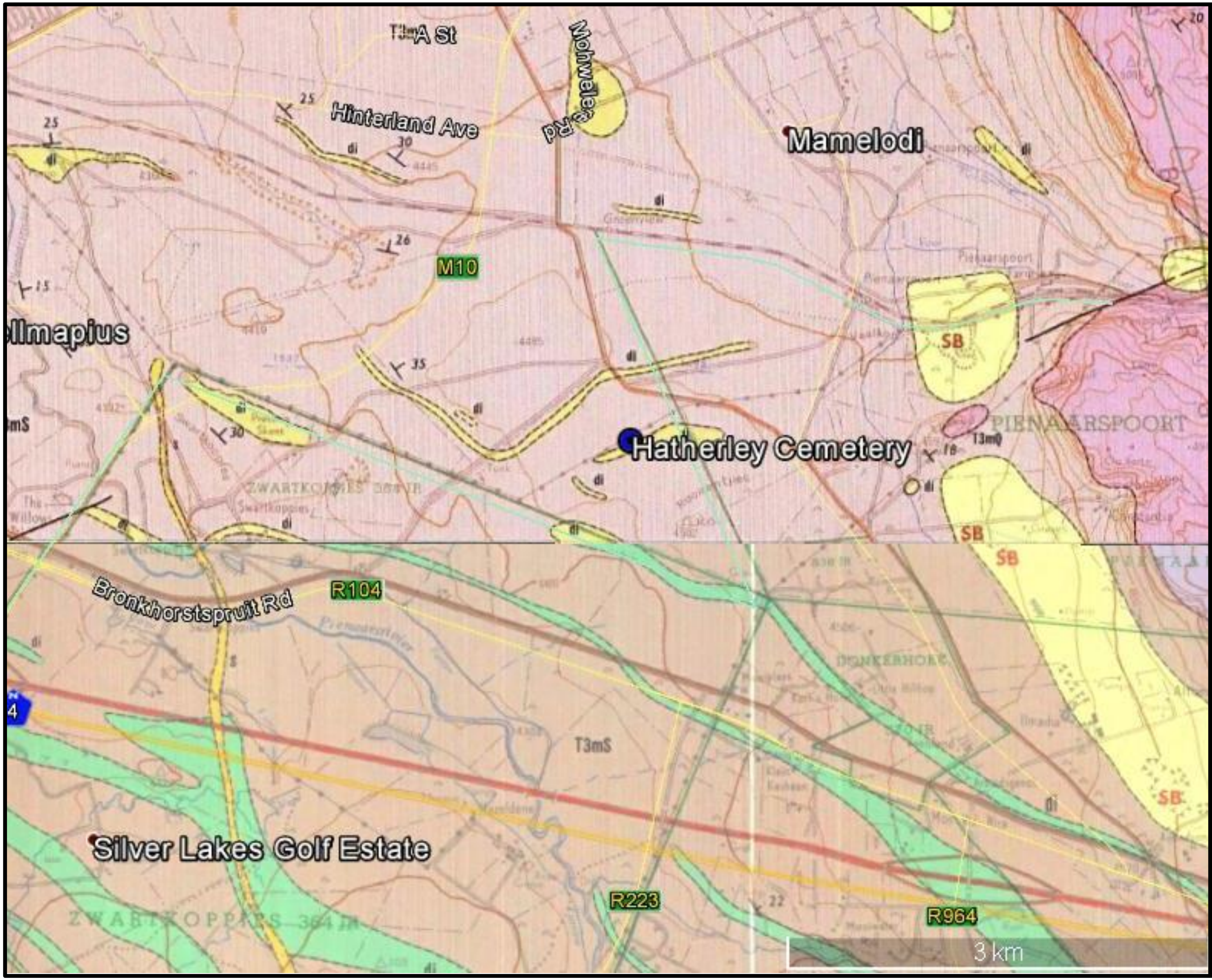
● Cemetery

N

Project nr: 111404

aurecon

Lynnwood Bridge Office Park
4 Daventry Street
Lynwood Manor 0040
www.aurecongroup.com



Project Title:

HYDROGEOLOGICAL INVESTIGATION AT THE HATHERLEY CEMETERY

Map Title:

HATHERLEY CEMETERY: Geological Setting

Map Number:

Map 2

LEGEND

di: Diabase

T3mS: Silverton Shale Formation, Pretoria Group

N

Project nr: 111404

aurecon

Lynnwood Bridge Office Park
4 Daventry Street
Lynnwood Manor 0040
www.aurecongroup.com

Project Title:

HYDROGEOLOGICAL INVESTIGATION AT THE HATHERLEY CEMETERY

Map Title:

Hatherley Cemetery: Borehole Locations

Map Number:

Map 3

LEGEND

◉ Borehole

N

Project nr: 111404

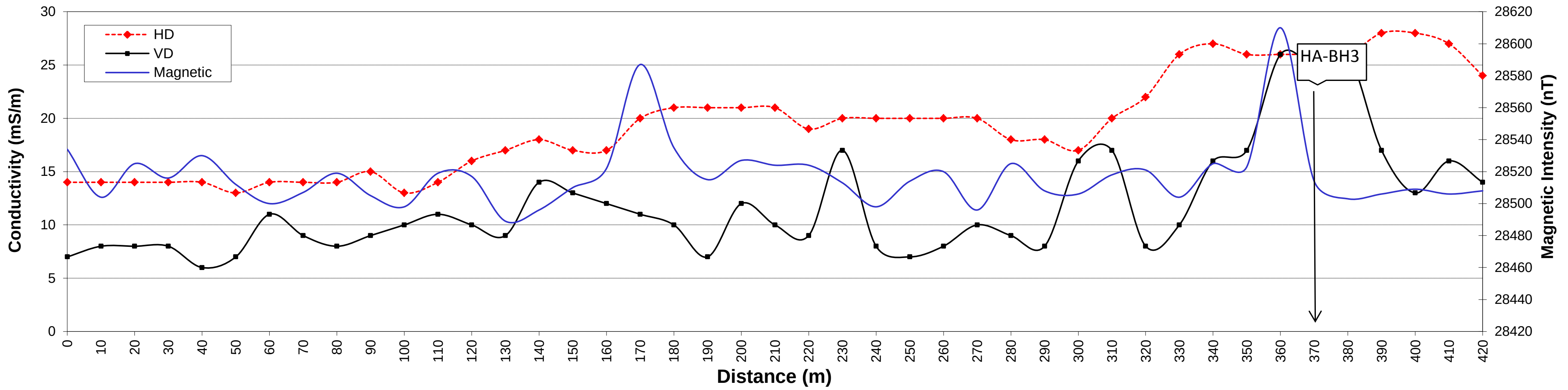
aurecon

Lynnwood Bridge Office Park
4 Daventry Street
Lynwood Manor 0040
www.aurecongroup.com

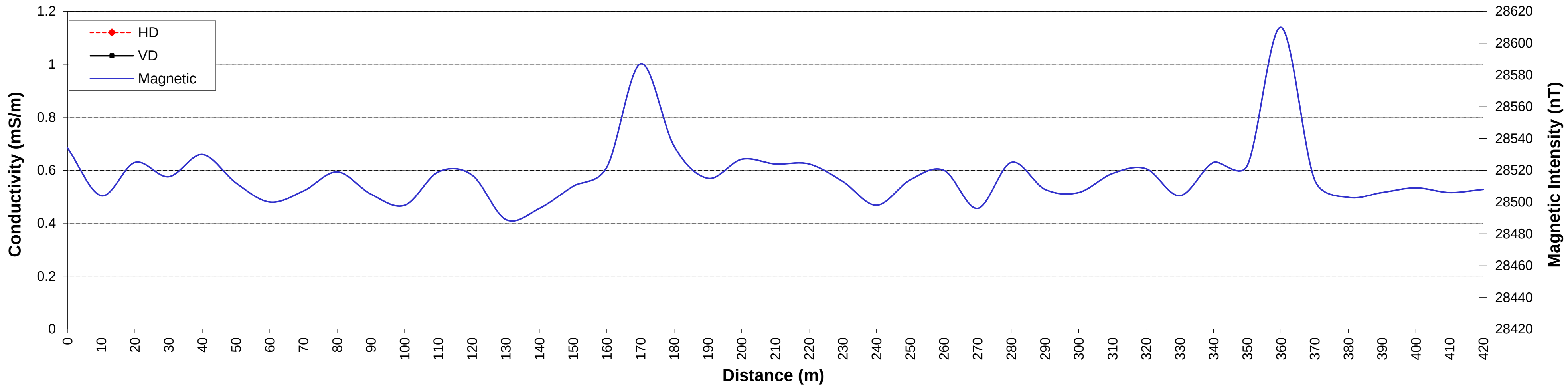
APPENDIX B

GROUND GEOPHYSICAL PROFILES

EM-34 (L=20m) & MAGNETIC PROFILE



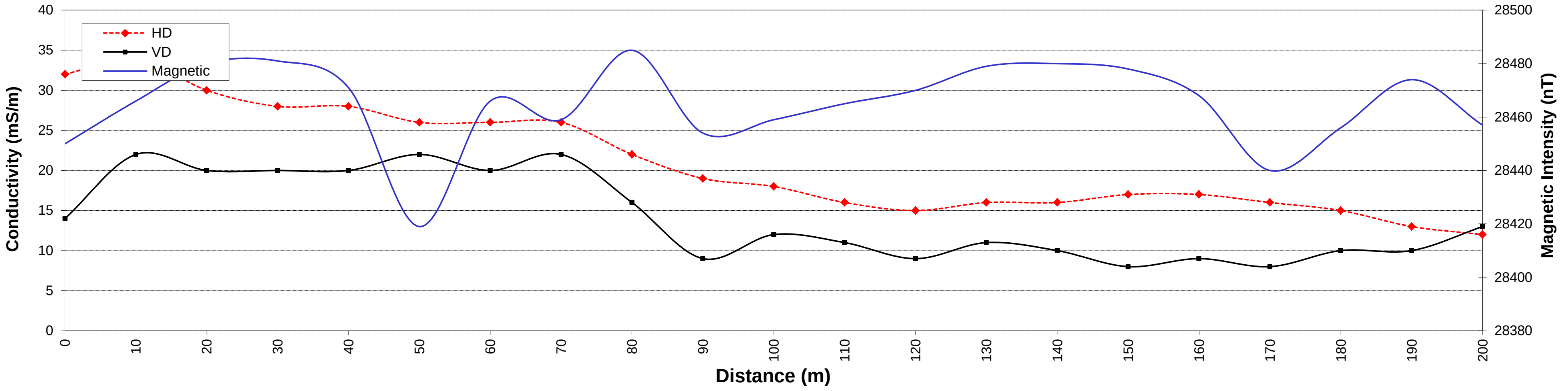
EM-34 (L=40m) & MAGNETIC PROFILE



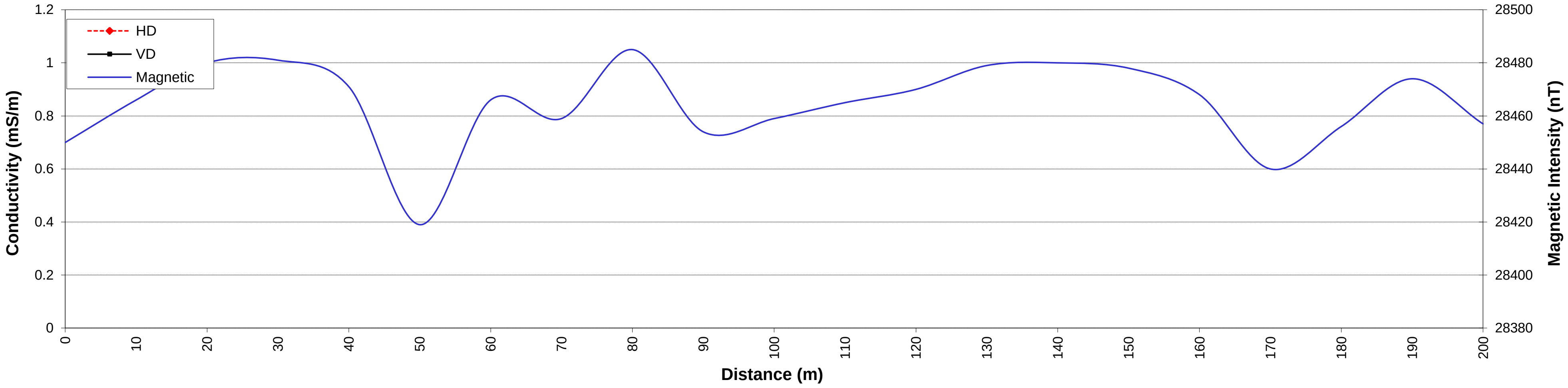
Project:	Hatherly Cemtery	**Profile Number:**	T1	**Start Coordinate:**	**S**	25.74423 °
Project Number:	111404	**Profile Direction:**	NE-SW	***(WGS84)***	**E**	28.41375 °
Survey Area:	Mamelodi	**Station Spacing:**	10m	**End Coordinate:**	**S**	25.74593 °
Date of Survey:	24/02/2015	**Coil Spacing:**	20m		**E**	28.41026 °

aurecon

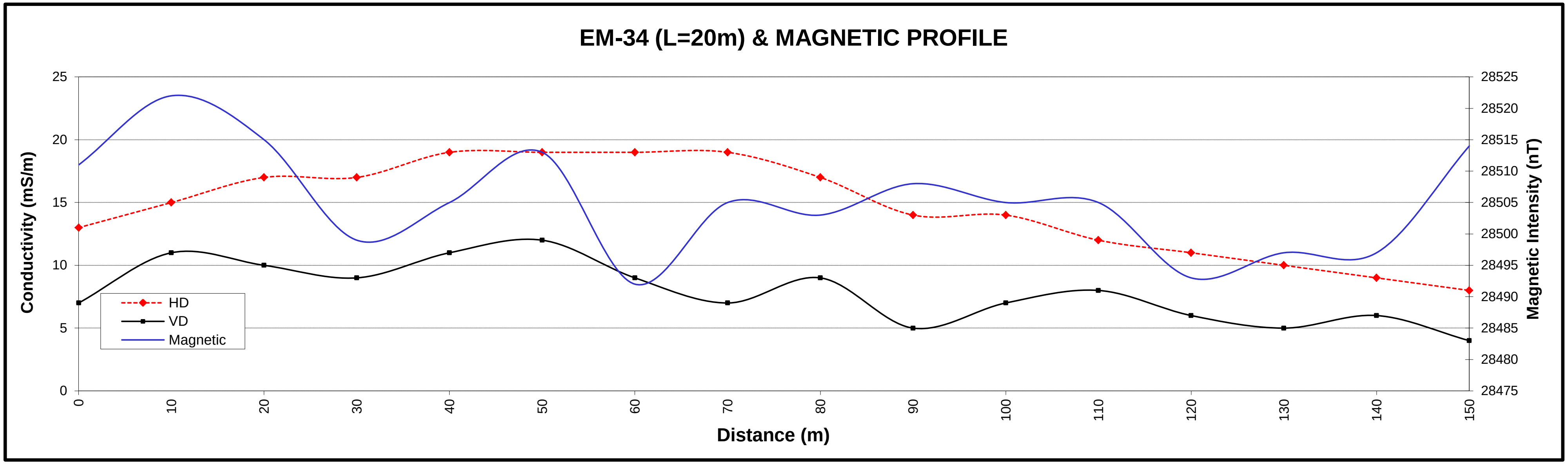
EM-34 (L=20m) & MAGNETIC PROFILE

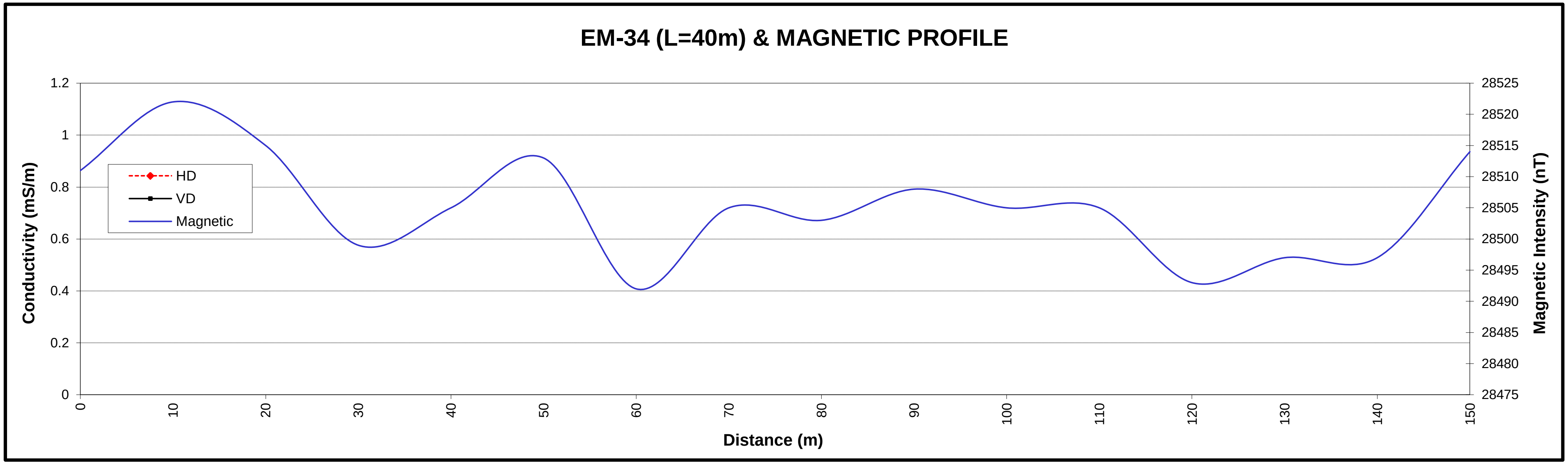


EM-34 (L=40m) & MAGNETIC PROFILE



Project:	Hatherly Cemtery	**Profile Number:**	T2	**Start Coordinate:**	**S**	25.74592 °
Project Number:	111404	**Profile Direction:**	NE-SW	***(WGS84)***	**E**	28.41064 °
Survey Area:	Mamelodi	**Station Spacing:**	10m	**End Coordinate:**	**S**	25.74558 °
Date of Survey:	24/02/2015	**Coil Spacing:**	20m		**E**	28.40876 °





Project:	Hatherly Cemtery	**Profile Number:**	T3	**Start Coordinate:**	**S**	25.74648 °
Project Number:	111404	**Profile Direction:**	NE-SW	***(WGS84)***	**E**	28.40957 °
Survey Area:	Mamelodi	**Station Spacing:**	10m	**End Coordinate:**	**S**	25.74706 °
Date of Survey:	24/02/2015	**Coil Spacing:**	20m		**E**	28.40823 °

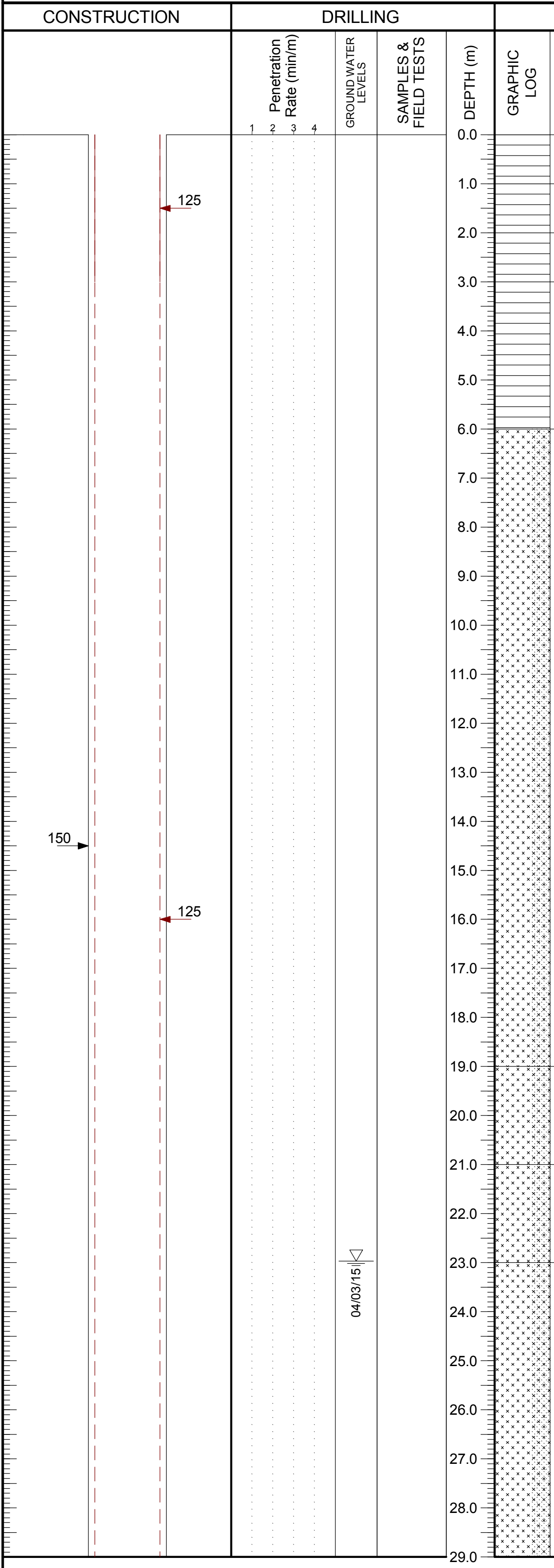
APPENDIX C

BOREHOLE LOGS

PROJECT : Hatherley Cemetery
LOCATION : Mamelodi, Gauteng
CLIENT : City of Tshwane MM

HOLE NO : HA-BH3
FILE / JOB NO : 111404
SHEET : 1 OF 1

CONTRACTOR : SGRS
DRILLER : Andries
DATE STARTED : 15/3/4
DATE COMPLETED : 15/3/4
RIG TYPE : Audie Eng Spider
LOGGED BY : MT
DATE LOGGED : 15/3/3
CHECKED BY : MT
ANGLE FROM HORIZONTAL : 90°
HOLE DIA : 150 mm
HOLE DEPTH : 29 m
COLLAR HEIGHT : 0.43 m
LATITUDE : 25.74584°
LONGITUDE : 28.41054°
ELEVATION : 1363.000 (MSL)
GRID & DATUM : WGS84



MATERIAL

	MATERIAL DESCRIPTION
	SHALE: Red Shale
1.00m	SHALE: Orange
2.00m	SHALE: Yellow, completely weathered
3.00m	SHALE: Cream, completely weathered
6.00m	DIABASE: Highly weathered - Yellow
19.00m	DIABASE: Moderately weathered - Yellowish grey
21.00m	DIABASE: Slightly weathered - Grey
23.00m	DIABASE: Fresh. Dark grey
29.00m	

BOREHOLE HA-BH3 TERMINATED AT 29.00 m

───	Hole
— —	Casing (plain / perforated)
→	Hole diameter (mm)
←	Casing diamater (mm)

APPENDIX D

SLUG TEST ANALYSIS

Lynwood Bridge Office Park
4 Daventry Street
Lynwood Manor

Slug test analysis

No:

Project: Hatherley Cemetery

Client:

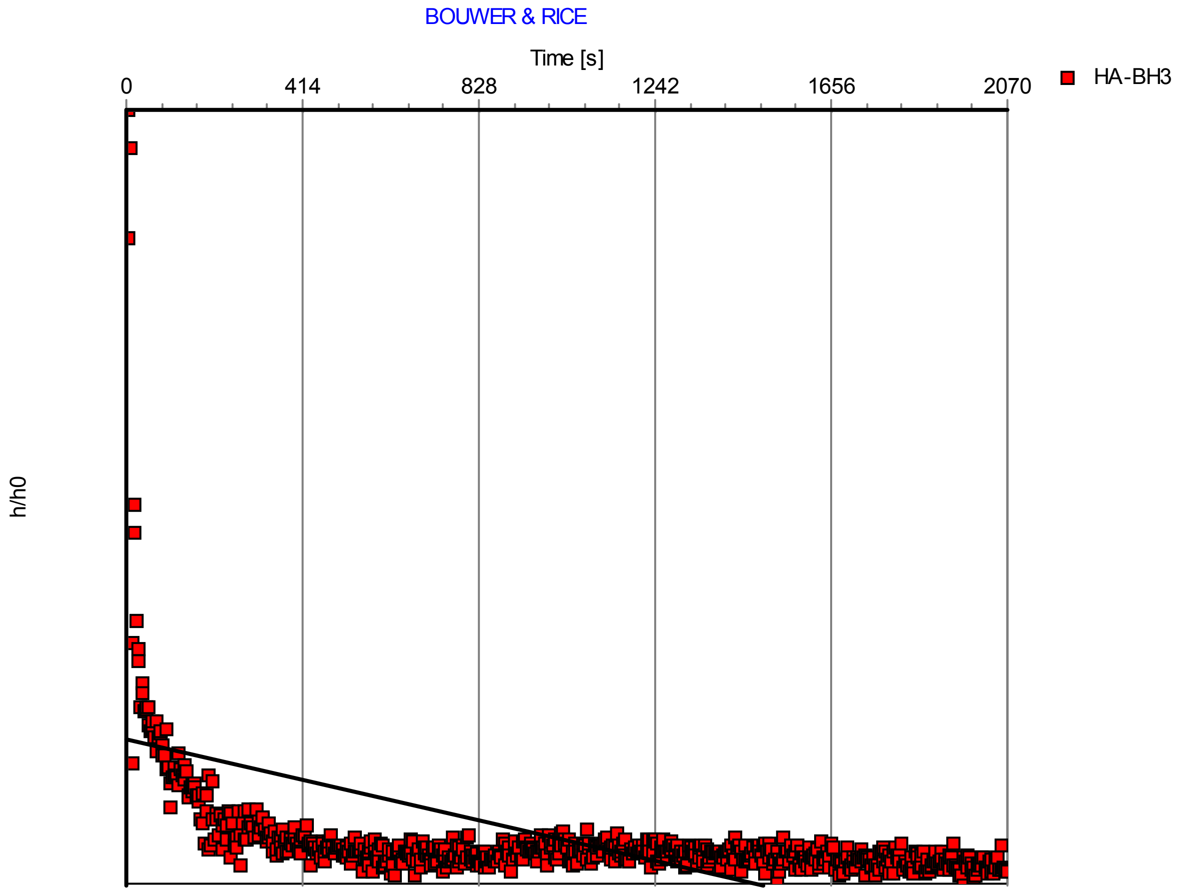
Location:	Slug test: HA-BH3		Test well: HA-BH3

Test performed by: M Terblanche
Test date: 2015/03/17

Evaluated by: M Terblanche
Evaluation date: 2015/03/17

Analysis method: BOUWER & RICE

Aquifer thickness: 8.03 [m]



Conductivity: 3.97×10^-4 [m/d]

APPENDIX E

LABORATORY REPORTS

aquatico
Laboratories (Pty). Ltd.

T0374

Test Report

Client: Aurecon
Address: Lynwood Bridge Office Park, No. 4 Daventry str., Pretoria, 0081
Report no: 23505
Project: Aurecon

Date of certificate: 18 March 2015
Date accepted: 13 March 2015
Date completed: 18 March 2015
Revision: 0

Lab no:				206257	206258
Date sampled:				12-Mar-15	12-Mar-15
Sample type:				Water	Water
Locality description:				HA-BH 1 AND 2	HA-BH 3
	Analyses	**Unit**	**Method**		
A	pH @ 25°C	pH	ALM 20	8.34	7.87
A	Electrical conductivity (EC) @ 25°C	mS/m	ALM 20	69.9	73.9
A	Total dissolved solids (TDS)	mg/l	ALM 26	406	441
A	Total alkalinity	mg $CaCO_3$/l	ALM 01	326	417
A	Chloride (Cl)	mg/l	ALM 02	24.0	14.4
A	Sulphate (SO_4)	mg/l	ALM 03	32.5	17.1
A	Nitrate (NO_3) as N	mg/l	ALM 06	3.13	0.478
A	Ammonium (NH_4) as N	mg/l	ALM 05	0.019	0.019
A	Orthophosphate (PO_4) as P	mg/l	ALM 04	0.066	0.080
A	Fluoride (F)	mg/l	ALM 08	0.204	0.257
A	Calcium (Ca)	mg/l	ALM 30	24.6	48.8
A	Magnesium (Mg)	mg/l	ALM 30	71.3	63.9
A	Sodium (Na)	mg/l	ALM 30	39.5	38.2
A	Potassium (K)	mg/l	ALM 30	0.965	2.26
A	Aluminium (Al)	mg/l	ALM 31	<0.003	<0.003
A	Iron (Fe)	mg/l	ALM 31	<0.003	<0.003
A	Manganese (Mn)	mg/l	ALM 31	<0.001	<0.001
A	Total hardness	mg $CaCO_3$/l	ALM 26	355	385

A = Accredited N = Non accredited O = Outsourced S = Sub-contracted NR = Not requested RTF = Results to follow NATD = Not able to determine
The results relates only to the test item tested.
Results reported against the limit of detection.
Results marked 'Not SANAS Accredited' in this report are not included in the SANAS Schedule of Accreditation for this laboratory.
Uncertainty of measurement available on request for all methods included in the SANAS Schedule of Accreditation.

M. Swanepoel
Technical Signatory