

**GEOHYDROLOGICAL ASSESSMENT STUDY FOR A GENERAL
WASTE LANDFILL SITE AT WALKERVILLE LOCATED ON THE R82
NORTH OF VEREENIGING**

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EXECUTIVE SUMMARY

This document presents the results of a hydrogeological - and contamination risk analyses investigation as part of an environmental impact assessment for a permit application for a landfill. The Midvaal Local Municipality is managing an existing medium sized general landfill at Walkerville, located east of the R82 road approximately 22km north of Vereeniging.

The study is aimed at establishing a baseline reference of hydrogeological data and to calculate the contamination risk which the landfill site poses to the groundwater regime. Geo-logic Trading Trust was appointed by SCIP Engineering Group to do the study.

A desk study was performed to gather relevant geological and geohydrological information. A hydro - census followed the desk study to establish information such as water levels and borehole depths on all existing boreholes in the Walkerville area. Nine existing monitoring boreholes on site were visited. The purpose of this survey was to gather relevant geohydrological information of current groundwater use in the area.

A geophysical study investigated the integrity of the geology at the existing landfill site. Two existing monitoring boreholes, located on the proposed development area, was yield tested by submitting it to step tests and a constant discharge test, with recovery tests following, according to specifications laid down by the Department of Water Affairs and Forestry under the publication, ***“Minimum Standards and Guidelines for Groundwater Resource Development for the Community Water Supply and Sanitation Programme” (1997).***

The yield tests was analysed with the FC Method to be able to calculate aquifer parameter of the saturated zone.

Test pits were dug and prepared for double ring inflow meter tests to be able to calculate the hydraulic conductivity of the un-saturated zone. These pits were also used to log the lithology of the upper layer. The hydraulic parameters, geology - and groundwater occurrence information were utilized to calculate the contamination risk for the site.

The geophysical study, the available drilling information (Jones & Wagener), the infiltration rate measurements and groundwater movement calculations all leads to the conclusion that

the existing landfill site conditions pertaining to groundwater contamination risk is relative low. The following facts support this assessment:

- The lithology on site consists of a number of layers.
- The top material seems to be alluvium up to 2 metres.
- From 2 metres to 13 metres fairly weathered Andesite with fairly high hydraulic conductivities are found.
- More competent medium hard rock Andesite is found from 13 metres downward.
- The magnetic data does not show any prominent intrusive material in the form of linear structures on site. The data show a relative flat graph with no obvious structures or weathered zones.
- No prominent weathered zone could be detected by the Electromagnetic study. From a geophysical perspective, the existing landfill site is well located on what seems to be a block of uniform Andesite. No zone could be pinpointed that can possibly carry groundwater on a noticeable scale.
- The maximum hydraulic conductivity value of 0.032m/d indicates that the rock formations in the vicinity of the landfill site have low hydraulic conductivities. This is also confirmed by the drilling logs in the report from Jones & Wagener.
- A flow velocity of 0.245m/a was calculated for the aquifer which can be regarded as very slow.
- The chemical classification of water from borehole WBH1D can be categorized as Class 2, due to elevated Mercury levels of 3.146ug/l, marginal water quality, may be used for a limited period only, without health effects by the majority of individuals.
- The chemical classification of water from borehole WBH2D can be categorized as Class 3, Poor water quality, poses a risk of chronic health effects, especially in babies and elderly. This is mainly due to Turbidity and color. The Mercury level is also elevated to 1.494ug/l which can be categorized as Class 2.
- The bacteriological quality from WBH1D can be categorized as Class 1, Good water quality, suitable for lifetime use, rare instances of sub-clinical effects. The COD level however shows no contamination with limited bacteriological activity. A high Heterotrophic Plate Count and Faecal Coliform Bacteria count show that the contaminants reached the aquifer below the landfill site. The Chemical Oxygen Demand (COD) level is also high confirming an active bacteriological process.
- The bacteriological quality from WBH2D can be categorized as Class 3, Poor water quality, poses a risk of chronic health effects, especially in babies and elderly.
- The difference in bacteriological water quality of the two boreholes WBH1D and WBH2D clearly show that groundwater enters the landfill site from the north western side of the landfill as shown on Map 3 and Map 4 gathers organic pollutants and exit the site on the south eastern side of the landfill site. Chemically however the water

quality on the down slope side of the landfill site is the same as the water entering the landfill site.

The following recommendations are made:

- Routine monitoring of water levels, rainfall figures and water quality is strongly recommended and should strictly be adhered to. This data will form the basis from which any changes in the groundwater regime are recognised.
- Water quality monitoring of the nine existing monitoring boreholes must be done at a three monthly interval. Major cat and an-ions and bacteriological parameters must be analysed for.
- Hydrogeological monitoring data (described above) should be evaluated bi-annually by a qualified hydrogeologist.
- A Groundwater Management Plan with relevant Groundwater Monitoring and Reporting Protocol should be established and calibrated annually.
- Groundwater level monitoring in all nine the boreholes must also be done on a three monthly basis.
- A liner layer consisting of a G layer of at least 150mm thickness must be constructed at the base of the landfill with the topsoil material to protect the aquifer from contamination.

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1. INTRODUCTION

1.1 Background

This document presents the results of a hydrogeological - and contamination risk analyses investigation as part of an environmental impact assessment for a permit application for a landfill. The Midvaal Local Municipality is managing an existing medium sized general landfill at Walkerville, located east of the R82 road approximately 22km north of Vereeniging.

The study is aimed at establishing a baseline reference of hydrogeological data and to calculate the contamination risk which the landfill site poses to the groundwater regime. Geo-logic Trading Trust was appointed by SCIP Engineering Group to do the study.

1.2 Minimum Requirements for Waste Disposal by Landfill

The “Minimum Requirement for Waste Disposal by Landfill” document is used as criteria which forms part of the Department of Water Affairs and Forestry’s Waste Management Series. This series establishes a reference framework of standards for waste management in South Africa. It also facilitates the enforcement of the landfill permitting system provided for in terms of Section 20(1) of the Environmental Conservation Act, 1989 (Act 73 of 1989). (Ref 1)

The Act states that no person shall establish, provide or operate any disposal site without a Permit issued by the Minister of Water Affairs & Forestry and subject to the conditions contained in such a Permit. This applies to all new and operating sites. Unpermitted closed sites are controlled in terms of Sections 22, 22A and 23 of The Water Act of 1956, (Act 54 of 1956). The act is being phased out to be replaced by the National Water Act, 1998 (Act 36 of 1998) and The Water Services Act, 1997 (Act 108 of 1997). (Ref 1)

The objective of setting Minimum Requirements is to take pro-active steps to prevent the degradation of water quality and environment, and to improve the standard of waste disposal in South Africa. To ensure practical and affordable environmental protection, graded requirements are applied to different classes of landfill. The landfill class is determined from the waste type, size of operation, and potential for significant leachate generation. Where

significant leachate is generated, leachate management is mandatory. Where hazardous waste is involved, the most stringent Minimum Requirements are applicable. (Ref 1)

1.3 Scope of Investigation

The scope of work can be defined as follows:

- (a) Do a desk study of existing information such as geological - and geohydrological maps and existing borehole information.
- (b) Do a hydro census of boreholes and possible contamination sources in a 1 km radius of the existing landfill development boundaries, to establish information such as static and dynamic water levels, existing water abstraction figures in the area, borehole depths and water end users.
- (c) Study the ground water regime in terms of geology and related aquifers.
- (d) Do double ring inflow meter test to calculate the hydraulic parameters of the unsaturated zone to be able to calculate the contamination risk involved for the site.
- (e) Give guidelines for a groundwater monitoring system.
- (f) Do pump tests on available monitoring facilities to be able to calculate hydraulic parameters for the saturated zone.
- (g) Give a base line reference of the groundwater quality of the site and surrounding areas.
- (h) Give a reference of current baseline contamination levels by taking water samples to be analysed for these parameters.
- (i) Compile a technical report detailing the results/findings of the investigation.

1.4 Landfill Site Classification

Since landfills differ from one another in terms of size, type and potential threat to the environment, a classification system has been developed, whereby landfills can be differentiated. Once a landfill has been placed in a class, only the requirements appropriate to that class need to be met. In this way the Minimum Requirements ensure environmental acceptability for the full spectrum of landfills, from a small communal operation to a regional hazardous waste landfill in a cost effective way. Ref 1)

The waste type disposed of at Walkerville Waste Disposal Site is General Waste. The Maximum Rate of Deposition (MRD) is between 25 to 30 tons per day putting the landfill in a Small (S) Landfill Size Class. The Climate Water Balance is B negative (B⁻).

2. CLIMATE AND REGIONAL SETTING

Midvaal village is located in quaternary sub-catchment C22E. The site is located in Weather Bureau section number 0475 and in rainfall zone C2B. The closest weather stations are rainfall station number 0475717, and rainfall station number 0476145. These weather stations are respectively located west and north east existing Walkerville landfill site.

The rainfall period for these two stations covers the years from 1925 to 1989 for station 0475717 and for the years 1940 to 1989 for station 0476145. The mean annual precipitation (MAP) at station 0475717 is 631mm per annum and 629mm per annum for station 0476145. Rainfall occurs as typical summer thunderstorms with heavy lightning and strong winds. Summer rainfall is typically in November to February in which in the order of 60 % of rainfall normally occurs.

The evaporation Zone is 11A with a Mean Annual Evaporation of between 1600 to 1700mm (S – Pan) value.

3. TOPOGRAPHY AND SURFACE WATER DRAINAGE

The existing landfill site at Walkerville is located on the eastern side of the R 82 road from Vereeniging to Johannesburg. The small landfill serves the Walkerville agricultural holdings and the Walkerville Village. The site do have a topographical slope direction of nearly west to east towards a small non perennial river flowing from north to south and then turning directly east. This non-perennial stream originates approximately 650m north east of the landfill site. The distance from the landfill towards the non-perennial stream is in the order of 50 metres.

On the existing landfill site surface water drainage is in a directly eastern direction towards the non-perennial steam.

4. GEOLOGY AND GROUNDWATER REGIME

The site is underlain by andesitic lavas of the Hekpoort Formation, Pretoria Group, Transvaal Sequence. Faulting is present in the area and a north-west / south east trending fault line to the south of the site has resulted in shale of the Timeball Hill Formation occurring immediately south of the Walkerville Landfill Site. Regionally Pockets of older, underlying Malmani Dolomites exposed at surface through the process of erosion. Dolomite rock was however not encountered on site during the investigation.

Below is a short summary of the lithology of the interested area:

<u>Era</u>		<u>Group</u>	<u>Subgroup</u>	<u>Formation</u>	<u>Lithology</u>	<u>Colour</u>
Vaalian	Transvaal Sequence	Pretoria		Hekpoort	Andesite, agglomerate, tuff	Vh
				Boshoek	Quartzite, conglomerate	Vbo
				Timeball Hill	Ferruginous shale, hornfels	Vt
					Ferruginous quartzite	Vt
					Ferruginous shale, hornfels	Vt
			Rooihoogte		Quartzite	Vr
					Shale	Vr
					Chert breccia, conglomerate	Vr
		Chuniespoort	Malmani		Dolomite, chert and remnants of chert breccia of the Rooihoogte Formation	Vmd
					Quartzite, conglomerate, shale	Vbr

5. METHODOLOGY

A desk study was performed to gather relevant geological and geohydrological information. A hydro - census followed the desk study to establish information such as water levels and borehole depths on all existing boreholes in the Walkerville area. Nine existing monitoring boreholes on site were visited. The purpose of this survey was to gather relevant geohydrological information of current groundwater use in the area.

A geophysical study investigated the integrity of the geology at the existing landfill site. Two existing monitoring boreholes, located on the proposed development area, was yield tested by submitting it to step tests and a constant discharge test, with recovery tests following, according to specifications laid down by the Department of Water Affairs and Forestry under the publication, ***“Minimum Standards and Guidelines for Groundwater Resource Development for the Community Water Supply and Sanitation Programme” (1997).***

The yield tests was analysed with the FC Method to be able to calculate aquifer parameter of the saturated zone.

Test pits were dug and prepared for double ring inflow meter tests to be able to calculate the hydraulic conductivity of the un-saturated zone. These pits were also used to log the lithology of the upper layer. The hydraulic parameters, geology - and groundwater occurrence information were utilized to calculate the contamination risk for the site.

6. DESK STUDY

The desk study consulted the following sources:

- The 1: 250 000 scale Geological Series Map, sheet number 2628 East Rand.
- The 1: 50 000 scale Topographical Map, sheet number 2627BD.
- Surface Water Resources of South Africa 1990 Book of Maps Volume 2.
- Jones & Wagener, **Walkerville Landfill Site Test Pit Investigation**, Report number JW32/07/A213.

The relevant geohydrological information guided the scope of work for the groundwater and contamination risk study.

7. FIELDWORK RESULTS

7.1 Hydro Census

During a field visit of the planned development, 9 monitoring wells inside the development boundary was visited, and 9 hydro census boreholes outside the development boundary were found. Information on the boreholes visited, is included in the list below in Table 1.

Details such as a water level, water end user and co- ordinates were noted. The borehole positions and numbers can be found on the Locality - and Geology Map, Map1 and 2 bound in after the text of this report.

The static water levels measured during the census on the existing boreholes in the area show a groundwater flow trend in an eastern direction. The abstraction figures in general, in this area, can be considered as low, and is mainly for domestic use or small scale farming.

Walkerville WBH1S



TABLE 1: Borehole Hydro Census Details

Borehole number	Co-ordinates		Surface Altitude	Water level Depth	Ground water Altitude	Remarks
	Latitude	Longitude	(mamsl)	(mbgl)	(mamsl)	
Boreholes Located on the Development						
WBH1S	26.47792	27.93975	1569	-	-	Depth Drilled 12m, Casing Diameter 165mm. Constructed in 2007 by Environmental Drilling
WBH1D	26.47792	27.93977	1569	19.68	1548.79	Depth Drilled 40m, Casing Diameter 165mm. Constructed in 2007 by Environmental Drilling. Water strike at 13 metres
WBH2S	26.47878	27.94284	1558	11.68	1545.65	Depth Drilled 14m, Casing Diameter 165mm. Constructed in 2007 by Environmental Drilling
WBH2D	26.47881	27.94283	1558	12.25	1545.16	Depth Drilled 37m, Casing Diameter 165mm. Constructed in 2007 by Environmental Drilling. Water strike at 13 metres and 36 metres.
WBH3S	26.47967	27.94268	1558	10.78	1546.78	Depth Drilled 12m, Casing Diameter 165mm. Constructed in 2007 by Environmental Drilling
WBH3D	26.47968	27.94270	1558	7.66	1549.77	Depth Drilled 42m, Casing Diameter 165mm. Constructed in 2007 by Environmental Drilling. Water strike at 13 and 39 metres.
KGC1	26.47791	27.94288	1560	10.93	1549.07	Casing 165mm.
KGC2	26.47880	27.93957	1570	22.81	1546.98	Depth Drilled 31m, Casing Diameter 165mm.
KGC3	26.48068	27.94293	1555	12.05	1542.95	Casing 165mm.
Hydro Census Boreholes						
HBH 01	26.48600	27.94312	1561	-	-	Borehole Blocked, Casing Diameter 165mm.
HBH 02	26.48449	27.94757	1552	11.64	1540.36	Submersible pump, 40mm pump outlet.
HBH 03	26.48689	27.93434	1574	32.87	1541.13	Submersible pump, 45mm pump outlet, yield +/- 18000lh.
HBH 04	26.47509	27.93811	1578	26.31	1551.69	Submersible Pump, 50mm pump outlet, Depth +/- 70m.
HBH 05	26.47414	27.93214	1594	20.38	1573.62	Submersible pump, 40mm pump outlet.
HBH 06	26.48015	27.93347	1585	17.69	1567.31	Submersible pump, 45mm pump outlet.
HBH 07	26.48457	27.94922	1582	0	-	Mono pump.40mm pipe. Domestic use.
HBH 08	26.48524	27.95104	1548	0	-	Not in use or equipped. Closed borehole.
HBH 09	26.48733	27.94721	1564	0	-	Mono head. Not in use.

Walkerville WBH1D



Walkerville WBH2S



Walkerville WBH2D



Walkerville WBH3S



Walkerville WBH3D



Walkerville KGC1



Walkerville KGC2



Walkerville KGC3



Existing Monitoring Boreholes on Walkerville Landfill Site

The “Walkerville Landfill Site Testpit Investigation” study of Jones & Wagener report on the three existing monitoring boreholes KGC1 to KGC3. No further information about monitoring boreholes KGC1 to KGC3 is revealed. They also drill the new monitoring boreholes WBH1 to WBH3. No mentioning in their report is made that these three boreholes rather consists of three sets of deep and shallow boreholes which are numbered WBH1S, WBH1D, WBH2S, WBH2D, WBH3S and WBH3D. We however believe that these three sets of deep and shallow boreholes (six in total) were constructed during this study.

Borehole WBH1S (Ref 1) (Note the letter “S” was added by the author)

Borehole was found on site, marked as WBH1S, but no mentioning is made of this borehole drilled during the same study.

Borehole WBH1D (Ref 1) (Note the letter “D” was added by the author)

Borehole was found on site, marked as WBH1D. 0 to 4 Hillwash. 4 to 14 Residual Andesite gravels. 14 to 16 Andesite weathered. 16 to 20 hard rock Andesite. 20 to 24 hard rock Andesite. 24 to 40 hard rock Andesite. Water strike encountered at 13 metres.

Borehole WBH2S (Ref 1) (Note the letter “S” was added by the author)

Borehole was found on site, marked as WBH2S, but no mentioning is made of this borehole drilled during the same study.

Borehole WBH2D (Ref 1) (Note the letter “D” was added by the author)

Borehole was found on site, marked as WBH2D. 0 to 1 Hillwash. 1 to 5 Residual Andesite gravels. 5 to 13 Soft rock Andesite. 13 to 15 Soft rock Andesite. 15 to 20 Jointed Andesite. 20 to 40 hard rock Andesite. Water strike encountered at 13 and 36 metres.

Borehole WBH3S (Ref 1) (Note the letter “S” was added by the author)

Borehole was found on site, marked as WBH3S, but no mentioning is made of this borehole drilled during the same study.

Borehole WBH3D (Ref 1) (Note the letter “D” was added by the author)

Borehole was found on site, marked as WBH3D. 0 to 4 Hillwash. 4 to 14 Residual Andesite

gravels. 14 to 16 Andesite weathered. 16 to 20 hard rock Andesite. 20 to 24 hard rock Andesite. 24 to 40 hard rock Andesite. Water strike encountered at 13 metres.

Borehole KGC 1 to KGC3

These three boreholes are only mentioned in the report of Jones and Wagener dated February 2007. No information was given in their report on these boreholes.

7.2 Test Pits and Percolation Tests

Infiltration rates of the upper soils or the Hydraulic Conductivity of the unsaturated zone are measured in the field by using a double-ring infiltrometer. This method describes a procedure for field measurement of the infiltration rate of soils. Infiltration rate is defined as a soil characteristic, determining and describing the maximum rate at which water can enter the soil under specified conditions, including presence of an excess of water. Infiltration rates have application to problems such as erosion rates, leaching and drainage efficiencies, irrigation, water spreading, rainfall runoff, and evaluation of potential septic-tank disposal fields, among other applications.

Rates determined by ponding of large areas are considered the most reliable method of determining infiltration rate, but the high cost makes the infiltrometer-ring method more feasible and economical. The infiltration rate is controlled by the least permeable zone in the subsurface soils. The double-ring infiltrometer is used to help divergent flow in layered soils by providing an outer water barrier to encourage only vertical flow from the inner ring. Many other factors affect the infiltration rate in addition to the soil structure, for example, the condition of the soil surface, the moisture content of the soil, the chemical and physical nature of the soil and the applied water, the head of applied water, and the temperature of the water. The tests done at the same site are not likely to give identical results and the rate measured by the procedure described in this test method is primarily for comparative use. Some aspects of the test, such as the length of time the tests should be conducted and the head of water to be applied, must depend upon the experience of the user, the purpose for testing, and the kind of information that is sought.

Two open cylinders, one inside the other, are driven into the ground and partially filled with water, which is then maintained at a constant level. The volume of water added to maintain the water level constant is the measure of the volume of water that infiltrated the soil. The volume infiltrated during timed intervals is converted to an infiltration velocity, usually expressed in inches per hour or centimeters per hour or centimeters per second. The

maximum infiltration velocity is equivalent to the infiltration rate.

Two new test pits were dug and prepared for double ring inflow meter tests. The infiltration rates of the two test pits done for the study can be found described in Table 2 below. The positions of these test pits can be found on Map 1, 2 and 3.

Test pit 01 is located on the eastern boundary near the northern corner of the site. Sandy soil, Dark brown with individual ferrirete granules ranging from 1 to 15 mm diameter. The hydraulic conductivity rate measured at this pit is 4.42×10^{-4} cm/s or 1.5899 cm/h or 0.3816 m/d.

Test pit 02 is located on the eastern boundary in the centre of the site. Very clayey yellow to grey with angular ferrirete lumps of 20 to 30 mm in diameter. The hydraulic conductivity rate measured at this pit is 6.92×10^{-3} cm/s or 24.91 cm/h or 5.98 m/d.

TABLE 2: Information on Test Pits

Co-ordinates	Real Time	Elapsed Time	Quantity of water (ml)	Infiltration rate (cm/s)	Infiltration rate (cm/h)	Infiltration rate (m/d)
Pit 1 10/03/2010 <u>Co-ordinate</u> S -26.47833 E 27.94267	9h55	0	-		-	-
	10h10	15	200	2.95×10^{-4}	1.0599	0.2544
	10h25	30	500	7.36×10^{-4}	2.6498	0.6360
	10h40	45	250	3.68×10^{-4}	1.3249	0.3180
	10h55	60	300	4.42×10^{-4}	1.5899	0.3816
	11h25	90	500	3.68×10^{-4}	1.3249	0.3180
	11h55	120	300	2.21×10^{-4}	0.7949	0.1908
Pit 2 10/03/2010 <u>Co-ordinate</u> S -26.47973 E 27.94210	12h55	0	-		-	-
	13h10	15	7500	1.10×10^{-2}	39.7473	9.5394
	13h25	30	5600	8.24×10^{-3}	29.6780	7.1227
	13h40	45	5000	7.36×10^{-3}	26.4982	6.3596
	13h55	60	4400	6.48×10^{-3}	23.3184	5.5964
	14h25	90	5800 + 3600	6.92×10^{-3}	24.9083	5.9780
	14h55	120	5100 + 2450	5.56×10^{-3}	20.0061	4.8015

Test Pit 1



Test Pit 2





From these two tests it can be seen that the weathered Andesite host rock is ten to twenty times more permeable as the clayey top soil found on site. The study from Jones & Wagener found the soil material on site suitable to construct a lining layer on the bottom of the landfill site and to use it as covering material. We recommend this to be done to lower the infiltration rate of water into the weathered Andesite rock strata.

7.3 Geophysical Study

One geophysical traverse, Traverse 1 was surveyed on the eastern boundary or surface and groundwater flow down side, with the aim to study the geophysical integrity of the geology.

Geophysical Survey Methods for Borehole Drill Site Establishment

Two geophysical methods namely the Magnetic and the Frequency Domain Electromagnetic method were employed for the survey.

The Magnetic method attempts to differentiate between lateral differences in the earth's magnetic field. These differences or anomalies indicate to different types of underlying rock formations and/or variations in depth of these different formations. The magnetic surveys are normally done in a linear pattern or traverse and found application in the following geohydrological regimes.

- a) tracing of intrusive dolerite or diabase dykes or sills,
- b) tracing of contact zones between different formations, and
- c) tracing of possible fault zones.

The Electromagnetic method is attempting to measure the conductivity of rock. The application in groundwater exploration can be found in the fact that there is a relationship between the conductivity of a formation and the porosity thereof, the connection between pores, the volume of water in the pore and the conductivity of the water in the pore. The method can be used to do lateral profiling of strata and found application in the following situations.

- a) The identification of thin linear zones of conductivity, in particular fracture zones, fault zones, weathered dykes and contact zones of different hydrological regimes.

The geophysical graphs can be found in Appendix A.

Magnetic Survey

The magnetic data does not show any prominent intrusive material in the form of linear structures on site. The data show a relative flat graph with no obvious structures or weathered zones.

From the Magnetic study it is clear that the most eastern side of the landfill site seems to be stable Andesite with no visible geological contact zones and/or intrusive material.

Electromagnetic Survey

The frequency domain electromagnetic method (FDEM) was used to do the electromagnetic survey. Eight set frequencies are used to do a traverse capable of penetrating the geological strata in depth. The frequencies 4800Mhz, 2400Mhz, 1200Mhz, 600Mhz, 300Mhz, 150Mhz, 75Mhz and 37Mhz are used each penetrating deeper respectively from the high frequency only penetrating the top surface down to the low frequency penetrating in depth.

No prominent weathered zone could be detected by the Electromagnetic study. From a geophysical perspective, the existing landfill site is well located on what seems to be a block of uniform Andesite. No zone could be pinpointed that can possibly carry groundwater on a noticeable scale.

7.4 Test Pumping of Boreholes

Two existing monitoring boreholes were submitted to test pump procedures for the investigation. A step Tests and a Constant Discharge Test were performed on the two

existing monitoring boreholes WBH1D and WBH2D.

A step test consists of pumping a borehole at different rates for fifteen minutes per step, until the maximum rate the borehole can deliver. The water level is constantly monitored and noted during each step. This gives an indication of the possible yield the borehole can sustain for a Constant Discharged Test. A step test also gives an indication of the potential of the aquifer in the immediate area around the borehole.

The Constant Discharge Test's duration was 5 hours, with a sudden switch off of the pump after the constant pump cycle, with a recovery test following immediately afterwards. The Constant Discharge Curve was analysed utilising the Basic FC, FC inflection point, Cooper-Jacob and Barker/Bangoy methods, to give an indication of Transmissivity and Storativity values. A summary of these methods and Graphical presentations of the draw down curves and recovery curves can be found in Appendix B. Table 3, listed below, gives a summary of the pump test data.

Monitoring Borehole WBH1D was pumped for two steps at rates of 0.19 and 0.37 l/s. The water table did reach pump inlet after 3 minutes in the second step. A maximum inflow of 0.26 l/s was measured during the last minutes of the second step. The borehole recovered in 20 minutes back to the original static water level.

A constant discharge test followed the step and recovery tests at a rate of 0.16 l/s for 5 hours or 300 minutes. The water level had a steady decline, as is normally expected, to reach 12.08 metres at 5 hours. The pump was switched off and the recovery measured over a period of 40 minutes. The water level after 40 minutes was back to the original static water level, which can be rated as very fast.

Monitoring Borehole WBH2D was pumped for one step at a rate of 0.50 l/s. The water table did reach pump inlet after 15 minutes in the first step. A maximum inflow of 0.34 l/s could be measured during the last 5 minutes of the first step. The borehole recovered in 60 minutes back to the original static water level.

A constant discharge test followed the step and recovery tests at a rate of 0.20 l/s for 5 hours or 300 minutes. The water level had a steady decline, as is normally expected, to reach 8.95 metres at 5 hours. The pump was switched off and the recovery measured over a period of 90 minutes (1.5 hours). The water level after 90 minutes was back to the original static water level, which can be rated as very fast.

TABLE 3: Test Pumping Results

Bh No. BH Depth & Static Water Level	Step Test				Constant Discharge Test			Comment on the Water Level Recovery Rate
	Step No.	Rate (l/s)	Dur. (min)	D/D (m)	Rate (l/s)	Dur. (min)	D/D (m)	
WBH1D Depth: 40m Static water level: 19.10m	1	0.20	15	9.00	0.16	300	12.08	100% in 40 minutes
	2	0.37	5	12.10				
WBH2D Depth: 37m Static water level: 12.82m	1	0.51	15	18.50	0.20	300	8.95	100% in 90 minutes
ST - Step Test					Dur. - Duration			
CDT - Constant Discharge Test					D/D – Draw down			
SWL - Static Water Level in metres below ground level								

Hydraulic Conductivity

The hydraulic conductivity can be calculated by using the aquifer thickness and the transmissivity values made available by the borehole yield test. A mean Transmissivity value of $0.8\text{m}^2/\text{d}$ was calculated by the Cooper Jacob method for the two boreholes. The borehole drilling record of the three deep boreholes (Jones & Wagener) show a maximum aquifer thickness of 25 metres in thickness.

T = Transmissivity of the saturated zone in m^2/d . A Transmissivity value of $0.8\text{m}^2/\text{d}$ was used.

K = Hydraulic Conductivity in m/d .

D = Depth of the saturated zone in m . The penetration rate shows a maximum thickness of 25 metres.

$$T = K \times d$$

$$K = T/d$$

$$K = 0.8/25$$

$$K = 0.032\text{m}/\text{d}$$

The maximum hydraulic conductivity value of $0.032\text{m}/\text{d}$ indicates that the rock formations in the vicinity of the landfill site have low hydraulic conductivities. This is also confirmed by the drilling logs in the report from Jones & Wagener. The geophysical study shows un-

weathered Andesite in depth. Both the saturated and un-saturated zones show low hydraulic conductive properties. This can be used to calculate groundwater flow velocity.

The groundwater contour map generated from the hydrocensus data used together with the calculated hydraulic conductivities and with Darcy's law was used to calculate the rate at which groundwater motion and contaminant migration in the saturated zone may take place under normal unstressed conditions. A flow velocity of 0.245m/a was calculated for the aquifer.

TABLE 4: Calculated Groundwater Flow Rates

Borehole Number	K (m/d)	Actual Groundwater Gradient	Flow Velocity (m/d)	Flow velocity (m/year)	Comments
WBH1D and WBH2D	0.032	0.021	6.72×10^{-4}	0.245	Existing monitoring boreholes used

As can be seen from the data in Table 4, the calculated flow velocities are extremely slow in the saturated zone.

7.5 Water Quality

Two water samples were retrieved from borehole WBH1D and WBH2D during a test pumping procedure and preserved and delivered to an accredited water laboratory to be analysed for water quality purposes. A full cat and an-ion analyses and a Total Coliform Bacteria, Faecal Coliform Bacteria, Standard Plate Count, Ammonia nitrogen, O-phosphate and Chemical oxygen demand analyses were done on the samples.

Chemical Water Quality

WBH1D

The chemical classification of water from this borehole can be categorized as Class 2, due to elevated Mercury levels of 3.146ug/l, marginal water quality, may be used for a limited period only, without health effects by the majority of individuals.

WBH2D

The chemical classification of water from this borehole can be categorized as Class 3, Poor water quality, poses a risk of chronic health effects, especially in babies and elderly. This is

mainly due to Turbidity and color. The Mercury level is also elevated to 1.494ug/l which can be categorized as Class 2.

Bacteriological Water Quality

WBH1D

The bacteriological quality from WBH1D can be categorized as class 1, Good water quality, suitable for lifetime use, rare instances of sub-clinical effects. The COD level however shows no contamination with limited bacteriological activity.

WBH2D

A high Heterotrophic Plate Count and Faecal Coliform Bacteria count show that the contaminants reached the aquifer below the landfill site. The Chemical Oxygen Demand (COD) level is also high confirming an active bacteriological process. The bacteriological quality from WBH2D can be categorized as Class 3, Poor water quality, poses a risk of chronic health effects, especially in babies and elderly.

The difference in bacteriological water quality of the two boreholes WBH1D and WBH2D clearly show that groundwater enters the landfill site from the north western side of the landfill as shown on Map 3 and Map 4 gathers pollutants and exit the site on the south eastern side of the landfill site. Chemically however the water quality on the down slope side of the landfill site is the same as the water entering the landfill site.

TABLE 5: Water Quality of Monitoring Boreholes

DETERMINANT	UNIT	SOUTH AFRICAN DRINKING WATER STANDARDS SABS 241 : 2001 : ABBREVIATED				
		Walkerville WBH2D	Walkerville WBH1D	Class I (Acceptable)	Class II (Max Allowable)	Class II (Max period)
pH	-	7.1	6.9	5 - 9.5	4 - 10	No limit
Electric conductivity	mS/m	58	69	< 150	150 - 370	7 years
Total dissolved solids	mg/l	486	537	< 1 000	1 000 - 2 400	7 years
Colour	mg/l Pt	>70	-	<20	20-50	No limit
Turbidity	NTU	>1000	-	<1	1-5	No limit
Suspended Solids	mg/l	4110	-	n.s.	n.s.	n.s.
Total hardness as CaCO ₃	mg/l	290	340	n.s.	n.s.	n.s.
Calcium hardness as CaCO ₃	mg/l	140	150	n.s.	n.s.	n.s.
Magnesium hardness as CaCO ₃	mg/l	150	190	n.s.	n.s.	n.s.
Total alkalinity as CaCO ₃	mg/l	250	290	n.s.	n.s.	n.s.
Sodium	mg/l	20	13	< 200	200 - 400	7 years

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Calcium	mg/l	56	60	< 150	150 - 300	7 years
Magnesium	mg/l	36	46	< 70	70 - 100	7 years
Bicarbonate	mg/l	305	354	n.s.	n.s.	n.s.
Chloride	mg/l	35	35	< 200	200 - 600	7 years
Sulphate	mg/l	25	25	< 400	400 - 600	7 years
Nitrate	mg/l	3.5	3.9	< 10.0	10.0 - 20.0	7 years
Fluoride	mg/l	0.2	0.3	< 1.0	1.0 - 1.5	1 year
Ammonia nitrogen	mg/l	0.7	0.3	-	-	-
O-Phosphate as P	mg/l	1.7	-	-	-	-
COD	mg/l	480	10			
Sodium	mg/l	22	19	< 200	200 – 400	7 years
Potassium	mg/l	1.6	0.8	< 50	50 - 100	7 years
Boron	mg/l	0.002	0.003	-	-	-
Chromium	ug/l	1.245	0.261	< 100	100 - 500	3 months
Lead	ug/l	0.000	0.000	< 20	20 - 50	3 months
Cadmium	ug/l	0.144	0.34	< 5	5 - 10	6 months
Mercury	ug/l	1.494	3.146	< 1	1 - 5	3 months
Heterotrophic plate count	cfu/ml	15520	7040	-	-	-
Faecal coliform bacteria	cfu/100ml	110	0	Not detected	1	10

Green: Class 1, Good water quality, suitable for life time use, rare instances of sub-clinical effects.

Yellow: Class 2, Marginal water quality, may be used without health effects by the majority of individuals for a limited period only.

Red: Class 3, Poor water quality, poses a risk of chronic health effects, especially in babies and elderly.

8. GEOHYDROLOGICAL ASSESSMENT

The lithology on site consists of a number of layers. (Ref 1).

TABLE 6: Summary of Typical Soil Profile

Depth (m)	Description	Comment
0.0 – 1.0	Hillwash: Dry, orange brown, firm, slightly clayey sandy SILT with isolated fine gravels.	Two areas where horizon has been excavated (Figure 1). Sampled for determining suitability as a capping or lining material.
1.0 – 1.4	Alluvial Gravel: Relatively closely packed, sub-rounded to sub-angular calcite, quartzite and andesite COBBLES and GRAVELS in a matrix of dry, red brown, slightly clayey silt. Overall consistency is dense but friable.	Not suitable for use as a capping or lining material. Could possibly be used as fill for terracing.
1.4 – 2.0	Alluvium: Slightly moist, red brown speckled black, stiff, poorly cemented and ferruginised, slightly clayey SILT with scattered rounded fine quartz gravels.	Sampled for determining suitability as a capping or lining material.
2.0 – 5.0	Residual andesite: Slightly moist, khaki stained orange and black, very stiff, relict jointed, clayey SILT.	Sampled for determining suitability as a capping or lining material. Test
5.0 – 13.0	Residual andesite: Slightly moist, yellow brown, probably stiff, slightly clayey silt.	Seepage recorded between 8m and 13m.
13 – 24.0	Andesite: Khaki, medium weathered, jointed, medium hard rock to hard rock	Seepage recorded at upper contact
24 - 40	Andesite: Grey, unweathered, hard rock to very hard rock.	Seepage on fractures from 36m to 41m.

The top material seems to be alluvium up to 2 metres. From 2 metres to 13 metres fairly weathered Andesite with fairly high hydraulic conductivities. More competent medium hard rock Andesite is found from 13 metres downward.

The top material of up to 2 metres is dug out to be used as covering material for the landfill. The next layer, the residual Andesite forming a clayey material will have low permeability properties protecting the very low yielding aquifer below.

The drilling results captured in Jones and Wagener report confirm the lithology and low yielding aquifer. The geophysical study, and especially frequencies 2400 to 37Mhz, also confirms the above findings.

The groundwater movement of 6.72×10^{-4} m/d calculated in section 8.5 is slow and will protect the low yielding aquifer below.

From a contamination point of view the study shows a very low yielding aquifer with limited groundwater movement and therefore limited chance of contaminated groundwater spreading to the non-perennial river systems.

9. CONTAMINATION RISK ASSESSMENT

9.1 Parsons Rating System

The “Parsons Rating System” is an aquifer classification system developed to implement a strategy for managing groundwater quality in South Africa. Classification, vulnerability and susceptibility are rated for a specific aquifer to be studied.

a) Aquifer Classification

The aquifer at the proposed Vaal Marina is classed as a **minor** aquifer region and can be described as a low to moderately yielding aquifer system of variable water quality.

b) Aquifer vulnerability

A **Moderate** tendency or likelihood does exist for contamination to reach a specific position in the groundwater system after introduction at some location above the uppermost aquifer.

c) Aquifer susceptibility

The aquifer is rated to have a **Medium** susceptibility. Susceptibility is a qualitative measure of the relative ease with which a groundwater body can be potentially contaminated by anthropogenic activities and includes both aquifer vulnerability and the relative importance of the aquifer in terms of its classification.

d) Groundwater Quality Management Classification

The **GQM index of this option is rated at 4**, with a **Medium** protection level needed.

9.2 Existing Threat to Groundwater Quality

The landfill is an existing landfill which is well managed in terms of compaction and continuous covering with fairly clayey material mined on site. Leachate forming is not expected with no leachate emanating on site during the field visit.

9.3 Water Resources

Five boreholes are in use inside a 1km radius from the landfill site. Four of these boreholes are located upstream of the landfill site and can therefore not be influenced by the landfill site. Only borehole H/BH 02 that is in use is located inside the 1km radius and on the groundwater flow down side of the landfill.

9.4 Contamination Risk from an On-Surface Contamination Source

As far as the contamination risk from the existing landfill is concerned, the assessment is based on the level of risk of the source. Risk levels are based on three factors: 1) attenuation ability in unconsolidated materials; 2) contamination load and travel time of degradable pollutants, in aquifer systems and 3) vulnerability of the aquifer and behavior of interstitial water regimes. Soil or unconsolidated material may provide a very effective attenuation buffer for certain contaminants and may have a very low attenuation on other contaminants. The nature of the soil materials and the thickness of this zone, are key issues in determining attenuation capacity. The nature of the host rock is partially weathered Andesite that is un-weathered in depth.

Romero (1970, 1972) assessed the characteristics of biological pollutant travel in unconsolidated sedimentary formations based on grain sizes. His data suggested that soil material with grain sizes greater than 0.25mm would provide a short-circuiting of the attenuation system. Soil with percolation rates of 50-300 mm/hour is commonly accepted for installation of conventional waste disposal units (Allen, et al, 1973). Ward (1989) mentions that in certain hydrogeological environments, notably where fine-grained unstructured loams attain a thickness of at least 3m above the water table, biological pollutant attenuation is rapid and the risk of groundwater contamination minimal. The rapid drop-off of bacteriological indicators was confirmed by a local investigation conducted in Ivory Park in Midrand, where soil's permeability was tested to be within 54 mm/hour, which is typical of very fine sands or silty sands.

The travel time is equivalent to bacteriological and viral survival times in groundwater systems in the UK, 50 day protection against bacteriological and viral contamination is afforded to sources of water supply. In addition, the travel- time concept also allows physical, biochemical and dilution mechanisms to reduce concentration of chemicals in solutions to accepted levels. According to Lewis, et al (1982), travel time of 50 days may appear to be very conservative. They implied that a travel time of 10 days would be sufficient in normal hydrogeological situations. In much of this country with semi-arid climate, where temperatures are much higher than in the UK, these conditions would reduce bacterial and viral survival times.

The soil's hydraulic conductivity measured in test pit TP1 is 4.42×10^{-4} cm/s or 1.5899cm/h or 0.3816m/d, whilst the hydraulic conductivity in test pit TP2 is 6.92×10^{-3} cm/s or 24.91cm/h or 5.98m/d. Test pit TP1 are located on the top soil material covering the landfill site whilst test pit TP2 are located on weathered and fractured Andesite.

The hydraulic flow time to the water table = depth to water table ÷ permeability. The hydraulic flow time, in the unsaturated zone measured at test pit TP1 is 26.2 days for contaminated water to reach the aquifer below. The hydraulic flow time, in the unsaturated zone measured at test pit TP2 is 1.2 days for contaminated water to reach the aquifer below.

From the above calculation it is clear that the fractured host rock have a very high hydraulic conductivity. The hydraulic conductivity is low only when the host rock is full decomposed to clay minerals. In other words the topsoil material representing the final product of weathered Andesite have a much lower hydraulic conductivity as halve weathered and fractured Andesite with high hydraulic conductivity values.

During the process whereby the topsoil material is removed and the semi weathered host rock is exposed the contamination risk is increased dramatically. A liner layer must be constructed at the base of the landfill with the topsoil material to protect the aquifer from contamination.

10. CONCLUSIONS AND RECOMMENDATIONS

The geophysical study, the available drilling information (Jones & Wagener), the infiltration rate measurements and groundwater movement calculations all leads to the conclusion that the existing landfill site conditions pertaining to groundwater contamination risk is relative low. The following facts support this assessment:

- The lithology on site consists of a number of layers.
- The top material seems to be alluvium up to 2 metres.
- From 2 metres to 13 metres fairly weathered Andesite with fairly high hydraulic conductivities are found.
- More competent medium hard rock Andesite is found from 13 metres downward.
- The magnetic data does not show any prominent intrusive material in the form of linear structures on site. The data show a relative flat graph with no obvious structures or weathered zones.
- No prominent weathered zone could be detected by the Electromagnetic study. From a geophysical perspective, the existing landfill site is well located on what seems to be a block of uniform Andesite. No zone could be pinpointed that can possibly carry groundwater on a noticeable scale.
- The maximum hydraulic conductivity value of 0.032m/d indicates that the rock formations in the vicinity of the landfill site have low hydraulic conductivities. This is also confirmed by the drilling logs in the report from Jones & Wagener.
- A flow velocity of 0.245m/a was calculated for the aquifer which can be regarded as very slow.
- The chemical classification of water from borehole WBH1D can be categorized as Class 2, due to elevated Mercury levels of 3.146ug/l, marginal water quality, may be used for a limited period only, without health effects by the majority of individuals.
- The chemical classification of water from borehole WBH2D can be categorized as Class 3, Poor water quality, poses a risk of chronic health effects, especially in babies and elderly. This is mainly due to Turbidity and color. The Mercury level is also elevated to 1.494ug/l which can be categorized as Class 2.
- The bacteriological quality from WBH1D can be categorized as Class 1, Good water quality, suitable for lifetime use, rare instances of sub-clinical effects. The COD level however shows no contamination with limited bacteriological activity. A high Heterotrophic Plate Count and Faecal Coliform Bacteria count show that the contaminants reached the aquifer below the landfill site. The Chemical Oxygen Demand (COD) level is also high confirming an active bacteriological process.
- The bacteriological quality from WBH2D can be categorized as Class 3, Poor water quality, poses a risk of chronic health effects, especially in babies and elderly.

- The difference in bacteriological water quality of the two boreholes WBH1D and WBH2D clearly show that groundwater enters the landfill site from the north western side of the landfill as shown on Map 3 and Map 4 gathers organic pollutants and exit the site on the south eastern side of the landfill site. Chemically however the water quality on the down slope side of the landfill site is the same as the water entering the landfill site.

The following recommendations are made:

- Routine monitoring of water levels, rainfall figures and water quality is strongly recommended and should strictly be adhered to. This data will form the basis from which any changes in the groundwater regime are recognised.
- Water quality monitoring of the nine existing monitoring boreholes must be done at a three monthly interval. Major cat and an-ions and bacteriological parameters must be analysed for.
- Hydrogeological monitoring data (described above) should be evaluated bi-annually by a qualified hydrogeologist.
- A Groundwater Management Plan with relevant Groundwater Monitoring and Reporting Protocol should be established and calibrated annually.
- Groundwater level monitoring in all nine the boreholes must also be done on a three monthly basis.
- A liner layer consisting of a G layer of at least 150mm thickness must be constructed at the base of the landfill with the topsoil material to protect the aquifer from contamination.

REFERENCES

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APPENDIX A

Geophysical Study Information

APPENDIX B

Summary of Methods used for Yield Recommendations and Diagnostic Plots of Boreholes, Test Pumping Results and Recovery Rates

APPENDIX C

Water Quality Analyses