Alton Landfill Site Final Risk Assessment Report

September 2015

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THIS REPORT SHOULD BE REFERENCED AS:

GCS (Pty) Ltd. and CSIR (2015) Alton Landfill Site: Final Risk Assessment Report - Report prepared for the City of uMhlathuze (CoU). Durban.

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Executive Summary

The Council for Scientific and Industrial Research (CSIR) Durban Branch has been commissioned by the City of uMhlathuze (CoU) Municipality to manage the Alton landfill site project and requisite specialist studies. In line with this, CSIR (Durban) contracted GCS (Pty) Ltd (hereafter referred to as 'GCS') to undertake the required hydrogeological risk assessment.

Background

The Alton landfill site was previously used to store green waste such as grass and flowers, and domestic and commercial food waste, which were in turn used to support a green energy production initiative. This initiative was unsuccessful and short-lived and the landfill was decommissioned approximately 10 years ago. At present, the site is used for the temporary storage of general waste which is thereafter transported to the uThungulu landfill site for disposal.

Main objectives

- To examine the quality of groundwater within the study area in order to determine the level of contamination (of particular importance is bacterial contamination), and seasonal variations thereof, resulting from landfill activity.

Methodology

The following activities were conducted as part of this project:

- Gathering of hydrogeological and geological information on a desktop level and hydrochemistry data for all monitoring boreholes within the site.
- Undertaking a fieldwork assessment to obtain groundwater samples from existing boreholes for hydro-chemical analysis, and conduct a hydro-census within a 1km radius from the site.
- Conducting permeability testing on the down gradient side of the landfill to obtain hydraulic permeability of the unsaturated zone.
- Conducting aquifer testing in existing monitoring boreholes to obtain the hydraulic conductivity of the saturated zone
- Obtaining soil samples for chemical analysis to determine if the landfill is impacting the soils onsite, the extent of the impact, and to supply recommendations regarding remediation measures.

Limitations

During the desktop and site assessment phases it was discovered that some data gaps exist which may be regarded as limitations to the overall assessment output. These include:

- Information regarding the original construction of the landfill site was unavailable; including technical design and site selection criteria.
- Due to the age of the site, it can't be proved with certainty what has been historically dumped at the site.
- The water monitoring protocol applied did not allow for any groundwater level monitoring. Therefore, no time-series data exists, creating gaps in the overall scientific approach and understanding of the site.
- No borehole logs for the monitoring boreholes were supplied. As a result the onsite geology of the landfill site is unknown.

Findings

The main findings of the hydrogeological site assessment are discussed below:

Field observations

- During the fieldwork assessment, it was observed that the landfill is covered by permeable sand. Furthermore, it was observed that the top of the landfill is vegetated with grass and this will increase the recharge into the landfill. Diggings were visible all around the site, possibly dug by scavengers searching for steel and other wastes from the landfill. The sand cover and diggings may influence natural groundwater recharge patterns as exposed areas will result in higher recharge values. Higher recharge, in turn, may play a significant role in contaminant transport and overall pollution to the area due to steeper aquifer heads.
- Leachate and subsequent ponding, down gradient of the landfill and behind the non-operational pump station, was observed during the site assessment phase. The leachate had a strong smell and was brownish in colour.
- A non-perennial stream flows through the site on the western area down to borehole GL7 down gradient of the landfill site. The stream joins the main river further south of the landfill site.

Fieldwork assessment

- Groundwater levels within the site were measured in three occasions, firstly by GCS, Secondly by the CoU and thirdly by CSIR. The second water level data by CoU was found to be not accurate and it was discarded. Groundwater levels measured by GCS and CSIR indicate shallow groundwater level within the site.
- The results of the Aquifer testing conducted in two monitoring boreholes outside the landfill area (across the R34 road) indicate that hydraulic conductivity ranges between 0.1 and 0.3 m/day. This range suggests that any pollution plume originating from the landfill will move at an average rate of 0.2 m/day and in one year it would have moved in the order of 73m away from the landfill. This further suggests that the top, shallow aquifer is characterised by moderate to high hydraulic conductivity.
- Permeability testing results on the unsaturated zone within the site, close to the land on the down gradient side, showed a coefficient of between 0.0864 m/s to 1.7280 m/s. Based on these values it appears that the permeability class of the unsaturated zone down gradient of the landfill ranges from semi-permeable to permeable.

Groundwater quality

- Faecal coliforms were detected at borehole GL1 located along the eastern boundary of the landfill site. This borehole as well as boreholes GL8, GL15, GL17, GL18, GL20 and GL22 exhibited a high total coliform count.
- No Escherichia coli (E. coli), chromium VI, cyanide, mercury, cadmium or lead, were detected in the groundwater samples, with the exception of very low chromium concentrations at GL18 and GL19.
- Consistently high iron, chemical oxygen demand (COD) and sulphate concentrations above the general limits set by DWAF (1999) are observed at all monitoring boreholes.
- Neutral pH conditions exist at most of the boreholes, with the exception of slightly acidic conditions recorded at GL12 and GL19.
- High phenol concentrations are observed at GL7 and GL20 (before and after the R34 road), and could have adverse effects to downstream groundwater users.
- High ammonia concentrations above the DWAF (1999) general limits are observed at GL7, GL8, GL9, GL15, GL17, GL20, GL21 and GL22.

- It is clear that there is diffusion and advection of the chemical constituents at the site. Concentrations seem to be highest at the centre of the site (at GL15) migrating downstream towards the receiving stream (close to GL7). The concentrations of constituents also decreases the further one moves away from the receiving stream. GL1 also indicates that a plume might be moving to the east of the site.
- The water quality of the site is poor with respect to the outflowing seepage towards the receiving stream to the south of the site.

Site conceptual model

The study area falls on Maputaland Group stratigraphy, the upper (younger) formations of which consist of unconsolidated sedimentary material. The lithology of the area consists primarily of deep clay profiles with interbedded, water bearing, sand layers. The oldest layers of the lithology consist of weathered calcrete and Port Durnford Formation fossiliferous mudrock that becomes more competent with depth. The Port Durnford Formation acts as a confining layer to the deeper aquifers of the Uloa and Umkwelane Formation.

The field investigation showed that the upper lithology consisted mostly of a sandy aquifer. The static groundwater levels of this aquifer are generally very shallow in this area, at approximately 4 m below ground level, indicating a perched water table in the upper sandy aquifer. However, areas of low topography and near the stream will have water levels ranging from 0.5m to 1m. It is assumed that the deeper lithology consists mostly of clay type sediments which would act as a confining layer to the deeper aquifers. The groundwater flow direction within the site appears to be from NE to SW and towards the streams in low lying areas.

Soil chemistry

The purpose of undertaking the soil analysis was to assist with confirming soil classification, and to provide an indication of the soil quality for decisions regarding soil contamination and land capability. The following can be stated regarding soil chemistry based on the soil samples collected:

- The results obtained indicate slightly acidic soil at PT3, PT4, PT1, PT2 and PT6 (FSSA, 2007). Very acidic conditions are present at PT5, and from the data obtained it can clearly be seen that pH decreases with depth at each sampling point where the B horizon was sampled. The possible reason for the decrease in pH with depth is that the top A horizon is permeable and the pH is diluted by infiltrating rain water, whereas the B horizon is less permeable and therefore there is less dilution by rain water. Lower pH values will trigger the mobility of metals in the soil and in groundwater.

- Macro elements (Ca, Mg, K, Na and Cl) are present in relatively low concentrations at all the sampling points. Highest macro elemental concentrations are observed at PT3, PT5, PT2 and PT6. The data suggests that nutrient concentrations within the A horizon is much higher than that of the B horizon. The B horizon is mostly clay material with low permeability and as a result there is less leaching of dissolved substances from the top horizon to the clay layer. Groundwater will therefore flow horizontally through the interconnected pore spaces between sand grains following the topographic low areas into the stream. This will have adverse impacts on stream water quality as well as aquatic life.
- NO_3 and NH_4 concentrations are present in relatively equal quantities, however, at PT6 NO_3 concentrations are observed to be much higher than at the other sampling points. Sudden NO_3 concentration increases can be traced to microbial activity and nitrification processes within the immediate area at PT6.
- The sub-soil at soil sample site PT2 shows high sulphate concentration. High sulphate concentration was also observed at borehole GL20 which is located approximately 2m away from soil sample point PT2,. This suggests that groundwater quality is related to soil quality in that area.
- Comparing the micro-nutrients to the available DEA (2008) SSV1 limits indicates that metals and metalloids are present in fairly low concentrations and will be immobile due to neutral pH conditions at most of the sampling areas. None of the elements tested for succeeds the limits, however, due to limited leaching between the A and B horizons, elemental concentrations are much higher within the A horizon. If pH conditions decrease the metals will become soluble and enter the groundwater, or otherwise remain immobile within the soil.

<u>Recommendations</u>

- It is recommended that all mitigation measures be implemented as outlined under the mitigation section of this report.
- The landfill must be properly fenced and warning signs placed to prevent human traffic through the site and subsequent excavations.

- Three deep monitoring boreholes must be added to the current monitoring network. These boreholes need to reach depths of at least 5m into the bedrock or underlying impermeable/confining layer; i.e., the boreholes should not partially but instead fully penetrate the aquifer. This will enable a better understanding of the geology, deeper groundwater quality and aquifer dynamics. Two boreholes will be located within the site and one outside the site (hydraulically down gradient of the landfill).
- Water level measurements must be obtained during every sampling event on the site and be added to the database. It is important that monitoring staff be adequately trained, that the SABS and DW&S guidelines be followed and that the correct equipment be utilized.
- Two surface water monitoring points must be added to the current monitoring network; one upstream and the other downstream of the landfill. This will help to determine whether or not the landfill is impacting the non-perennial stream flowing through the site.

Risk assessment

Based on the available data received from CoU and data obtained during the desktop and fieldwork assessments it appears that a **medium to high** risk rating can be assigned to groundwater and surface water contamination based on current conditions of the landfill and the location of the surface water bodies in relation to the landfill. It is also believed that the identified risk can be reduced to a medium rating if the correct management plans and monitoring systems are applied as stipulated in Waste Management Series (Minimum Requirements for Waste Disposal by Landfill and Minimum Requirements for Water Monitoring at Waste Management Facilities) documents published by the Department of Water Affairs and Forestry (DWAF) in 1998.

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1. Introduction

The Council for Scientific and Industrial Research (CSIR) has been commissioned by the City of uMhlathuze (CoU) Municipality to manage the Alton landfill site project and requisite specialist studies. In line with this, the CSIR (Durban) contracted GCS (Pty) Ltd (hereafter referred to as 'GCS') to undertake the required hydrogeological risk assessment.

The Alton landfill site was previously used to store green waste such as grass and flowers, and domestic and commercial food waste, which were in turn used to support a green energy production initiative. This initiative was unsuccessful and short-lived and the landfill was decommissioned approximately 10 years ago. At present, the site is used for the temporary storage of general waste which is thereafter transported to the uThungulu landfill site for disposal.

1.1. Study objective

To examine the quality of groundwater within the study area in order to determine the level of contamination (of particular importance is bacterial contamination), and seasonal variations thereof, resulting from landfill activity.

1.2. Terms of reference

To achieve the above objective the following terms of references were agreed upon with CSIR in the kick-off meeting held at CSIR (Durban) on 01 September 2014:

1) Conduct a desktop study of existing information, such as geological and hydrogeological maps and existing borehole data;
2) Conduct a hydro census of boreholes and possible contamination sources within a 1km radius of the existing landfill development boundaries, to establish static and dynamic water levels, existing water abstraction figures in the area, borehole depth and water end users;
3) Study the groundwater regime in terms of geology and related aquifers;
4) Conduct soil permeability testing to calculate the hydraulic parameters of the unsaturated zone, and thereby determine the site's contamination risk;
5) Provide guidelines for a groundwater monitoring system;
6) Conduct pump tests on available monitoring facilities to calculate hydraulic parameters for the saturated zone;
7) Provide a baseline reference of groundwater quality on-site and in surrounding areas;

8) Provide a reference of current baseline contamination levels by collecting and analysing groundwater samples for key parameters; and

9) Compile a technical report detailing the results/findings of the investigation.

2. Methodology

The following methodology was applied:

- Gather information on the hydrogeology and geology within the landfill and surrounding areas. Reference was made to previous hydrogeological studies conducted around the Alton landfill area.
- Analyse hydrochemistry data for boreholes within the landfill site provided by CoU.
- Undertake a simple gap analysis by applying an internationally accepted risk assessment methodology i.e. the DRASTIC (Introduced by US. Environmental Protection Agency) method. This analysis will be used to compare available data and create a benchmark for the risk assessment methodology.
- Compile a desktop study report detailing all available information.
- Carry out a site visit and walkover to assess the site in terms of topography, land cover, drainage and the overall physical appearance and current status of the site.
- Collect groundwater samples from existing monitoring boreholes, measure water levels and determine borehole depths.
- Conduct a hydro census around the landfill site to determine if there are groundwater users who abstract water from boreholes, and identify other possible sources of pollution within a 1km radius from the landfill.
- Carry out aquifer testing on monitoring boreholes to determine the hydraulic parameters of the aquifer.
- Conduct permeability testing on the unsaturated zone to determine its permeability.
- Collect soil samples from within the landfill site for soil contamination analysis.

3. Site location and description

The study area is located at the corner of R34 and Alugang Street, approximately 3 km southwest of Richards Bay central and approximately 2 km north of the Port of Richards Bay. The site is surrounded by heavy industries such as Foskor, Mondi and BHP Billiton Hillside. Refer to Figure 14-1 in Appendix A for the locality map of the site and the hydro-census boreholes. To be noted however, is that Foskor and Mondi are located beyond the 1 km radius of the site, and therefore do not have an impact on groundwater quality within the landfill site as explained in the sections below.

A non-perennial stream (Stream 3 on Figure 14-1) flows through the site, from north to south on the western area, and borehole GL7 which is situated down gradient of the landfill has been drilled into the banks of this stream. Other streams (Streams 1 and 2 on Figure 14-1) on the western side of the site flow in a southerly direction. These streams join together further south of the site and flow to the Richards Bay Harbour. The topography within the site decreases towards the west in the northern part of the site and towards the south of the site including the non-perennial stream flowing through the site.

4. Site assessment

The site was assessed in phases as follows:

Phase 1: Desktop Assessment (Hydrogeological Desktop Assessment Report (2015) and Section 4.1 of this report);

Phase 2: Field work and data assessment (Sections 4 - 7 of this report); and

Phase 3: Risk Assessment and reporting (Sections 8 - 13 of this report).

4.1. Desktop assessment

The historical groundwater quality data from the Alton landfill site was obtained during a desktop phase. More groundwater quality data was received from Foskor, Hillside Aluminum and Mondi.

Foskor and Mondi are located outside of a 1km radius from the landfill site and groundwater flow from these two companies is most likely to be towards the south following the topography. It is therefore not anticipated that any of the pollution originated from their areas will influence water quality within the landfill site.

Hillside Aluminum shares the boundaries with the Alton landfill site. Groundwater quality data from Hillside was also received to compare with the groundwater quality within the site. However, the latest data (July 2014) from Hillside suggested high Iron and Aluminum in groundwater within the Hillside Aluminum site. No groundwater levels were supplied for boreholes at Hillside Aluminum. As a result the groundwater flow direction from Hillside was not determined.

The desktop hydrogeological assessment report for the Alton landfill site was submitted to CSIR on the 2nd of January 2015. All the data gathered during the desktop study was used to inform the compilation of this report. The following limitations were identified during the desktop study:

- Borehole logs for the monitoring boreholes were unavailable. As a result the onsite geology of the landfill site is unknown.
- No borehole depths were supplied during the desktop study; however, borehole depths were measured as part of the field assessment. Borehole depths will give an indication of the depth of monitoring.
- No historical groundwater levels were available during the desktop study. However, groundwater levels were measured on two occasions as part of the field assessment. Groundwater levels will help understand water level fluctuations within the site
- No information on the original design and construction of the landfill was available. Therefore, there is uncertainty regarding the critical design parameters considered during construction, including linings, sub-surface drainage, seepage management and detection of tow drain seepage.
- Furthermore, the recharge to aquifers by normal precipitation usually plays an important role at landfill sites. However, it is not clearly understood how this has been managed historically.

The following groundwater quality issues were noted in the desktop assessment report:

- Groundwater quality within the landfill area is poor with elevated concentrations of metals (i.e. lead, iron, manganese, Hexavalent chromium and sodium), ammonia and high electrical conductivity values, above the general limits.
- Chemistry data on boreholes also indicate high concentrations of oil and grease.
- Concentrations of phenolic compounds are high throughout the site with seasonal variations.
- Borehole water quality data indicates acidic groundwater conditions within the site.

4.2. *Field work and data assessment*

This section supplies details of the field work conducted as indicated in the Terms of Reference (ToR). The field work was conducted from the 20th of October 2014 to the 22nd of October 2014 and included:

- Borehole sampling to obtain groundwater samples for hydrochemical analysis.
- Shallow aquifer testing to determine the hydraulic conductivity of the shallow, unconfined aquifer. This was done by pumping the borehole dry while measuring the drawdown at 1 minute intervals. The pump was stopped and the recovery measurements were taken and recorded. The data was used to determine hydraulic conductivity using aquitesolv and aquifer test programs.
- Permeability testing on the unsaturated zone to ascertain hydraulic permeability of this zone. Permeability testing was conducted in auger holes used for soil sampling. The test was performed using a simple field test to determine the coefficient of permeability, as prescribed by the Food and Agriculture Organization (FAO) of the United Nations.
- Soil permeability testing to determine the hydraulic permeability of the unsaturated zone.
- Soil sampling for soil contamination analysis.
- Hydrocensus to determine if there are any groundwater or surface water users within a 1 km radius from the site who abstract water from boreholes.

4.2.1 ***Borehole Sampling***

Groundwater samples were collected from 13 monitoring boreholes. The following water samples were collected from each borehole:

- 1 x 2L plastic bottle for inorganic water analyses;
- 1 X 1L of sample in a clean glass bottle for phenol analyses; and
- 1 X 500mL of sample in a clean sterilised plastic bottle for microbiological tests.

Table 4-1 below shows the co-ordinates of the sampled boreholes, water levels and other field measurements. The site localities are indicated on the map provided in Appendix A (Figure 12-1). The collected samples were submitted to the CSIR in Durban, a SANAS accredited laboratory, for hydro-chemical analysis.

Table 4-1: *Table showing borehole coordinates water levels and field measurements*

Site ID	South (dd.ddddd)	East (dd.ddddd)	Elevation	BH depth (m)	WL (m)	pH	EC (mS/cm)	TDS (ppt)	Temp (˚C)	Comments	Collar (m)
GL1	S28.76738	E32.02128	36	8	3.4	6.58	0.97	0.48	22.8	Up gradient borehole.	0.5
GL15	S28.76876	E32.01791	33	7	4.13	6.64	3.1	1.55	28	Borehole close to the stream. Water has a strong smell.	0.9
GL8	S28.77214	E32.01673	28	7	4.87	6.24	0.54	0.27	22.7	---	0.6
GL2	S28.77212	E32.01714	29	8	4.58	5.9	1.08	0.54	23.2	---	0.51
GL9	S28.77215	E32.01747	29	7	1.05	6.03	1.96	0.98	22.6	---	0.4
GL7	S28.77235	E32.01726	29	8	0.5	6.67	6.02	3.01	22.3	Borehole in the stream. Water has a strong smell.	0.39
GL10	S28.77217	E32.01795	31	---	---	---	---	---	---	Vandalised	
GL12	S28.77221	E32.01768	30	7	4.18	5.12	0.64	0.32	24.4	---	0.36
GL6	S28.77213	E32.01814	---	---	---	---	---	---	---	Dry	
GL17	S28.77144	E32.01745	30	8	3.1	6.7	7.08	3.54	26.1	---	0.48
GL18	S28.7714	E32.01717	30	8	4.3	6.5	0.33	0.16	25.3	---	0.47
GL19	S28.77142	E32.01684	29	8	4.56	5.17	0.98	0.48	24	---	
GL20	S28.77142	E32.01782	31	8	1.62	6.78	8.83	4.42	27.1	Orange water with strong smell.	0.43
GL21	S28.77143	E32.01829	33	8	3.43	5.54	4.25	2.12	24.6	---	0.52
GL22	S28.77146	E32.01866	34	8	5.05	6.83	3.45	1.72	24.6	---	0.52

4.2.2 *Aquifer Testing*

Due to small diameters of the inner casing in most monitoring boreholes within the landfill site and inaccessibility to some boreholes outside the landfill site, pump testing was conducted in only two monitoring boreholes (GL2 and GL12) which were accessible with the pump due to their large inner casing diameters. Due to the very low water level in the borehole (average water level of 3.44 mbgl) a micro purge pump was used to pump the borehole dry and measure the recovery. The drawdown data and the recovery data were applied to calculate hydraulic conductivity. The data was analysed using the Aquifer Test and Aquitesolv programs to obtain transmissivity (T) and hydraulic conductivity (K) values.

Table 4-2 below shows the results obtained from aquifer testing. Based on these results it is fair to assume that the hydraulic conductivity ranges between 0.1 m/day and 0.3 m/day. These values are in line with the known values for fine grained clayey to silty sands. The analysis graphs are included in Appendix C.

Table 4-2: *Aquifer test results*

Borehole Characteristic	Borehole ID	
	GL2	GL12
Borehole Depth (mbgl)	8	7
Static Water Level (mbgl)	4.58	4.30
Time pumped (min)	5.00	10.00
Pump to level (m)	7.78	6.93
Recover to (m)	4.89	4.44
Time recovery (min)	28.00	15.00
% recovery	90.31	94.68
T (m^2/day) Aquifer test	0.86	0.86
T (m^2/day) Aquitesolv	1.97	1.53
K (m/day) Aquifer test	0.11	0.11
K (m/day) Aquitesolv	0.25	0.19

4.2.3 *Soil sampling and permeability testing*

Soil samples were collected using a hand auger from predetermined positions within the site. The sample points were selected based on distance from the landfill. The selected sample points formed two distinct sampling lines; one being close to the landfill (approximately 50m away) and the other being approximately 100m away on the down gradient side of the landfill. The aim of adopting this sampling approach was to enable comparison between soil quality near the landfill and soil quality further away from the landfill. The co-ordinates of the auger holes are shown in Table 4-4 and the position of the holes are depicted in Figure 14-1 (Appendix A). The primary objectives of soil sampling were to: determine whether soil near the landfill site, especially those that are hydraulically down gradient of the landfill, is contaminated; the potential distribution of soil contamination; and gain a better understanding of the composition of the soils in the study area.

Soil samples were collected from soil horizons within the top 2 m from the surface. Where groundwater was intercepted, soil samples were collected above and below the groundwater seepage level.

Permeability testing was carried out on three auger holes dug for soil sampling which are located close to the landfill (GPS co-ordinates provided in Table 4-3). The reason for selecting auger holes close to the landfill was to determine the hydraulic permeability of the unsaturated zone near the landfill where seepage is most likely to occur, and help understand the probability thereof. The auger holes were filled up with water several times to saturate the area around the auger holes until the rate of drawdown was constant. Subsequently, falling head tests were conducted to determine the rate at which the drawdown occurred. The field data was used to calculate the coefficient of permeability.

Table 4-3 shows the results of the permeability testing. The coefficient of permeability (K) was calculated from the field results using the formula $K= (D\div2) \times \ln(h_2\div h_1)/ 2(t_2-t_1)$ suggested by the FAO of the United Nations. In this formula $(D \div 2)$ is the radius of the hole or half its diameter in meters; ln refers to the Napierian or natural logarithm; h_1 and h_2 are the two consecutive depths of water in meters, h_1 at the start and h_2 at the end of the time interval; $(t_2 - t_1)$ expresses the time interval between two consecutive measurements, in seconds. The values obtained were compared to a standard permeability range as per Table 11-1 in Appendix B.

Table 4-3: *Permeability testing results*

Site ID	Southing	Easting	Hole depth (m)	Coefficient of permeability (K) (m/s)	Comments
PT1	28.77132	32.01874	2	0.000012837	Permeable
PT2	28.77144	32.01792	1	0.000004363	Permeable
PT3	28.77136	32.01715	2	0.000001211	Semi-permeable

Table 4-4: *Soil sampling and permeability testing coordinates*

Site ID	South	East	Soil sampling	Permeability testing
PT1	28.77132	32.01874	x	x
PT2	28.77144	32.01792	x	x
PT3	28.77136	32.01715	x	x
PT4	28.77043	32.01591	x	
PT5	28.77223	32.01771	x	
PT6	28.76764	32.02094	x	

4.2.4 *Groundwater levels and groundwater flow direction*

Groundwater levels were measured as part of the field assessment and the results indicate that shallow groundwater levels, on average 3.44 mbgl, predominantly occurred at the site.

Figure 4-3 shows the direction of groundwater flow. It can be seen from the map that groundwater within the site flows from north east to south west.

A second round of water level measurements was conducted on the 5th of March 2015 by CSIR personnel to confirm the initial water levels measured during the site visit in October 2014. The results are tabulated and represented graphically as shown in Table 4-1, Figure 4-1 and Figure 4-2. No significant water level changes are observed, only slight variations which were less than a meter in some boreholes. It is highly recommended that groundwater levels within the site are measured in conjunction with monthly sampling. This will assist in understanding groundwater level fluctuations within the site.

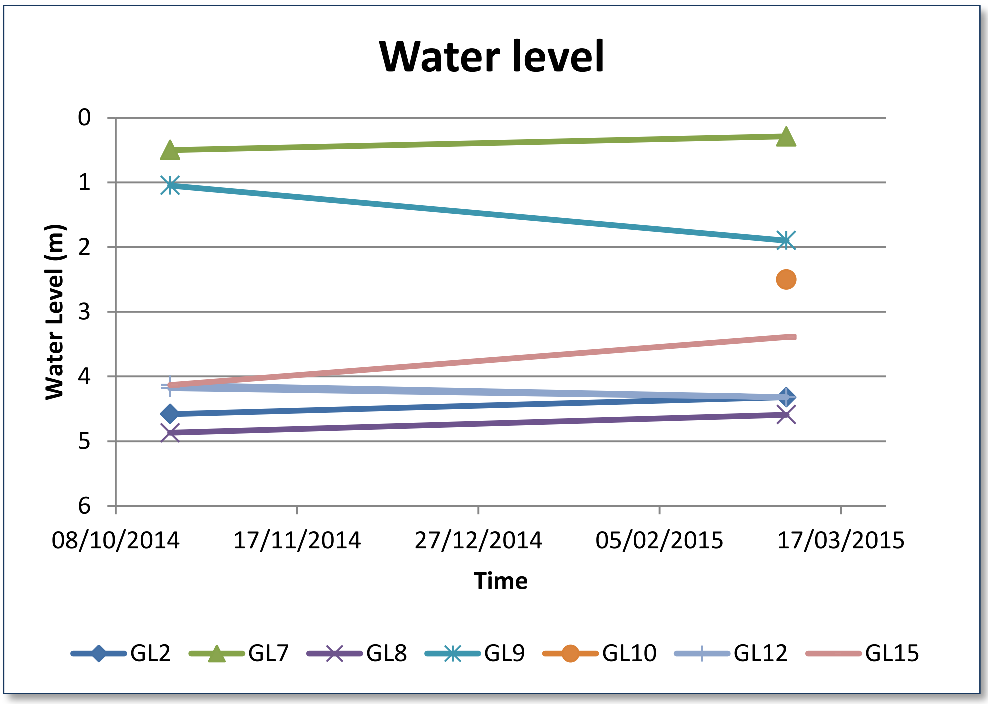


Figure 4-1: Water level trend graph (1)

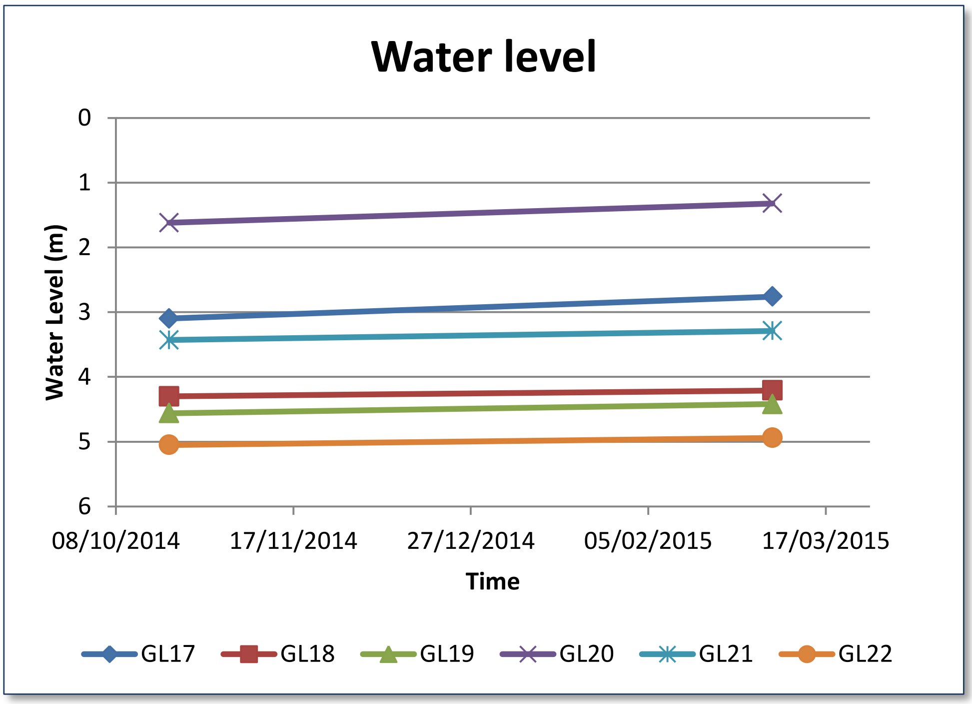


Figure 4-2: Water level trend graph (2)

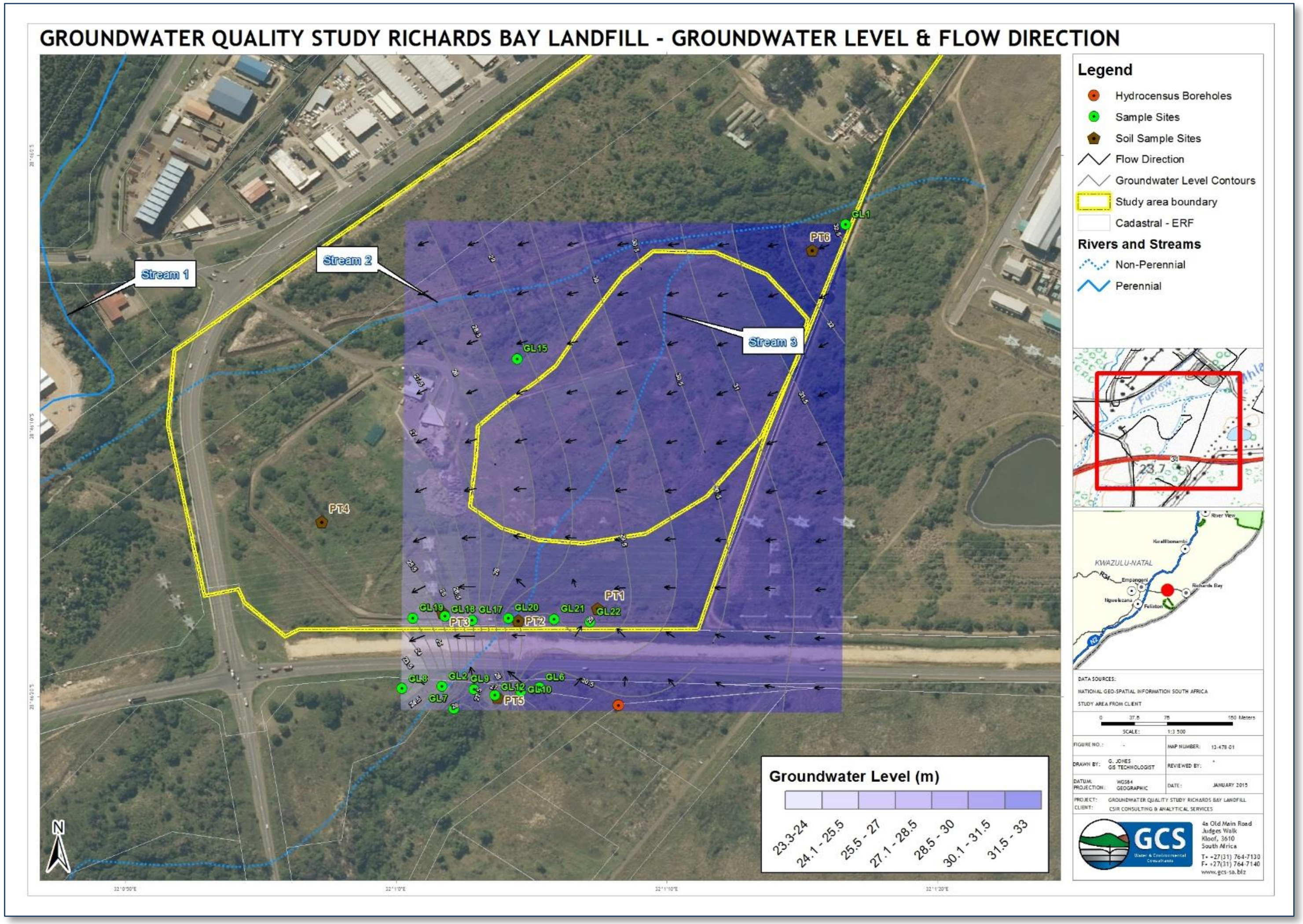


Figure 4-3: Map showing groundwater flow direction

5. Hydrochemistry

Table 5-1 lists the hydrochemistry results for all groundwater monitoring points in comparison to the DWAF (1996) Domestic Use Limits, DWAF Aquatic Ecosystem limits (1999) and DWAF General Limits (1999). These limits are used as a means of comparison but the results should be analysed in the context of the landfill and its operations. Additionally a piper plot, shown in Figure 5-1, was created to represent groundwater chemistry in the area.

The following can be said about the chemistry results obtained:

- Faecal coliforms were detected at borehole GL1 located along the eastern boundary of the landfill site. The borehole, as well as boreholes GL8, GL15, GL17, GL18, GL20 and GL22, exhibits a high total coliform count. High coliforms within the groundwater pose a significant threat to downstream water users, especially humans and aquatic life.
- No *Escherichia coli* (*E. coli*), chromium VI, cyanide, mercury, cadmium or lead, were detected in the groundwater samples, with the exception of very low chromium concentrations at GL18 and GL19.
- Consistently high iron, chemical oxygen demand (COD) and sulphate concentrations above the general limits set by DWAF (1999) are observed at all monitoring boreholes. High iron and sulphate can have adverse impacts on human health and aquatic life. Chemical Oxygen Demand (COD) has often been used as a wastewater indicator to indirectly measure the amount of organic compounds in water. COD represents the amount of oxygen consumed to chemically oxidize organic water contaminants to inorganic end products. The higher the chemical oxygen demand, the higher the amount of pollution in the test sample.
- Neutral pH conditions exist at most of the boreholes, with the exception of slightly acidic conditions recorded at GL12 and GL19.
- High phenol concentrations are observed at GL7 and GL20 (before and after the R34 road), and could have adverse effects on downstream groundwater users and aquatic life.
- High ammonia concentrations above the DWAF (1999) general limits are observed at GL7, GL8, GL9, GL15, GL17, GL20, GL21 and GL22.If groundwater contaminated with ammonia seeps into the stream, this will elevate ammonia levels in the stream and result in both aquatic life and downstream users being adversely impacted.

- It is clear that there is diffusion and advection of the chemical constituents at the site. Concentrations seem to be highest at the centre of the site (at GL15) migrating downstream towards the receiving stream (close to GL7). The concentration of constituents also decreases further away from the receiving stream. Furthermore, the results obtained for borehole GL1 indicates that a plume might be moving east of the site.
- The water quality of the site is poor with respect to the outflowing seepage towards the receiving stream, situated south of the site.

The following can be stated from the piper plot produced for the site (refer to Figure 5-1):

- The data plots close to the saline apex indicating predominant saline water on site, explaining the high Na and Cl concentrations observed.
- Results for GL1 to the east of the site indicate natural water-rock interaction with hard water (high HCO_3, Ca and Mg) with respect to the other boreholes. This borehole also has the highest coliform count.
- Data for GL15, GL20, GL7, GL8 and GL2 indicates mixing of different waters, which explains irregular elevated constituents observed in the samples collected at these boreholes when compared to boreholes further away, to the south of the stream.

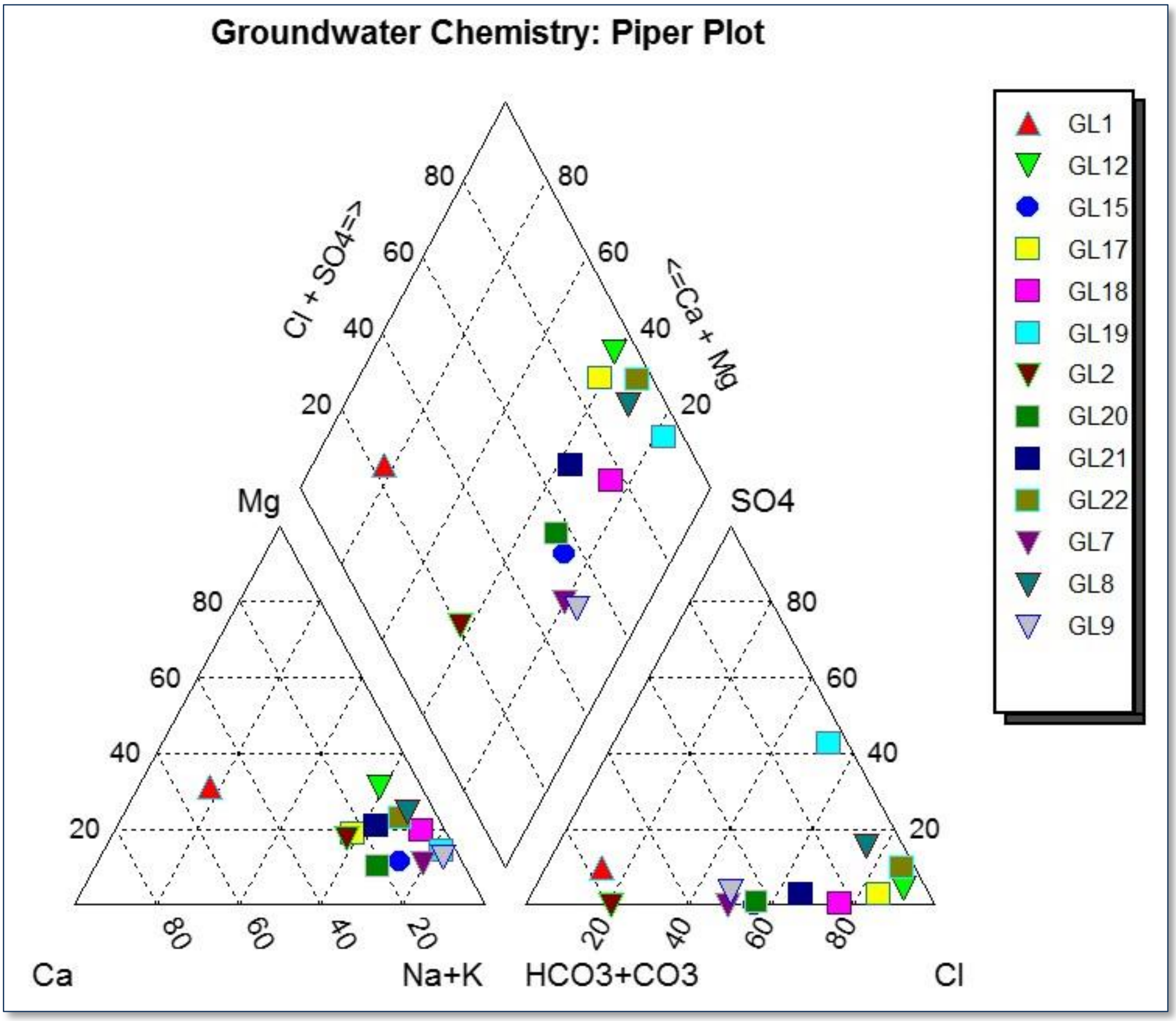


Figure 5-1: *Piper plot of monitoring boreholes*

Table 5-1: *Hydrochemistry results for monitoring boreholes in comparison to DWAF limits for domestic use (DWAF, 1996)*

Determinants	*Units*	*GL1*	*GL2*	*GL7*	*GL8*	*GL9*	*GL12*	*GL15*	*GL17*	*GL18*	*GL19*	*GL20*	*GL21*	*GL22*	*DWAF limits for domestic Use (DWAF, 1996)*
Dissolved Iron	mg/L	0.155	72.2	0.337	0.157	0.225	0.154	0.469	0.25	0.309	48	0.853	0.522	0.159	0.1
Dissolved Sodium	mg/L	46.6	79.6	726	52	219	112	299	841	42.6	112	959	588	464	100
Dissolved Lead	mg/L	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	10
Dissolved Magnesium	mg/L	47.4	23.2	78.3	9.68	34.6	10.4	71.3	85.6	7.79	20.5	98.9	116	46.7	30
Dissolved Potassium	mg/L	5.84	4.96	351	8.9	53.5	2.63	234	436	2.52	4.46	620	45.6	211	100
Dissolved Boron	mg/L	0.07	0.04	0.51	0.06	0.08	0.03	0.98	1.2	0.05	0.05	1.7	0.06	0.24	---
Dissolved Nitrate and Nitrite	mg/L	3.83	0.031	0.03	0.111	0.022	0.06	0.018	0.018	0.016	0.017	0.016	0.016	0.022	6
Dissolved Cadmium	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.005
Dissolved Mercury	µg/L	<1	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	1
Dissolved Calcium	mg/L	129	12.4	167	19.4	16.1	4.15	166	293	9.87	13.4	135	50.6	24.2	32
Chloride	mg/L	47	315	1168	92.1	441	97.8	225	1526	62	208	1483	1211	538	100
Fluoride	mg/L	0.24	<0.09	0.54	0.13	<0.09	<0.09	3.4	2	0.22	0.11	0.13	<0.09	<0.09	1
Total Chromium	mg/L	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	0.012	0.085	<0.006	<0.006	0.067	0.05
Chromium VI	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.05
Total Cyanide	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	10
Electrical conductivity	mS/m	109	109	668	47.1	209	69.3	343	773	33.4	107	971	473	384	70
Total Dissolved Solids	mg/L	642	495	3512	252	1047	395	2000	3834	162	543	4545	2735	1561	---
pH	pH units	7.06	5.82	6.94	5.82	6.15	5.36	7.31	6.91	6.39	5.33	7.05	5.92	7.04	6-9
Sulphates	mg/L	46.2	21.2	2.27	3.95	1.62	107	1.86	23.5	3.84	31.6	3.76	334	52.2	200
Ammonia (Dissolved)	mg/L	0.311	0.779	134	2.3	40.7	0.046	63	163	0.249	0.401	358	18.2	89.9	1
Total alkalinity	mg/L	458	33.4	1586	23.3	228	14.2	1473	2031	50.5	14.2	2637	250	923	---
Chemical oxygen demand	mg/L	29.9	45.6	462	18.7	151	5.31	343	552	61.2	50.1	642	234	287	10
Phenols	µg/L	<10	<10	590	<10	<10	<10	610	<10	<10	<10	390	<10	<10	1
Faecal coliforms	CFU/100mL	700	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0
E-coli	CFU/100mL	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0
Total coliforms	CFU/100mL	1600	<1	<1	1200	<1	<1	50	100	80	<1	800	60	1100	5

KEY:	
(shaded)	Values exceeding DWAF Domestic Use limits

Table 5-2: *Hydrochemistry results for monitoring boreholes in comparison to the DWAF General limits (DWAF, 1999)*

Determinants	*Units*	*GL1*	*GL2*	*GL7*	*GL8*	*GL9*	*GL12*	*GL15*	*GL17*	*GL18*	*GL19*	*GL20*	*GL21*	*GL22*	*General Limits (DWAF, 1999)*
Dissolved Iron	mg/L	0.155	72.2	0.337	0.157	0.225	0.154	0.469	0.25	0.309	48	0.853	0.522	0.159	0.3
Dissolved Sodium	mg/L	46.6	79.6	726	52	219	112	299	841	42.6	112	959	588	464	90
Dissolved Lead	mg/L	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	0.01
Dissolved Magnesium	mg/L	47.4	23.2	78.3	9.68	34.6	10.4	71.3	85.6	7.79	20.5	98.9	116	46.7	---
Dissolved Potassium	mg/L	5.84	4.96	351	8.9	53.5	2.63	234	436	2.52	4.46	620	45.6	211	---
Dissolved Boron	mg/L	0.07	0.04	0.51	0.06	0.08	0.03	0.98	1.2	0.05	0.05	1.7	0.06	0.24	0.5
Dissolved Nitrate and Nitrite	mg/L	3.83	0.031	0.03	0.111	0.022	0.06	0.018	0.018	0.016	0.017	0.016	0.016	0.022	---
Dissolved Cadmium	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.005
Dissolved Mercury	µg/L	<1	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	---
Dissolved Calcium	mg/L	129	12.4	167	19.4	16.1	4.15	166	293	9.87	13.4	135	50.6	24.2	---
Chloride	mg/L	47	315	1168	92.1	441	97.8	225	1526	62	208	1483	1211	538	---
Fluoride	mg/L	0.24	<0.09	0.54	0.13	<0.09	<0.09	3.4	2	0.22	0.11	0.13	<0.09	<0.09	1
Total Chromium	mg/L	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	0.012	0.085	<0.006	<0.006	0.067	---
Chromium VI	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.05
Total Cyanide	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	0.02
Electrical conductivity	mS/m	109	109	668	47.1	209	69.3	343	773	33.4	107	971	473	384	75
Total Dissolved Solids	mg/L	642	495	3512	252	1047	395	2000	3834	162	543	4545	2735	1561	---
pH	pH units	7.06	5.82	6.94	5.82	6.15	5.36	7.31	6.91	6.39	5.33	7.05	5.92	7.04	5.5-9.5
Sulphates	mg/L	46.2	21.2	2.27	3.95	1.62	107	1.86	23.5	3.84	31.6	3.76	334	52.2	0.05
Ammonia (Dissolved)	mg/L	0.311	0.779	134	2.3	40.7	0.046	63	163	0.249	0.401	358	18.2	89.9	1
Total alkalinity	mg/L	458	33.4	1586	23.3	228	14.2	1473	2031	50.5	14.2	2637	250	923	---
Chemical oxygen demand	mg/L	29.9	45.6	462	18.7	151	5.31	343	552	61.2	50.1	642	234	287	75
Phenols	µg/L	<10	<10	590	<10	<10	<10	610	<10	<10	<10	390	<10	<10	0.01
Faecal coliforms	CFU/100mL	700	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0
E-coli	CFU/100mL	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0
Total coliforms	CFU/100mL	1600	<1	<1	1200	<1	<1	50	100	80	<1	800	60	1100	0

KEY:	
(shaded)	Values exceeding DWAF General limits

Table 5-3: Hydrochemistry results for monitoring boreholes in comparison to DWAF limits for aquatic ecosystems (DWAF, 1996)

Determinants	Units	GL1	GL2	GL7	GL8	GL9	GL12	GL15	GL17	GL18	GL19	GL20	GL21	GL22	DWAF limits for aquatic ecosystem (DWAF, 1996)
Dissolved Iron	mg/L	0.155	72.2	0.337	0.157	0.225	0.154	0.469	0.25	0.309	48	0.853	0.522	0.159	---
Dissolved Sodium	mg/L	46.6	79.6	726	52	219	112	299	841	42.6	112	959	588	464	---
Dissolved Lead	mg/L	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	0.0005
Dissolved Magnesium	mg/L	47.4	23.2	78.3	9.68	34.6	10.4	71.3	85.6	7.79	20.5	98.9	116	46.7	---
Dissolved Potassium	mg/L	5.84	4.96	351	8.9	53.5	2.63	234	436	2.52	4.46	620	45.6	211	---
Dissolved Boron	mg/L	0.07	0.04	0.51	0.06	0.08	0.03	0.98	1.2	0.05	0.05	1.7	0.06	0.24	---
Dissolved Nitrate and Nitrite	mg/L	3.83	0.031	0.03	0.111	0.022	0.06	0.018	0.018	0.016	0.017	0.016	0.016	0.022	---
Dissolved Cadmium	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.15
Dissolved Mercury	µg/L	<1	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	0.08
Dissolved Calcium	mg/L	129	12.4	167	19.4	16.1	4.15	166	293	9.87	13.4	135	50.6	24.2	---
Chloride	mg/L	47	315	1168	92.1	441	97.8	225	1526	62	208	1483	1211	538	---
Fluoride	mg/L	0.24	<0.09	0.54	0.13	<0.09	<0.09	3.4	2	0.22	0.11	0.13	<0.09	<0.09	1.5
Total Chromium	mg/L	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	0.012	0.085	<0.006	<0.006	0.067	0.014
Chromium VI	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	---
Total Cyanide	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	0.004
Electrical conductivity	mS/m	109	109	668	47.1	209	69.3	343	773	33.4	107	971	473	384	---
Total Dissolved Solids	mg/L	642	495	3512	252	1047	395	2000	3834	162	543	4545	2735	1561	---
pH	pH units	7.06	5.82	6.94	5.82	6.15	5.36	7.31	6.91	6.39	5.33	7.05	5.92	7.04	---
Sulphates	mg/L	46.2	21.2	2.27	3.95	1.62	107	1.86	23.5	3.84	31.6	3.76	334	52.2	---
Ammonia (Dissolved)	mg/L	0.311	0.779	134	2.3	40.7	0.046	63	163	0.249	0.401	358	18.2	89.9	15
Total alkalinity	mg/L	458	33.4	1586	23.3	228	14.2	1473	2031	50.5	14.2	2637	250	923	---
Chemical oxygen demand	mg/L	29.9	45.6	462	18.7	151	5.31	343	552	61.2	50.1	642	234	287	---
Phenols	µg/L	<10	<10	590	<10	<10	<10	610	<10	<10	<10	390	<10	<10	0.06
Faecal coliforms	CFU/100mL	700	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	---
E-coli	CFU/100mL	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	---
Total coliforms	CFU/100mL	1600	<1	<1	1200	<1	<1	50	100	80	<1	800	60	1100	---

KEY:	
	Values exceeding DWAF Aquatic Ecosystem limits

6. Soil chemistry

Ten soil samples were collected in close proximity to the landfill site. Figure 14-1 indicates the soil monitoring point positions. Two samples were taken at PT1, PT2, PT3 and PT4 from the A and B horizon. One sample was collected from PT5 and PT6 at a depth of 1 meter. Samples were sent for analysis by Eko-Analytica (University of Potchefstroom), for the following constituents:

- pH (H_2O) and Electrical Conductivity (EC in *m*S/*c*m);
- Macro nutrients (Ca, Mg, K, Na, NO_3, Cl, NH_4 and PO_4); and
- Micro nutrients (B, Al, P, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Mo, Pd, Ag, Cd, Sb, I, Ba, Au, Hg, Tl, Pb, Bi, Th, U, SO_4).
-

Analysis entailed the use of saturated paste 1:2 ion extraction methods. The laboratory participated in the following quality control schemes:

- Agricultural Laboratory Association of South Africa; and
- International Soil Analytical Exchange (ISE), Wageningen, Nederland.

Discussion and results

The purpose of undertaking the soil analysis was to assist with confirming soil classification, and to provide an indication of the soil quality for decisions regarding land capability. Data reflecting soil quality on site was compared to screening values (SSV1) from the National Norms and Standards for the remediation of contaminated land and soil quality in the republic of South Africa, published in May 2014 (DWAF, 2014) . Any value from the soil quality analysis that exceeds the screening value implies a high concentration of that element and will be discussed in further detail. However, it must be noted that these screening values do not include most of the elements analysed. Therefore, some of the elements not mentioned under SSV1 will be compared to groundwater quality to determine if a relationship exists between groundwater chemistry and soil chemistry. Such a comparison will assist in deducing whether landfill activities are also contaminating the soils onsite.

The following can be said about the data obtained:

- Outlined in Figure 6-1 are the macro nutrients (Ca, Mg, K, Na and Cl) vs. pH for the horizons sampled at each monitoring point. The results obtained indicate slightly acidic soil at PT3, PT4, PT1, PT2 and PT6 (FSSA, 2007). Very acidic conditions are present at PT5, and from the data obtained it can be clearly observed that pH decreases with depth at each sampling point where the B horizon was sampled.
- Macro elements (Ca, Mg, K, Na and Cl) are present in relatively low concentrations at all the sampling points. The highest macro elemental concentrations are observed at PT3, PT5, PT2 and PT6. The data suggests that nutrient concentrations within the A horizon is much higher than that of the B horizon. This indicates that leaching of nutrients from the A to B horizon is limited and that possible soil contamination will be localized to the topsoil or A horizon.
- NO_3 and NH_4 concentrations are present in relatively equal quantities. However, at PT6 NO_3 concentrations are observed to be much higher than at the other sampling points (refer to Figure 6-2). At PT6, sudden NO_3 concentration increases can be traced to microbial activity and nitrification processes within the immediate area.
- The sub soil at soil sample site PT2 shows high a sulphate concentration. A high sulphate concentration was also observed at borehole GL20, located adjacent to, and approximately 2m away from, soil sample point PT2. This suggests that groundwater quality is related to soil quality in that area.
- Comparing the micro-nutrients to the available DEA (2008) SSV1 limits indicates that metals and metalloids are present in fairly low concentrations and will be immobile due to neutral pH conditions at most of the sampling areas. None of the elements measured succeeds the limits, however, elemental concentrations are much higher within the A horizons of all soil sample sites. If pH conditions decrease, the metals will become soluble and enter the groundwater, or otherwise remain immobile within the soil.

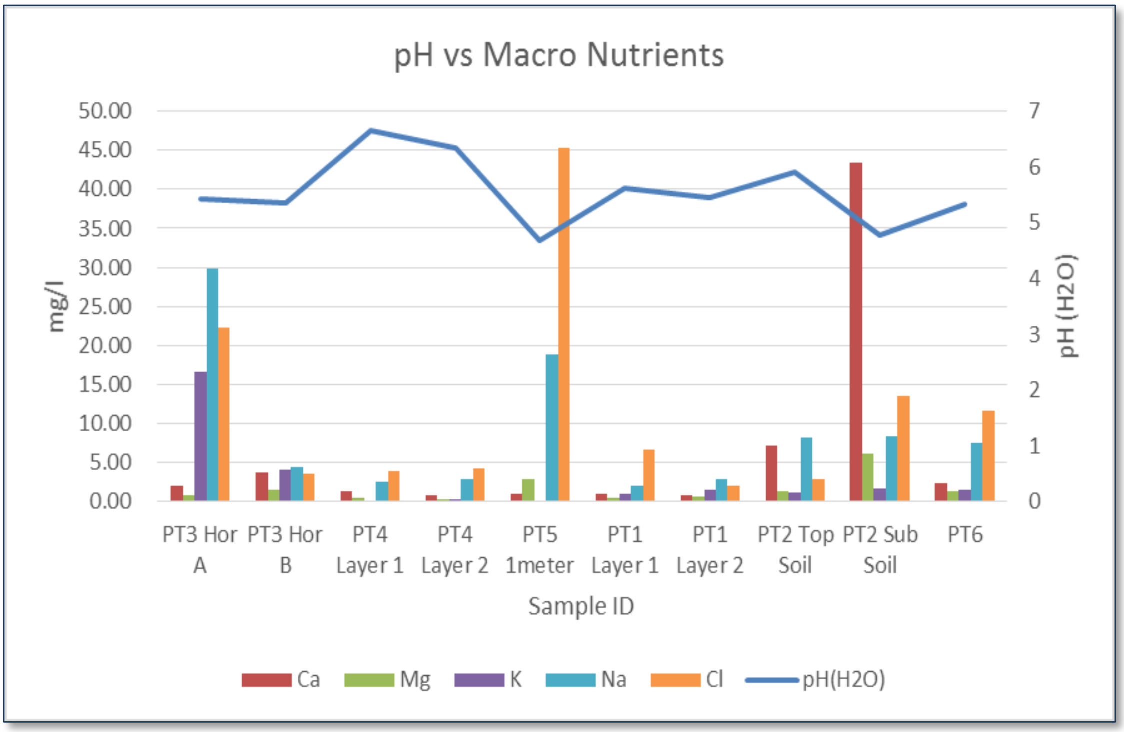


Figure 6-1: *pH vs Macro Nutrients*

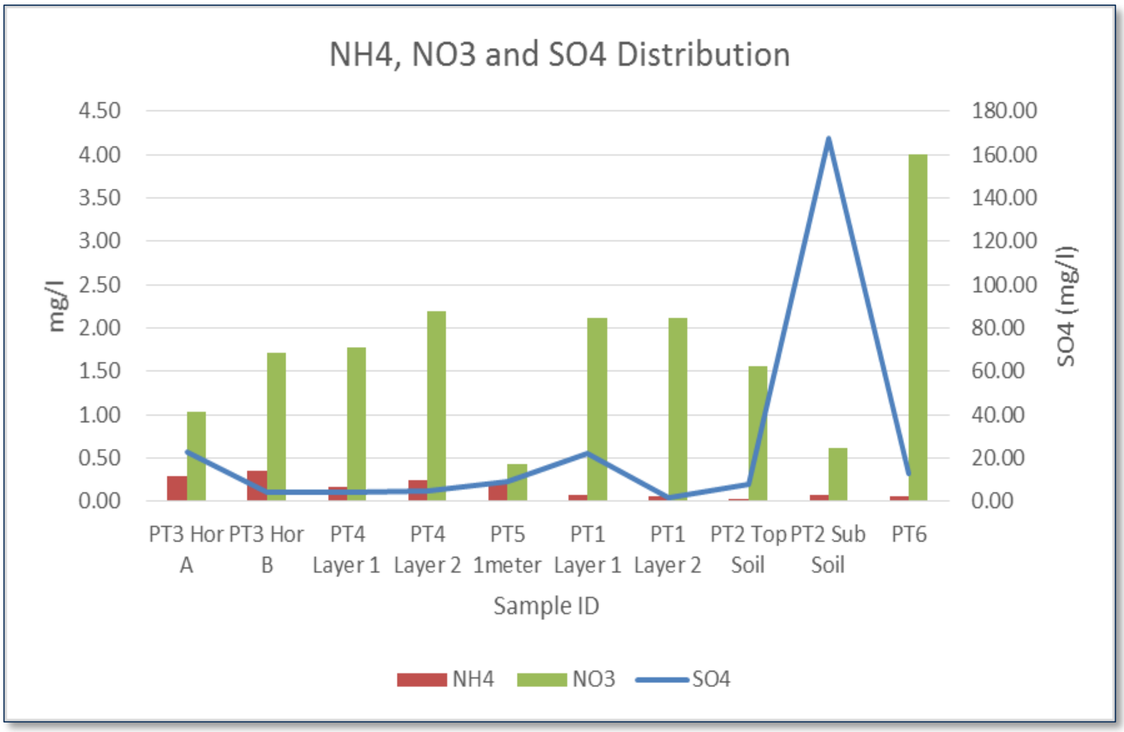


Figure 6-2: *NH_4, NO_3 and SO_4 distribution within soil horizons*

Table 6-1: *Soil chemistry results (metals)*

	Sample Results										SSV1 DEA (2008) Limits	
Sample Name	PT3 HOR A	PT3 HOR B	PT4 LAYER 1	PT4 LAYER 2	PT5 1 METER	PT 1 LAYER 1	PT 1 LAYER 2	PT 2 TOPSOIL	PT 2 SUBSOIL	PT 6		
pH	5.44	5.35	6.65	6.35	4.69	5.62	5.46	5.9	4.78	5.33	pH	-
CN	0.068	0.028	0.013	0.025	<0.01	<0.01	<0.01	0.017	<0.01	<0.01	CN	14
PO4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	PO4	-
SO4	22.97	4.17	4.25	4.88	9.45	22.14	1.87	8.13	167.69	12.69	SO4	4000
NO3	1.03	1.71	1.77	2.20	0.43	2.11	2.12	1.56	0.61	4.00	NO3	120
NH4	0.29	0.36	0.16	0.25	0.22	0.07	0.05	0.04	0.07	0.05	NH4	-
Cl	22.29	3.55	3.84	4.28	45.29	6.62	1.98	2.87	13.50	11.62	Cl	12000
B	0.0862	0.005307	0.0001769	0.0001518	0.00009497	0.0001769	0.0002139	0.00001698	0.00003151	0.00008571	B	-
Na	29.89	4.516	2.621	2.948	18.86	2.067	2.866	8.21	8.325	7.594	Na	-
Mg	0.8495	1.475	0.4306	0.3628	2.832	0.4095	0.6474	1.288	6.079	1.291	Mg	-
Al	6.976	5.197	2.427	2.686	1.406	2.231	0.01323	3.687	0.2249	5.49	Al	-
P	0.00009372	0.02418	0.0002516	0.0002487	0.0002523	0.0622	0.0002062	0.3388	0.0001925	0.08478	P	-
K	16.56	4.082	0.1131	0.2327	0.0002994	1.01	1.579	1.12	1.639	1.478	K	-
Ca	2.102	3.732	1.364	0.9091	1.008	0.9806	0.7568	7.247	43.33	2.306	Ca	-
Ti	0.2036	0.1839	0.08943	0.1736	0.05224	0.3421	0.003093	0.09528	0.0006402	0.1226	Ti	-
V	0.01454	0.03044	0.01447	0.01987	0.006674	0.03385	0.002435	0.01615	0.002466	0.006855	V	150
Cr	0.01494	0.01138	0.00435	0.007699	0.00001023	0.0269	0.00005873	0.008589	0.00006024	0.006615	Cr	-
Mn	0.003535	0.02209	0.02132	0.01974	0.00002238	0.03406	0.00001847	0.01488	0.9858	0.05961	Mn	740
Fe	0.8651	1.992	2.632	4.693	0.1424	9.498	0.000775	2.615	0.000002974	1.317	Fe	-
Co	0.003262	0.00222	0.00167	0.001724	0.001709	0.002802	0.001156	0.001511	0.01187	0.001695	Co	300
Ni	0.003257	0.00003005	0.00003213	0.00004328	0.00004798	0.00002664	0.00005254	0.00001028	0.01222	0.00002154	Ni	91
Cu	0.003719	0.0007487	0.00001806	0.00005824	0.00006732	0.005809	0.00004232	0.02276	0.01471	0.004927	Cu	-
Zn	0.00008313	0.0001281	0.00006463	0.00005105	0.0001494	0.00004583	0.0001136	0.006892	0.1509	0.0004904	Zn	240
As	0.00003868	0.00003913	0.00003966	0.00003555	0.00004816	0.00001998	0.00004888	0.00003581	0.00004682	0.0000427	As	5.8
Se	0.00008449	0.00009127	0.0001011	0.00009432	0.00008957	0.00009228	0.00009567	0.00008855	0.00009093	0.00008449	Se	-
Rb	0.01161	0.006458	0.002633	0.003001	0.001835	0.00299	0.002267	0.003362	0.004828	0.003416	Rb	-
Sr	0.01442	0.02105	0.007145	0.005472	0.01458	0.004953	0.006223	0.03027	0.2029	0.01696	Sr	-
Mo	0.0004739	0.000431	0.0003109	0.0004345	0.0002457	0.0005803	0.0001616	0.0005718	0.0002028	0.0004156	Mo	-
Pd	0.007256	0.007328	0.007169	0.007186	0.007181	0.007226	0.007154	0.007245	0.007425	0.007286	Pd	-
Ag	0.0000174	0.00001416	0.00001556	0.00001426	0.00001376	0.002137	0.001971	0.003496	0.0002309	0.00001047	Ag	-
Cd	0.00001613	0.00001669	0.0000163	0.00001651	0.00001634	0.00001655	0.00001606	0.00001522	0.000008454	0.00001651	Cd	7.5
Sb	0.004172	0.004264	0.004046	0.004018	0.004014	0.004083	0.004005	0.004126	0.003981	0.004126	Sb	-
I	0.006996	0.005991	0.005446	0.005727	0.003225	0.006948	0.004077	0.004024	0.003855	0.01474	I	-
Ba	0.05096	0.04314	0.02524	0.02131	0.02993	0.01904	0.02577	0.06091	0.06996	0.03758	Ba	-
Au	0.005773	0.005751	0.005755	0.005755	0.005775	0.005755	0.005753	0.005755	0.005839	0.005936	Au	-
Hg	0.000003722	0.000001175	0.000002873	0.000003787	0.000002546	0.000002416	0.000003265	0.000001501	0.000003461	0.00000235	Hg	1
Tl	0.00115	0.001131	0.001129	0.001126	0.001136	0.001147	0.001116	0.00114	0.00126	0.001134	Tl	-
Pb	0.008355	0.006741	0.006551	0.006873	0.004045	0.005657	0.003309	0.008646	0.004195	0.005345	Pb	20

Bi	0.004106	0.004096	0.004086	0.004095	0.004401	0.0041	0.004075	0.004089	0.004063	0.004161	Bi	-
Th	0.0073	0.00652	0.006577	0.006724	0.006152	0.007399	0.005978	0.006486	0.005979	0.00657	Th	-
U	0.003416	0.002578	0.002263	0.002375	0.002038	0.00224	0.002002	0.00245	0.002053	0.002193	U	-

7. Site hydrogeological conceptual model

Based on the work done on site and data supplied by CoU, the following conceptualisation of the site can be made:

The study area falls on Maputaland Group stratigraphy, the upper (younger) formations of which consist of unconsolidated sedimentary material. Literature shows that the lithology of the area consists primarily of deep clay profiles with interbedded, water bearing, sand layers. The oldest layers of the lithology consist of weathered calcrete and Port Durnford Formation fossiliferous mudrock that becomes more competent with depth. The Port Durnford Formation acts as a confining layer to the deeper aquifers of the Uloa and Umkwelane Formation.

The field investigation showed that the upper lithology consisted mostly of a sandy aquifer. The static groundwater levels of this aquifer are generally very shallow in this area, at approximately 4 m below ground level, indicating a perched water table in the upper sandy aquifer. It is assumed that the deeper lithology consists mostly of clay type sediments which would act as a confining layer to the deeper aquifers.

The shallow sandy aquifer will be most strongly influenced by the landfill as any seepage that enters the groundwater will flow along this zone, in a south westerly direction (refer to Figure 7-1). Due to the shallow nature of the aquifer, it is likely that the aquifer will contribute to the nearby streams as base flow. Therefore, the generated pollution plume will most likely intersect any streams located down gradient of the landfill.

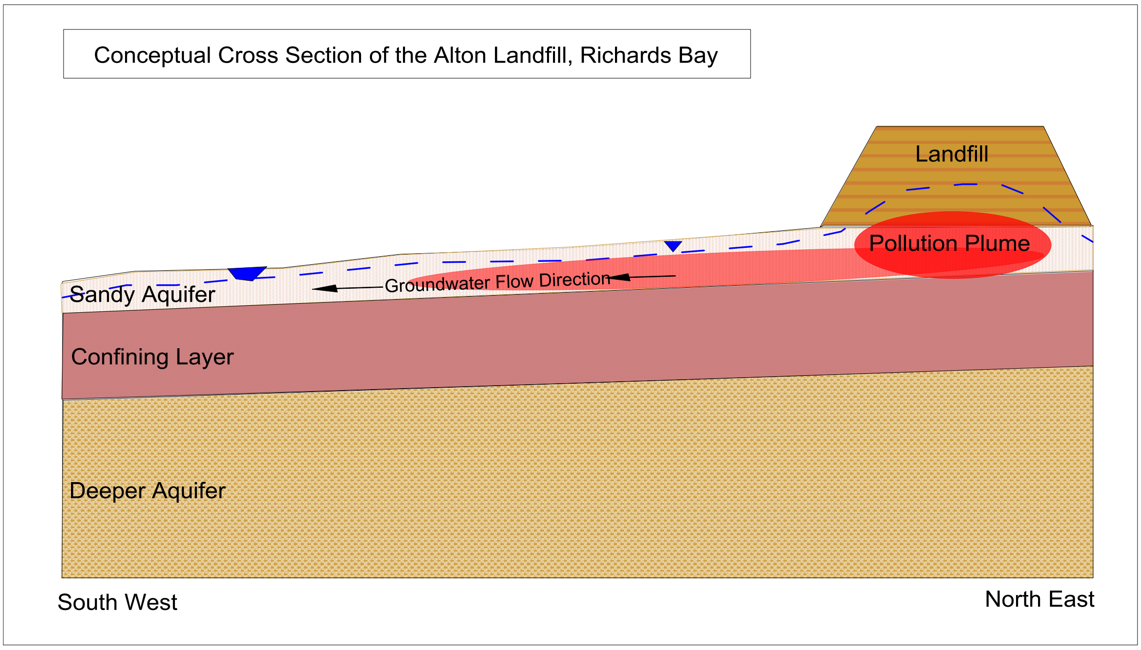


Figure 7-1: *Conceptual cross section of the study area*

8. Impact assessment

The disposal of solid waste into the landfill has been documented as the major source of groundwater and surface water contamination as a result of the leachate generated from these landfills (Afolayan, 2012). Landfills have historically been a primary method for waste disposal due to the convenience and low cost of dumping waste into a landfill. In the past, however, there were no guidelines for site selection and construction of landfills which serve to minimize groundwater and surface water contamination. Therefore, landfills which were developed prior to implementation of these guidelines pose a higher risk to groundwater quality due to: (1) uninformed site selection; (2) the use of inappropriate construction methods; and (3) the unfavourable quality and quantity of their leachate as a result of their age.

The following risk assessment is based on the information supplied by CoU and the fieldwork assessment conducted on site. It must be noted that information on the construction of the landfill and the exact age of the landfill was unavailable. For the purpose of this risk assessment it is assumed that the landfill is more than 10 years old and there is no separation between the landfill and the aquifer.

There are various methods used to conduct the hydrogeological risk assessment for a given pollution source at a given area. The DRASTIC method is one of the internationally accepted risk assessment methodologies developed by the US Environmental Protection Agency (EPA). The DRASTIC method was applied in this study as a benchmark for gap analysis and to compare the available data against what needs to be examined in order to complete a risk assessment.

Due to unavailable information regarding the site, the "Source Pathway Receptor" principle was applied, which is a simple and practical way to assess the risk and impacts on hydrogeology for a given project area. This principle contains three components that need to be assessed in all their various forms when conducting a complete risk assessment. Figure 8-1 is a schematic representation of the principle showing the three components.

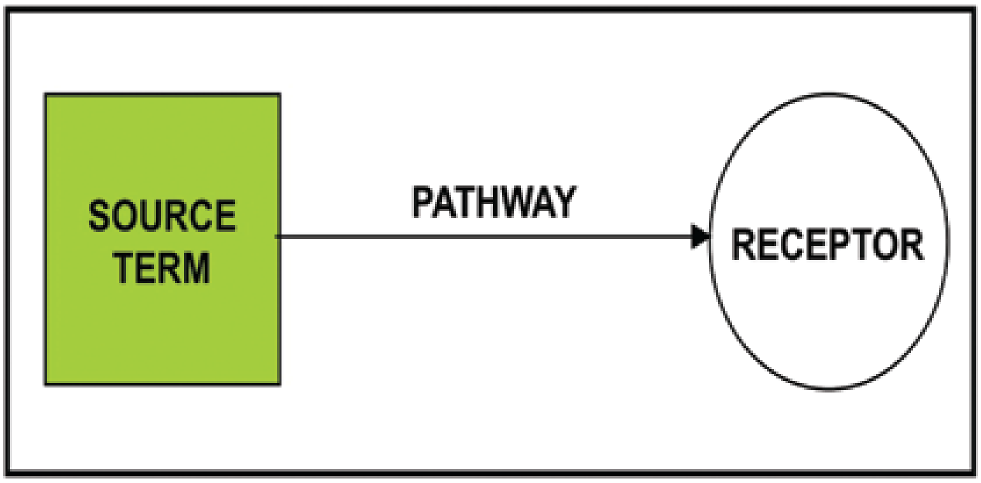


Figure 8-1: *General risk assessment components*

Source term

In the context of this study the main sources of pollution identified are the landfill and the non-operational pump station situated down gradient of the landfill adjacent to borehole GL20. Other sources that occur around the site include Hillside Aluminum, Mondi and Foskor. However, Foskor is located down gradient of the site and will not have an impact on groundwater quality within the site considering that groundwater flow direction is most likely to be from the landfill site towards Foskor. Furthermore, limited information is available on what groundwater management plans are being implemented at Hillside Aluminum, if any, to minimise impacts on groundwater from their operations.

Pathway

In the context of this study, and based on the literature review and fieldwork assessment, the following pathways exist within the study area.

- The unsaturated zone: the unsaturated zone in the site is composed of fine to medium clayey sand with low to medium permeability. The landfill is directly in contact with the unsaturated zone.
- Movement of contaminants may occur through the aquifer below the site. However, there is a lack of information on this aquifer as geology logs were unavailable and the monitoring boreholes on site are shallow, penetrating only the top 7- 8 m of the shallow unconsolidated aquifer.
- Contaminants can also be carried by runoff along walkways and natural watercourses.

Receptor

As the final component of the impact assessment, the receptor in the context of this study will be the following water resources:

- **Groundwater**; and
- **Streams and lakes**. The stream flowing through the site is the main receiver which in turn joins together with other streams flowing south on the western side of the site and flow into Richards Bay harbor. No users of the stream were identified during the hydrocensus.

The velocity at which the groundwater moves will determine the time it will take for the pollutants to reach the nearby receptor, such as streams flowing through the site. An accurate estimate of groundwater velocity can be calculated using Darcy's Law. Darcy's law is an equation that describes groundwater movement in aquifers based on three variables: horizontal hydraulic conductivity, horizontal hydraulic gradient and effective porosity. The equation for calculating ground water velocity is: V= KI/n.

In this formula V stands for "groundwater velocity," K equals the "horizontal hydraulic conductivity," I is the "horizontal hydraulic gradient," and n is the "effective porosity."

Horizontal hydraulic gradient (I) can be calculated from the formula $I = (h_1-h_2)/L$ where h_1 is the water level head in borehole 1 and h_2 is the water level head in borehole 2. L is the distance between borehole 1 and borehole 2. These values are based on pump test data, the geology of the site and Darcy's equation for groundwater flow velocity where hydraulic permeability (m/day) is multiplied by the gradient and divided by the porosity of the aquifer material on site.

If seepage from the landfill occurs and the pollutants enter the shallow groundwater aquifer, the minimum velocity of 0.0105 m/day and the maximum velocity of 0.032m/day are anticipated for groundwater flow in the area.

Assuming that the site has been operational for ten years, the current pollution plume should extend between 38.32 and 116.80 m from the landfill in a south westerly direction, as indicated on Figure 8-2. However, it should be noted that the plume will become more diffuse further away from the landfill.

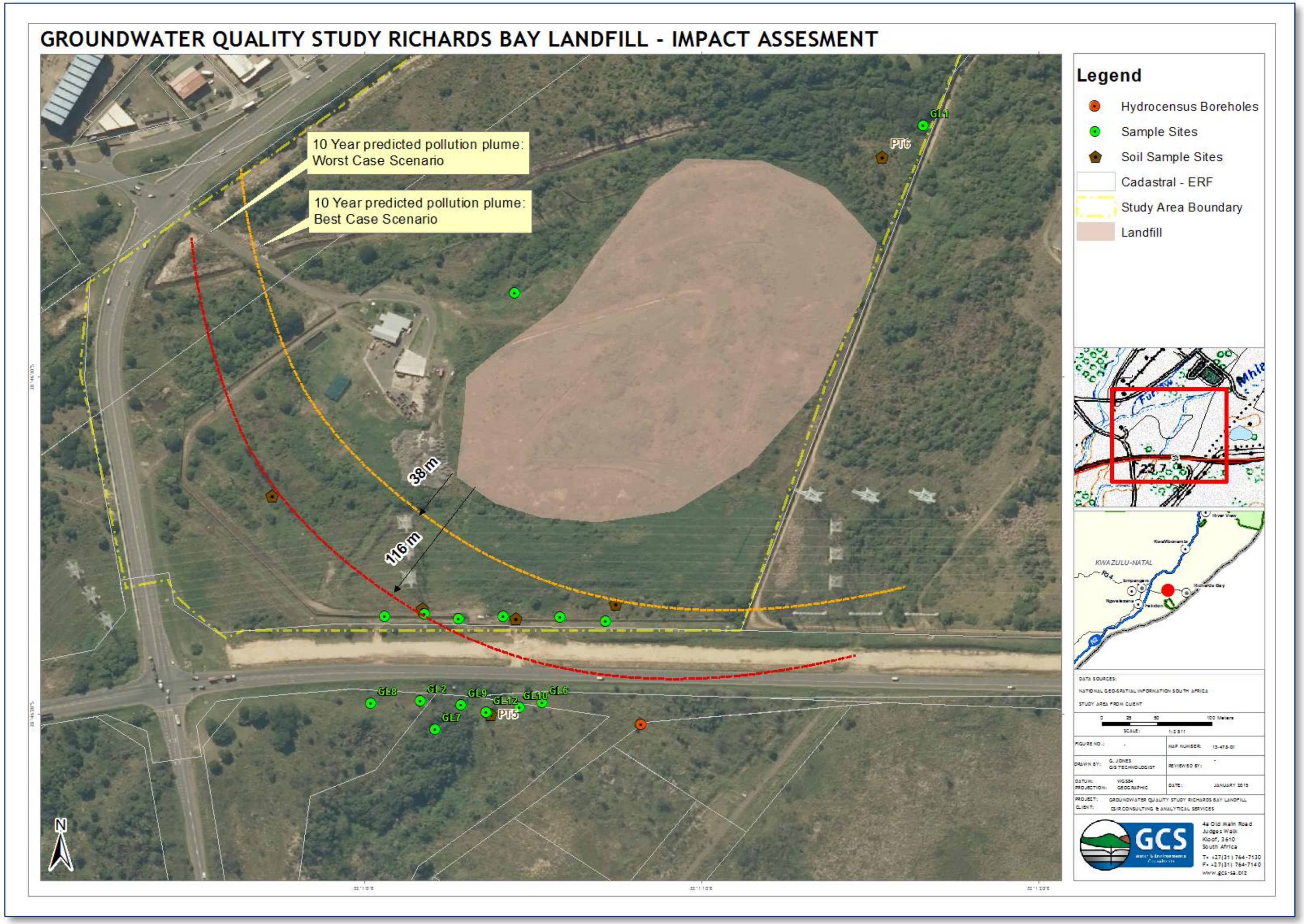


Figure 8-2: Predicted pollution plumes for Alton landfill

8.1. Risk assessment

In general, the risk to groundwater and soil contamination is higher if exposures of shallow aquifer systems are in contact pollutants released from uncontrolled contamination sources. It was indeed found that both of these appear to be true for the Alton site; i.e. shallow porous alluvial aquifer system and uncontrolled sources.

Furthermore, based on the field assessment, it was observed that the landfill is covered with a porous sandy/alluvial system. The surface was also identified as uneven and uncontrolled excavations by waste scavengers occurred. All these factors increase the risk of contamination by augmented recharge and porous flow. Figure 8-3 depicts an example of a typical scavenger digging. It can be seen from the photo that the landfill cover is not compacted and the soil cover has been compromised.

The non-operational pump station, located next to borehole GL20 may potentially overflow with leachate from the landfill and contaminate the stream located down gradient, adjacent to borehole GL7.

The absence of a proper leachate collection system at the site results into uncontrolled leachate and subsequent ponding in the depression next to the pump station. Secondary contamination or cross contamination may occur due to this ponding.

Figure 8-3: *Photo showing a hole in the landfill and a man searching for steel*

8.2. Risk assessment ratings

The risk assessment ratings for the Alton landfill site are based on the work completed on the site and the data supplied by CoU. Table 8-1 provides a description of the impact assessment criteria and shows the rating system used. The ratings for the Alton landfill site are specified in Table 8-2.

Table 8-1: *Impact Assessment Criteria Description and Rating System*

Score	Rating	Description
Impact Importance (Imp)		
5	High	The affected systems are near pristine and/or have numerous qualities which make them extremely valuable from an ecological and/or social (resource) perspective (i.e. the ecosystem services and goods provided are of high to very high importance).
4	Medium-High	The affected systems have qualities which make them highly valuable from an ecological and/or social (resource) perspective (i.e. the ecosystem services and goods provided are of moderately-high importance).
3	Medium	The affected systems have certain qualities which make them ecologically and/or socially valuable (i.e. the ecosystem services and goods provided are of moderate importance).
2	Medium-Low	The affected systems are of mild (moderately-low) importance in terms of ecological and/or social (resource) importance (i.e. the ecosystem services and goods provided are of mild/moderately low importance).
1	Low	The affected systems have very little value in terms of ecological and/or social (resource) importance (i.e. the ecosystem services and goods provided are of low importance).
Intensity (I)		
5	High	Impact affects the continued viability of the systems/components and the quality, use, integrity and functionality of the systems/components permanently ceases and are irreversibly impaired (system/population collapse). Rehabilitation and remediation often impossible. If possible rehabilitation and remediation often unfeasible due to extremely high costs of rehabilitation and remediation.
4	Medium-High	Impact affects the continued viability of the systems/components and the quality, use, integrity and functionality of the systems/components are severely impaired and may temporarily cease. High costs of rehabilitation and remediation, but possible.
3	Medium	Impact alters the quality, use and integrity of the systems/components but the systems/ components still continue to function but in a moderately modified way (integrity impaired but functionality and major key processes/drivers maintained).
2	Medium-Low	Impact alters the quality, use and integrity of the systems/components but the systems/ components still continue to function in a slightly modified way and maintain original integrity (no/limited impact on integrity).
1	Low	Impact affects the quality, use and integrity of the systems/components in a way that is barely perceptible.
Duration (D)		
5	Permanent	The only class of impact that will be non-transitory. Mitigation either by man or natural process will not occur in such a way or such a time span that the impact can be considered transient (Indefinite).
4	Long-term	The impact and its effects will continue or last for the entire operational life of the development, but will be mitigated by direct human action or by natural processes thereafter (30 – 100 years).
3	Medium-term	The impact and its effects will continue or last for some time after the construction phase but will be mitigated by direct human action or by natural processes thereafter (10 – 30 years).
2	Medium-short	The impact and its effects will continue or last for the period of a relatively long construction period and/or a limited recovery time after this construction period, thereafter it will be entirely negated (5 – 10 years).
1	Short-term	The impact and its effects will either disappear with mitigation or will be mitigated through natural process in a span shorter than the construction phase (0 – 1 years), or the impact and its effects will last for the period of a relatively short construction period and a limited recovery time after construction, thereafter it will be entirely negated (0 – 5 years).
Scale / Extent (S)		
5	National & International	Effects of an impact experienced within a large geographic area beyond national boundaries and occurring at national scale (500km radius of the site).
4	Municipal & Provincial	Effects of an impact experienced within the region beyond municipal and provincial boundaries and occurring at a municipal and provincial scales (e.g. between a 100km to 500km radius of the site).
3	Town & Suburban	Effects of an impact experienced within the local town or suburban area (e.g. between a 5km to 50km radius of the site).
2	Local	Effects of an impact experienced within the local area (within 5km radius of the site).
1	Site & Surrounds	Effects of an impact are experienced within or in close proximity (100m) to the project site. However, the size of the site needs to be taken into account.
Probability / Likelihood (P)		
5	Definite	Impact will certainly occur (Greater than 90% chance of occurrence).
4	Probable	The impact will likely occur (Between a 70% to 90% chance of occurrence).
3	Possible	The impact may/could occur and has occurred elsewhere under the same conditions (Between a 40% to 70% chance of occurrence).
2	Unlikely	The chance of the impact occurring is moderately-low (Between a 20% and 40% chance of occurrence).
1	Improbable	The chance of the impact occurring is extremely low (Less than a 20% chance of occurrence).

Status of Impact		
+	Positive	Impacts add value to the environment.
-	Negative	Impacts will degrade the environment.
N	Neutral	Impacts do not harm or add value to the environment.
SIGNIFICANCE = (I+D+S+P) x Imp		
>72	High	Totally unacceptable. Impact should be avoided and limited opportunity for offsets.
60 - 72	Medium-High	Generally to totally unacceptable. Ideally impact should be avoided unless offset by positive gains in other aspects of the environment that are of very to critically high importance i.e. national or international importance.
45 - 59	Medium	Undesirable to generally unacceptable. Ideally impact should be avoided unless offset by positive gains in other aspects of the environment that are of moderately-high to high importance.
32 - 44	Medium-Low	Acceptable.
4 - 31	Low	Acceptable.

Table 8-2: *Risk assessment ratings*

POTENTIAL ENVIRONMENTAL IMPACT	APPLICABLE AREA	ACTIVITY	ENVIRONMENTAL SIGNIFICANCE BEFORE MITIGATION								RECOMMENDED MITIGATION MEASURES	RECOMMENDED MANAGEMENT MEASURES	ENVIRONMENTAL SIGNIFICANCE AFTER MITIGATION								ACTION PLAN	FREQUENCY	RESPONSIBLE PARTIES/PERSON
			I	D	S	P	Imp	TOTAL	STATUS	SIGNIFICANCE			I	D	S	P	Imp	TOTAL	STATUS	SIGNIFICANCE			
ALTON LANDFILL SITE																							
Groundwater																							
Leachate generated from the landfill may potentially seep through the unsaturated zone into groundwater within the site. If the seepage occurs and the leachate from the landfill reaches groundwater, ***groundwater quality will be negatively impacted due to increased concentrations of metals, acidic pH, and other inorganic and organic substances dissolved in water***. However this will be governed by the composition of the leachate generated. The quality and quantity of the leachate depends on the age of the landfill.	The area that is most likely to be affected by any leachate from the landfill is the area hydraulically down gradient of the landfill in the direction of groundwater flow.	Landfill and pump station	5	4	3	5	4	68	-	MH	In order to minimise the seepage of any generated leachate by the landfill, the following protective measures must be applied by CoU in order to manage the potential impacts on groundwater, surface water and soil: • The top surface of the landfill must be covered with an impermeable layer to avoid rain water seeping into the landfill. • There should be a leachate collection system in an onsite leachate pond. Leachate from this pond must then be pumped and transported into a proper storage area. • Storm water must be collected in an onsite storm water dam. • Water samples must be collected from the leachate pond and storm water dam together with groundwater samples for chemical analysis. This will shed some light on the characteristics of the leachate and will help determine if there are additional sources contributing to poor groundwater quality onsite.	• The landfill must be fenced to stop people from digging into the landfill in search of steel. • Warning signs must be placed around the fence to notify people to stay away from the landfill. • Divert all clean water away from the landfill and contain all dirty water from the landfill in a storm water dam. • Cover the landfill with an impermeable clay layer. • Monitor leachate seepage from the landfill into groundwater by analysing groundwater quality from monitoring boreholes hydraulically down gradient of the landfill.	3	4	3	2	4	48	-	M	Implementation of all prevention measures and adherence to recommended minimum requirements for water monitoring at waste management facilities as specified in the document entitled "minimum requirements for waste disposal by landfill" " published by DWAF in 1998.	Monthly	Environmental Officer appointed by CoU

Surface water																							
The stream flowing through the site will most likely be the first surface water body to be negatively impacted by possible seepage of leachate from the landfill. This will result in a potential decrease in water quality and/or water pollution. This may occur through storm water runoff and groundwater seepage into the stream. When pollutants enter the stream, they will move faster than in groundwater and impact the streams further down gradient of the site.	All surface water bodies within the site and downstream of the site.	Land and Pump station	5	4	3	5	4	68	-	MH	Same as above	• The landfill must be fenced to stop people from digging into the landfill in search of steel. • Warning signs must be placed around the fence to notify people to stay away from the landfill. • Divert all clean water away from the landfill and contain all dirty water from the landfill in a storm water dam. • Monitor leachate seepage from the landfill into groundwater by analysing groundwater quality from monitoring boreholes hydraulically down gradient of the landfill.	3	4	3	2	4	48	-	M	Implementation of all prevention measures and adherence to recommended minimum requirements for water monitoring at waste management facilities as specified in the document entitled "minimum requirements for waste disposal by landfill" published by DWAF in 1998.	Monthly	Environmental Officer appointed by CoU
Soil																							
Soil contamination may potentially occur within the site due to horizontal migration of leachate and groundwater level fluctuations. When contaminated groundwater rises close to the surface, it will bring contaminants up into the vadoze zone. However, it is anticipated that soil contamination will be limited to the site (unlikely to occur beyond the site).	It is anticipated that soil contamination will be limited to the site (unlikely to occur beyond the site).	Land	3	4	2	3	4	48	-	M	Same as above	• The landfill must be fenced to stop people from digging into the landfill in search of steel. • Warning signs must be placed around the fence to notify people to stay away from the landfill. • Divert all clean water away from the landfill and contain all dirty water from the landfill in a storm water dam. • Monitor leachate seepage from the landfill into groundwater by analysing groundwater quality from monitoring boreholes hydraulically down gradient of the landfill.	2	3	2	2	4	36	-	ML	Implementation of all prevention measures and adherence to recommended minimum requirements for water monitoring at waste management facilities as specified in the document entitled "minimum requirements for waste disposal by landfill" "" published by DWAF in 1998.	Monthly	Environmental Officer appointed by CoU

9. Mitigation measures

The risk to groundwater, surface water and soil resulting from landfill operations is anticipated to be of medium to high significance if no mitigation measures and management plans are taken into consideration. However, when mitigation measures, management plans and monitoring systems are put in place, the impact significance can be reduced to medium or medium-low in some cases (refer to Table 8-2 above).

The following strategies will have to be adopted by CoU in order to minimize the potential impacts of the landfill on water resources and soil:

- Apply "Waste-Aquifer-Separation" principles by lining the bottom surface of the landfill with an impermeable lining such as compacted clay. However, although this is recommended for landfills, this is most likely unfeasible due to the age and size of the landfill as well as the associated costs.
- Recognised site closure practices (i.e. National Environmental Management: Waste Act, No. 25 of 2014) must be followed to ensure proper cover designs and applications.
- There should be leachate detection and collection systems in place such that leakages are directed to proper and lined pollution control dams.
- It is highly advisable that a proper storm water management plan be developed for the site where "clean-dirty-separation" principles are followed. Storm water must be collected in an onsite storm water dam if polluted.
- Water samples must be collected from the leachate pond and storm water dam together with groundwater samples for chemical analysis during routine time intervals. This will highlight the characteristics of the leachate and assist in ascertaining if there are other pollution sources contributing to poor groundwater quality onsite. Storm water from the landfill must be tested for pollution before discharging into the stream.

10. Management measures

- **Landfill cover or landfill capping**: To minimise the infiltration of rain water into the landfill, the top surface of the landfill must be covered by an impermeable clay layer. The landfill must be fenced to prevent people from digging into the landfill for steel, as the holes left after digging provides infiltration points for rain water.
- **Leachate collection**: To reduce the amount of leachate seeping into groundwater, a leachate collection system needs to be constructed using a graded underliner and drains that channel the leachate into a leachate pond. The leachate can be treated onsite or pumped and transported to a treatment plant somewhere where it can be treated to a quality standard that complies with the relevant DWA limits (general limits, aquatic ecosystem limits and domestic use limits) for discharging water into a stream.
- **Drainage:** Storm water management drainage lines must be constructed to allow for collection of storm water from the landfill in a storm water dam, and direct storm water from clean areas away from the site.
- If possible, separate the landfill from the aquifer (refer to mitigation measure regarding "Waste-Aquifer-Separation" principles in Section 9).

11. Monitoring measures

Groundwater quality

- Groundwater quality must be monitored through sample collection from monitoring boreholes and subsequent analysis. Groundwater samples need to be collected and preserved according to the South African guidelines for groundwater sampling and preservation such as Groundwater sampling manual prepared by John Weaver *et al.* for Water Research Commission (WRC, 2007). Samples must then be sent to a SANAS accredited laboratory for hydrochemical analysis.
- A groundwater quality database must be generated from the hydrochemistry data to observe water quality trends that are most likely to emanate as a result of the landfill.

Groundwater quantity

- Groundwater level must be measured on an ongoing basis within an accuracy of 0.1 m using an electrical contact deep meter to detect any changes or trends.

Surface water sampling

- Upstream and downstream surface water points need to be added to the current monitoring network at Alton landfill site. This will evaluate the contribution of the landfill to stream contamination.

- Samples must also be collected from the leachate pond and the storm water dam for hydrochemical analysis (refer to mitigation measures regarding the leachate pond and storm water dam in Section 9). If the quality of water from the storm water dam is found to be within the allowable general limits for discharging water into the stream, water from the storm water dam can then be discharged into the stream according to the legal requirements set by the Department of Water and Sanitation. Leachate needs to be disposed safely in a legal leachate disposal site.

Table 11-1: *Monitoring summary table*

Recommended monitoring measures	Applicable area	Frequency	Timeframe	Responsible person
Groundwater level/quantity	Landfill site	Quarterly	February, May, August & November.	Environmental Officer appointed by CoU
Groundwater quality	Landfill site	quarterly	February, May, August &November.	Environmental Officer appointed by CoU
Surface water quality	Landfill site	Quarterly	February, May, August & November.	Environmental Officer appointed by CoU

12. Conclusions

- Information regarding construction of the landfill is unavailable as the landfill was constructed long ago. In line with this, it is unlikely that construction was informed by guidelines on site selection and construction methods which allows for the minimisation of potential impacts on water resources.
- Water levels are not being measured. Such measurements are required to monitor groundwater level trends within the site. However, samples are collected on a monthly basis for chemical analysis by CoU. The chemistry data is used to update the borehole chemistry database for the site.
- The Alton landfill site was previously used to store green waste, such as grass and flowers; and domestic and commercial food waste; which were in turn used to support a green energy production initiative. This initiative was unsuccessful and short-lived and the landfill was decommissioned approximately 10 years ago. At present, the site is used for the temporary storage of general waste which is thereafter transported to the uThungulu landfill site.
- During the fieldwork assessment, it was observed that the landfill is covered by permeable sand and grass. There were also numerous holes on site, possibly dug by people searching for steel in the landfill. The sand cover and holes are of concern as they act as entry points for rain water into the landfill which affects the quality of groundwater within the site.
- Leachate ponding down gradient of the landfill and behind the non-operational pump station was observed. This leachate had a strong smell and was brownish in colour.
- Shallow groundwater levels were measured within the site in the order of 5 mbgl in high topographic areas and 0.5 mbgl in low topographic areas. When water level elevations were plotted against topographic elevations, a 61 percent correlation was obtained. This suggests that groundwater level within the site mirrors the topography. Groundwater flow direction appears to be from north east to south west.
- Groundwater within the site is poor with high concentrations of metals, ammonia, sulphate, EC, TDS, COD and total coliforms. E-coli concentration is below the detectable limits in all monitoring boreholes.
- Monitoring boreholes GL20 and GL7 are located in a depression close to the stream. Groundwater flow within the site is mainly towards these boreholes. Water quality from these boreholes is extremely poor, containing extremely high levels of ammonia, phenols and coliforms.
- Acidic pH conditions prevail within the site. Water samples collected from most monitoring boreholes (GL2, GL8, GL12, GL19 and GL21) were acidic in nature (low pH). Samples from other monitoring boreholes were neutral to slightly acidic.

- The soil chemistry analysis conducted indicates acidic pH conditions for soils within the site. High metal concentrations in soils are evident; however, none of the metals and anions exceed the Soil Screening values (SSV1) specified in the Department of Water Affairs National Norms and Standards for the remediation of contaminated land and soil quality in the republic of South Africa, under the National Environmental Management Waste Act (No. 59 of 2008), published in May 2014. Based on the results of the study, it appears that the landfill is impacting on both groundwater and soil quality within the site.

13. Recommendations

- It is recommended that all mitigation, management and monitoring measures be implemented as outlined under Sections 9, 10 and 11 of this report respectively.
- At least three deep monitoring boreholes must be drilled to monitor the water quality of the deep aquifer within the landfill site.
- Aquifer testing must be conducted on the deep boreholes to obtain hydraulic properties of the deep fractured aquifer.
- A groundwater flow model must be constructed based on the hydraulic parameters obtained from the aquifer testing. The groundwater flow model can then be used to construct a contaminant transport model for the landfill.

14. References

Afolayan et al, (2012). Hydrological implication of solid waste disposal on groundwater quality in urbanized area of Lagos state, Department of geography and planning, Lagos state University, Nigeria.

Department of Water Affairs and Forestry (1996). South African Water Quality Guidelines, Volume 1, Domestic Use. DWAF, Pretoria.

Department of Water Affairs and Forestry (1999). General and special limits authorisation. Discharge limits and conditions set out in the National Water Act, Government Gazette No.20526. Pretoria.

Department of Water Affairs and Forestry (1996). South African Water Quality Guidelines, Volume 1, Aquatic ecosystem. DWAF, Pretoria.

Department of Water Affairs and Forestry (2014). National Norms and Standards for the Remediation of Contaminated Land and Soil Quality, National Environmental Management: waste Act, 2008 (Act No.59 of 2008).

ftp://ftp.fao.org/fi/CDrom/FAO_Training/FAO_Training/General/x6706e/x6706e09.htm#104a.

John *et al.* (2007) Groundwater Sampling, a comprehensive guide for sampling methods prepared for the Water Research Commission. WRC Report No TT 303/07.

APPENDIX A: MONITORING MAP

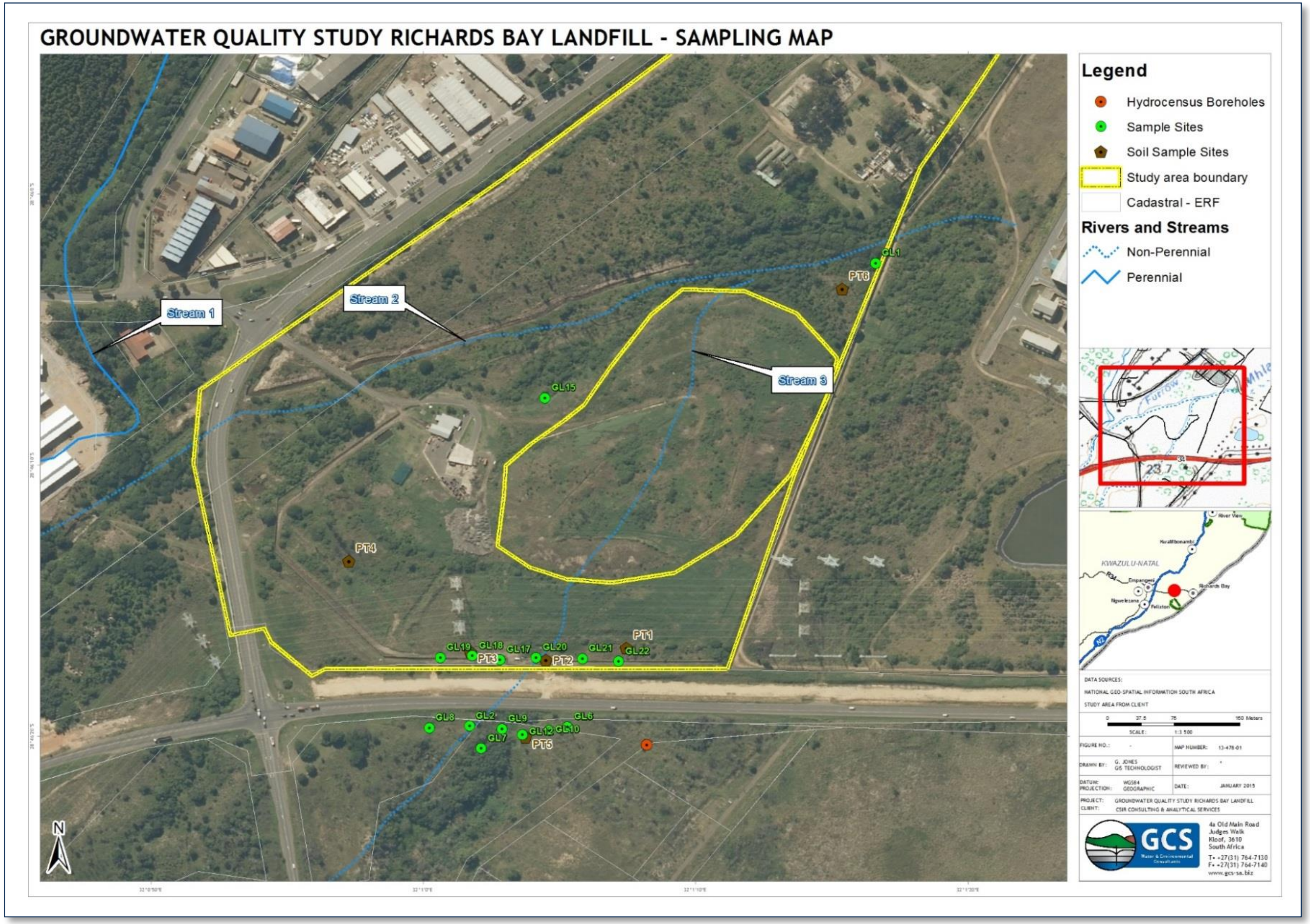


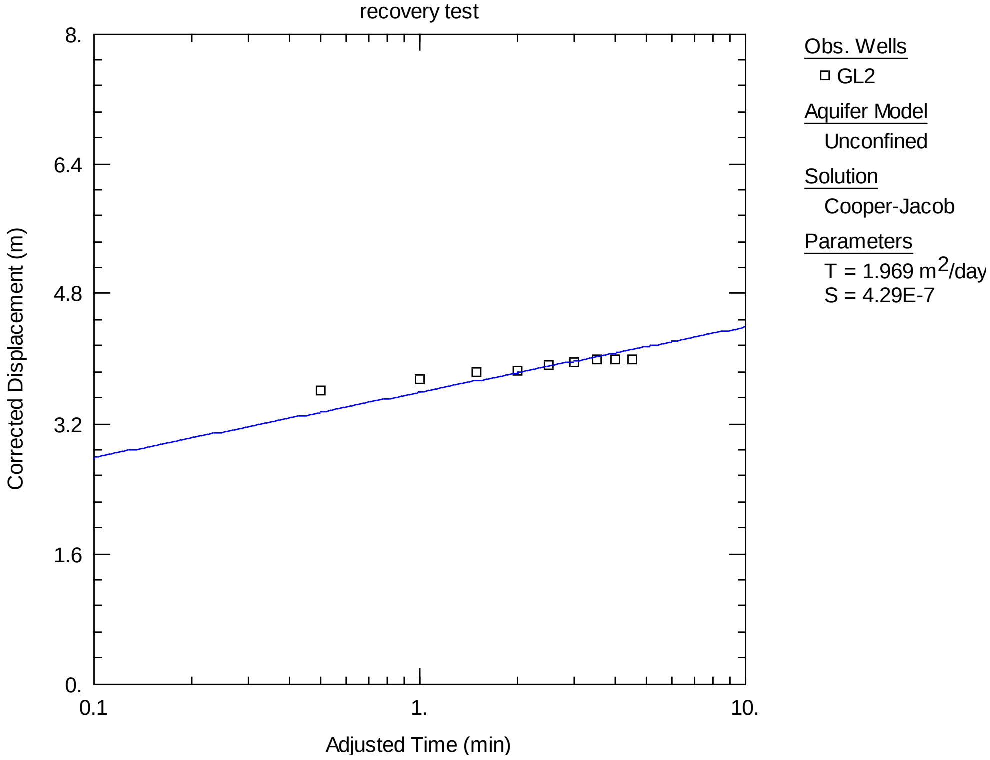
Figure 14-1: Monitoring map showing the positions of the boreholes and soil sampling points

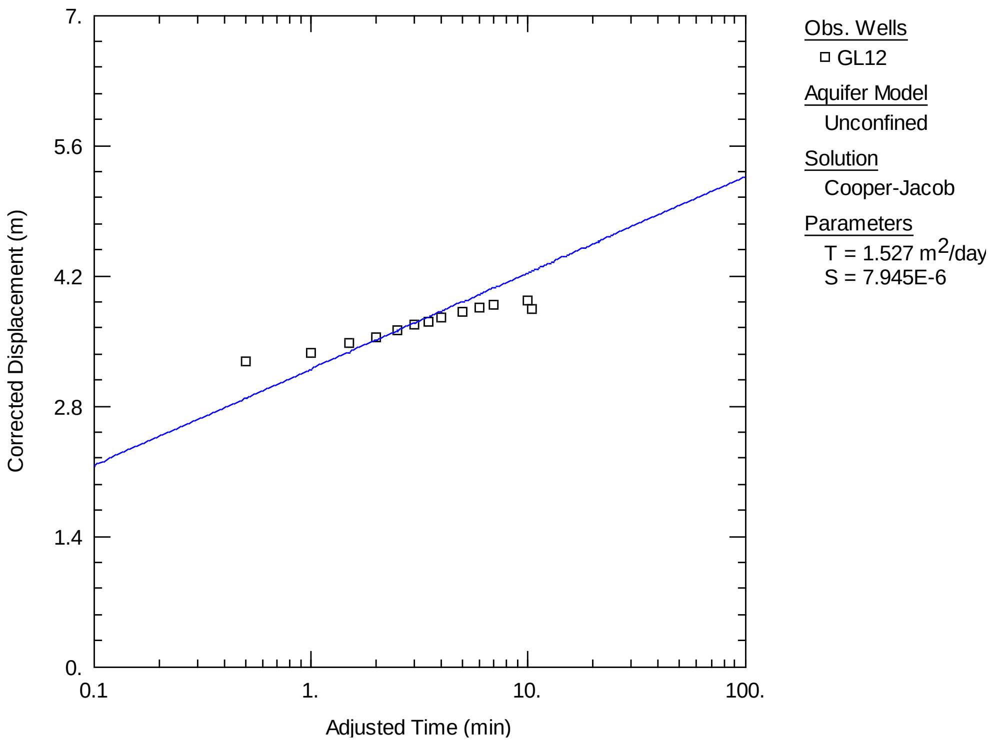
APPENDIX B: PERMEABILTIY CLASSESS

Table 14-1: *Permeability classes*

Soil permeability classes	Coefficient of permeability (K in m/s)	
	Lower limit	Upper limit
Permeable	2×10^{-7}	2×10^{-1}
Semi-permeable	1×10^{-11}	1×10^{-5}
Impermeable	1×10^{-11}	5×10^{-7}

APPENDIX C: AQUIFER TESTING GRAPHS





APPENDIX D: SOIL LOGS

Site ID	South (Degrees Decimals)	East (Degrees decimals)	Elevation (mamsl)	Depth (m)		Lithology	Description
				From	*To*		
PT1	28.77132	32.01874	29	0	1.2	Sand	Moist, yellowish brown, fine grain silty Sand. Colluvium
				1.2	2.207	Clay	Wet, Reddish brown, very fine grain with pashes of olive sand, sandy Clay.
PT2	28.77144	32.01792	19	0	0.5	Sand	Moist, dark grey, fine grain, silty Sand.
				0.5	1.1	Clay	Wet, Red, Very fine grain, sandy Clay.
PT3	28.77136	32.01715	26	0	1.9	Sand	Moist, light grey, mottled, fine grain silty Sand.
				1.9	2.15	Sand	Wet, Reddish brown, mottled, fine grain silty sand.
PT4	28.77043	32.01591	23	0	0.55	Sand	Moist, dark grey, fine grain silty Sand.
				0.55	0.95	Sand	Moist, light yellow, fine grain Sand.
				0.95	1.9	Clay	Wet, dark grey, very fine grain sandy Clay.
PT5	28.77223	32.01771	19	0	1.2	Clay	Wet, black, very fine grain mottled sandy Clay.
PT6	28.76772	32.02098	28	0	1.2	Sand	Moist, light yellow, fine grain Sand.

KEY:	
(yellow)	Sand
(red)	Clay

APPENDIX E: SITE PHOTOS

<table>
<tr><th colspan="3">HYDROGEOLOGICAL ASSESSMENT PHOTOGRAPHIC LOG</th></tr>
<tr><td>Client Name: CoU</td><td>Site Location: Alton landfill-Richards Bay</td><td>GCS Project No.
13-478
CSIR Project No.
CSIR\CAS\EMS\uMhlathuze\Forensic Ecological Study</td></tr>
</table>

<table>
<tr><td>Photo No. 1</td><td>Date: 20/10/2014</td><td rowspan="3"></td></tr>
<tr><td colspan="2">Direction Photo Taken:
S-N</td></tr>
<tr><td colspan="2">Description:
This photo shows a hole in the landfill and a man who was searching for steel. There are a number of these holes in the landfill. Rain water is most likely to infiltrate into the landfill through these holes.</td></tr>
<tr><td>Photo No. 2</td><td>Date: 21/10/2014</td><td rowspan="3"></td></tr>
<tr><td colspan="2">Direction Photo Taken: NW-SE</td></tr>
<tr><td colspan="2">Description:
Monitoring borehole GL7 next to the stream that flows through the site.</td></tr>
</table>

HYDROGEOLOGICAL ASSESSMENT PHOTOGRAPHIC LOG

Client Name: CoU	**Site Location:** Alton landfill-Richards Bay	**GCS Project No.** 13-478 **CSIR Project No.** CSIR\CAS\EMS\uMhlathuze\Forensic Ecological Study
Photo No. 3 / **Date:** 21/10/2014 **Direction Photo Taken:** N-S **Description:** Uncovered areas within the landfill. The covered areas are vegetated with grass.		

HYDROGEOLOGICAL ASSESSMENT PHOTOGRAPHIC LOG

Client Name: CoU	Site Location: Alton landfill Richards Bay	GCS Project No. 13-478 CSIR Project No. CSIR\CAS\EMS\uMhlathuze\Forensic Ecological Study

Photo No. 4	**Date:** 20/10/2014
Direction Photo Taken: E-W	
Description: TP11. Non-operational Pump station.	

Photo No. 5	**Date:** 21/102014
Direction Photo Taken: E-W	
Description: Photo showing the soil layer from PT2.