GROUNDWATER/SURFACE WATER MONITORING AT KARWYDERSKRAAL LANDFILL SITE – NOVEMBER 2010 MONITORING

CLIENT: OVERBERG DISTRICT MUNICIPALITY

PROJECT NO. 1031 ***REPORT NO.: B2011-02_01***

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FEBRUARY 2011

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ABBREVIATIONS

DWA	Department of Water Affairs
Ca	calcium
Cl	chloride
COD	chemical oxygen demand
Cr	chromium
Cu	copper
DOC	dissolved organic carbon
EC	electrical conductivity
F	flouride
Fe	iron
HCO_3	bicarbonate
K	potassium
m	metres
Mg	magnesium
Mn	manganese
mamsl	metres above mean sea level
mbgl	metres below ground level
mS/m	milliSiemens per meter
mg/l	milligrams per litre
Na	sodium
NO_3	nitrate
NH_4	ammonia
P	phosphorus
Pb	lead
ODM	Overberg District Municipality
SO_4	sulphate
WISH	Windows Interpretation System for Hydrogeologists

1. INTRODUCTION

The Karwyderskraal Landfill Site, a licensed GMB^{+} facility, is currently being operated by the Overberg District Municipality (ODM). As part of the license conditions, the ODM must conduct the monitoring of groundwater, surface water and leachate at the Karwyderskraal Landfill Site and in the surrounding area. A well – established monitoring network exists at the Karwyderskraal Landfill Site. Monitoring dates back to 1998, although it commenced in earnest in 2003. The monitoring includes bi – annual (end – summer and end – winter) sampling of the groundwater, surface water and leachate sites. Several sampling rounds have since been conducted by previous consultants Geostatus and GEOSS. Hence a number of technical reports are since available. A comprehensive monitoring database has also been established.

BMK Engineering Consultants was appointed in October 2010 to continue the bi – annual monitoring at Karwyderskraal Landfill Site for 1 year. This report documents the 1st monitoring round conducted on 1 November 2010

The Karwyderskraal Landfill Site is situated about 2 km north of the coastal town of Fisher Haven in the Overberg District of the Western Cape Province (Figure 1). More specifically, it is situated just off the R43 road that connects Hawston and Botrivier. The Karwyderskraal Landfill Site receives about 35,000 tons per year mainly from the Overstrand Municipality, Grabouw, Villiersdorp and some private companies in the area. As a GMB^{+} facility, the site is medium in size, receives general waste and is designed to accommodate the generation of leachate.

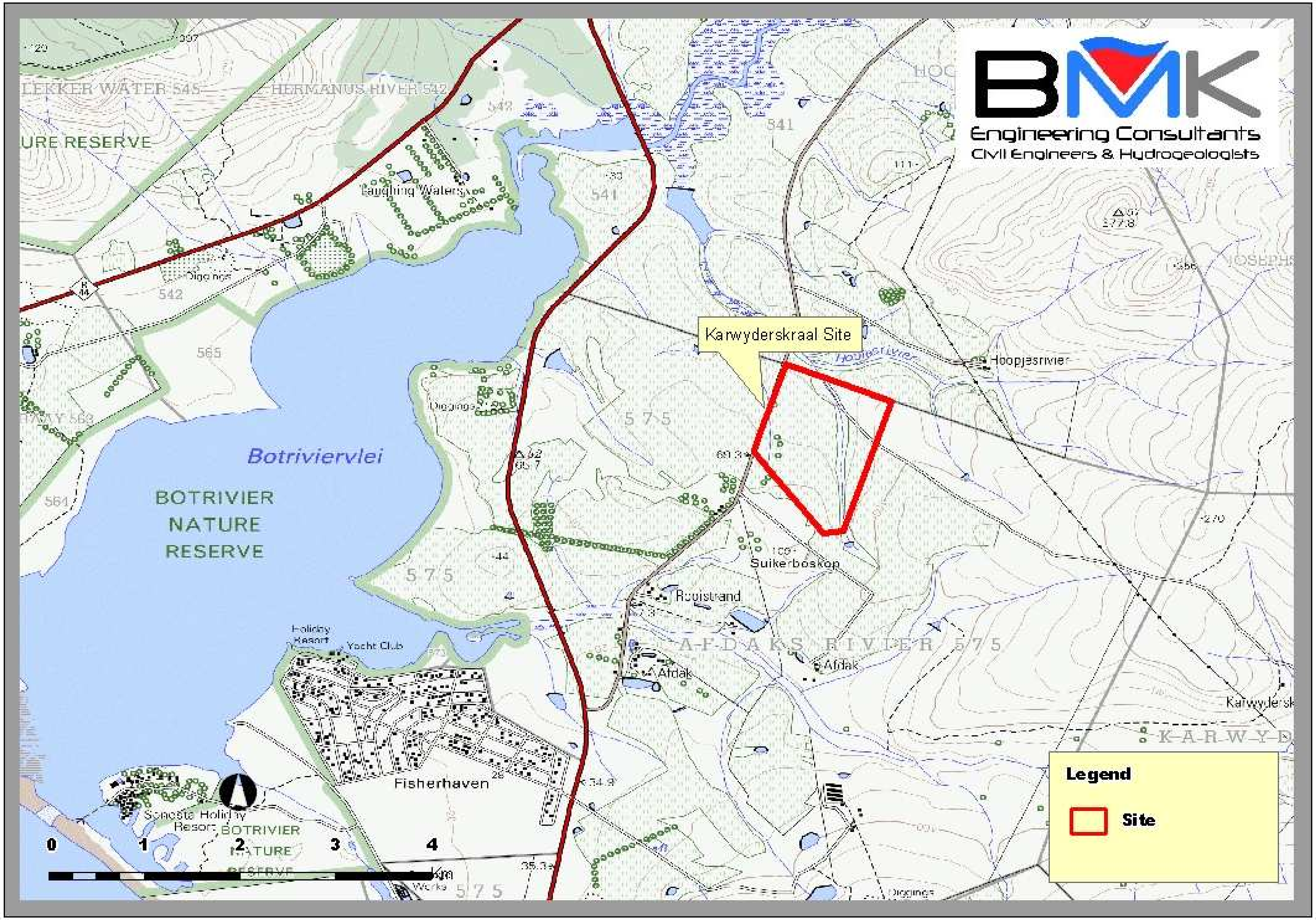

Figure 1: Locality Map of the Karwyderskraal Landfill Site

2. TERMS OF REFERENCE

According to the specifications, i.e. Quotation No: QKWK02/09/2010/11 – ", the scope of work for Annual Water Monitoring services for Karwyderskraal Landfill Site must include the following key tasks:

- The physical water sampling to be conducted on site at the specified monitoring points. One sampling run must be conducted during end – winter (October) and a 2nd during end – summer (April).
- Chemical laboratory analyses at an accreditated laboratory.
- Capturing of historical data from previous consultants reports.
- The results documented (Hard copy and CD) and copies distributed to the Overberg District Municipality, Department of Environmental Affairs and Development Planning and the Department of Water Affairs
- A Presentation and feedback to the Overberg District Municipality (Committee of Control at Karwyderskraal) at the end of the 2nd sampling run.

3. FIELD SAMPLING AND DATA COLLECTION

Field sampling was conducted on 1 November 2010. A 4x4 - mounted submersible pump was used to conduct the sampling at the borehole sites. At each borehole, an attempt was made to first purge the borehole for about 10 – 15 minutes, prior to taking the final sample. The reason for this is to obtain a representative sample of the aquifer, and not just a sample of the water in the borehole column. At all the sampling sites the relevant site parameters were measured and/or checked. These include GPS coordinates, ground elevations, water levels, collar elevations of boreholes, electrical conductivity (EC), pH, temperature, sodium chloride (NaCl) percentage per volume. In addition to this, general comments were made of the status of each site at the time of sampling.

A summary of the field sampling results is provided in Table 1 & 2. In total, 6 boreholes, 6 surface water sampling sites and 3 leachate sites were visited. A detailed layout of these sites is shown in Figure 2. Of all the boreholes visited, boreholes BH1 and BH2 were dry and were therefore not sampled. The other boreholes, i.e. BH3, BH4, BH5 and BH7 had some water and were sampled successfully. At the surface monitoring sites, i.e. SW2 and SW4, no sampling was possible due to either muddy or dry conditions. Of the 3 leachate sites, only LT1 could be sampled. LD1 had a huge obstacle in the downpipe, which prevented entry for sampling, whilst C3 was dry.

Rainfall data were collected from 2 sources, i.e. Overberg District Municipality and the Agricultural Research Council (ARC). The ARC rainfall station is situated at Afdaksrivier (Fisher Haven) about 2 km southwest of Karwyderskraal Landfill Site. Data from the latter rainfall station was used mainly to compare with that of Karwyderskraal and to determine the reliability of the Karwyderskraal rainfall data.

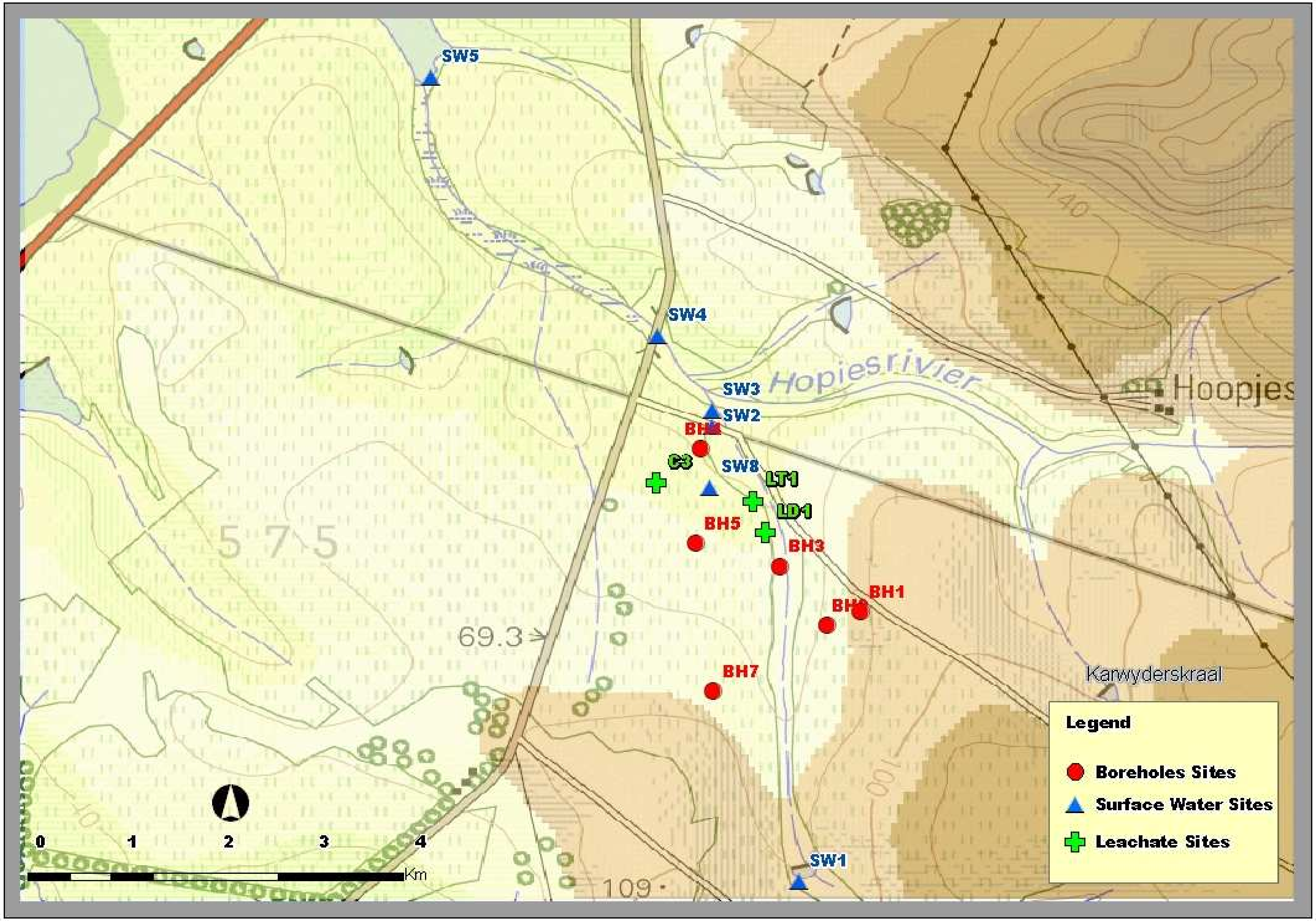

Figure 2: Monitoring Sites at Karwyderskraal Landfill Site

Table 1: Field data recorded during sampling

Site ID	Date	Time	Lat_WGS84	Long_WGS84	Elevation (mamsl)	Water Level (mbch)	Collar Height (m)	Water Level (mbgl)	EC (ms/m)	TDS (mg/l)	NaCl_%	Temp (degrees)
BH1	01-Nov-10	15:05	34.33753	19.16709	71							
BH2	01-Nov-10	15:00	34.33796	19.16601	70							
BH3	01-Nov-10	10:45	34.33607	19.16452	74	6.94	0.3	6.64	53.5	263	1.1	22.8
BH4	01-Nov-10	16:20	34.33232	19.16198	44	4.87	0.47	4.4	1005	4930	19.9	21.8
BH5	01-Nov-10	15:32	34.33535	19.16182	53	5.88	0.32	5.56	982	4800	19.4	22.1
BH7	01-Nov-10	11:40	34.34006	19.16239	66	22.36	0.3	22.06	240.2	1175	5.1	23.1
C3	01-Nov-10	16:15	34.33340	19.16057	52							
LD1	01-Nov-10	16:10	34.33498	19.16406	50							
LT1	01-Nov-10	16:45	34.33398	19.16367	46							
SW1	01-Nov-10	14:35	34.34612	19.16516	79				99.9	490	2.1	25.4
SW2	01-Nov-10	15:25	34.33160	19.16236	33							
SW3	01-Nov-10	17:26	34.33107	19.16236	21				43.2	215	0.9	21.6
SW4	01-Nov-10	17:35	34.32868	19.16061	21							
SW5	01-Nov-10	17:50	34.32042	19.15335	11				170.7	835	3.6	24.2
SW8	01-Nov-10	17:00	34.33356	19.16231	42				397	1940	8.3	27.1

Table 2: Comments of monitoring sites

Site ID	Comments
BH1	borehole dry; see previous comments GEOSS report
BH2	borehole dry; see previous comments GEOSS report
BH3	pump installed at ~27m; purged for 20 minutes; 2 samples taken
BH4	pump installed at ~10m; purged for ~10 minutes at flow rate of 0.2l/s; 2 samples taken
BH5	pump installed at ~15m; purged for about 15 minutes (0.2 l/s); 2 samples taken
BH7	pump installed at ~24m (close to bottom); very murky water pumped; pump sucked air after < 5mins - limited available drawdown
C3	Side surface channel crossing main road to office; dry, no sampling possible
LD1	Obstacle in pipe - cannot get pump in - no sampling done; water level meter confirmed major blockage in sampling pipe at about 2mbgl
LT1	Leachate pond sample; no field measurements taken due to concern over toxicity & damage to equipment; 2 samples taken
SW1	no water in mainstream channel, but only in upstream earth dam; sampled in earth dam - standing water; 2 samples taken
SW2	muddy stream bed on upstream side of road; no flow; site not sampled; side channel along road has a tiny trickle, but not representative of site
SW3	Side stream into Hopies River; stream not flowing - standing water - sampled nevertheless; 2 samples taken
SW4	Main Hopies River at bridge along main road to Botriver; dry; no sampling done
SW5	Sampled at southern side of Dam as the main stream enters Dam; 2 samples taken
SW8	Evaporation ponds with reeds; 2 samples taken

4. RAINFALL

The monthly rainfall data of Karwyderskraal Landfill Site are graphically displayed in Figures 3. Note that for the Karwyderskraal rainfall station, a mere 99.5 mm of rain was recorded during 2004 which seems suspiciously low for this area. From Figure 3, a seasonal effect is evident. Generally the peak rainfall occurs in winter from May to September, whilst the summer droughts occur from November to March. During the peak rainfall periods, the monthly rainfall can exceed 100 mm. The annual rainfall over the last 6 years varied from a minimum of 263 mm during 2010 to a maximum of 628 mm in 2006 (Table 3).

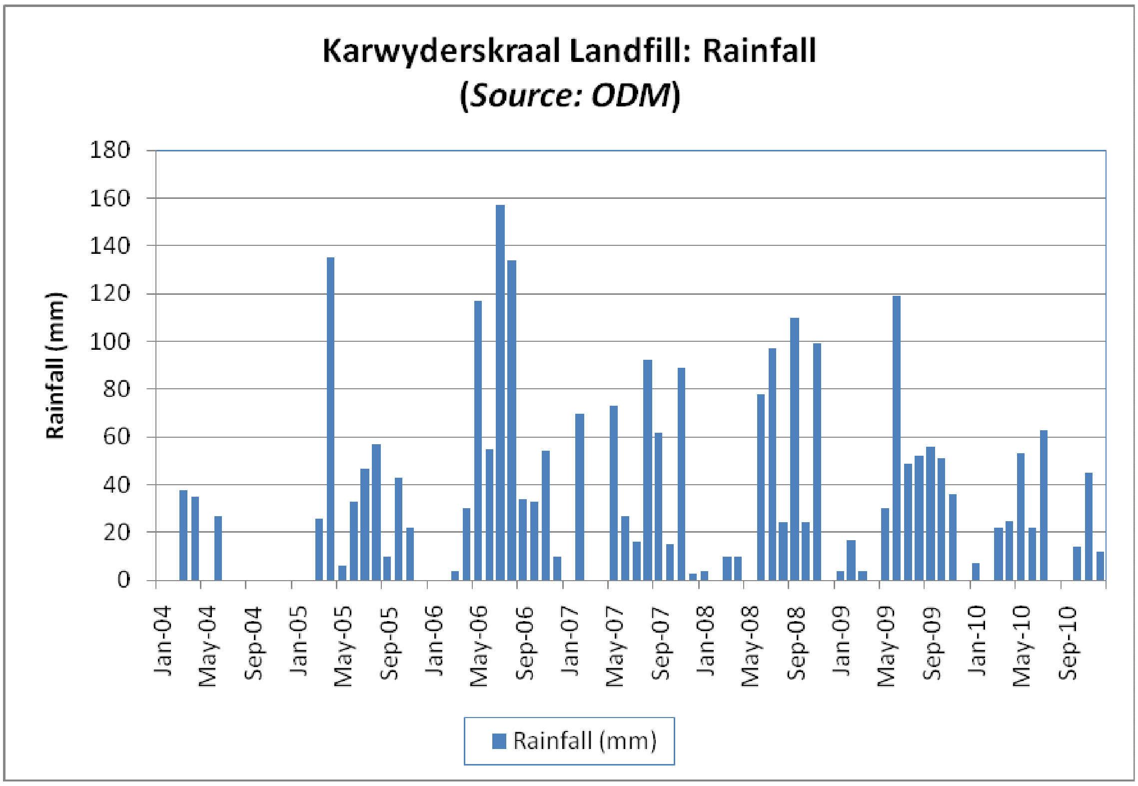

Figure 3: Monthly Rainfall of the Karwyderskraal Landfill Site

Table 3: Annual Rainfall of Karwyderskraal Landfill Site

Year	Annual Rainfall (mm) Karwyderskraal
2004	99.5*
2005	379
2006	628
2007	447
2008	456
2009	418
2010	263

The monthly rainfall data at Afdaksrivier (Fisher Haven) were used to compare with that of Karwyderskraal Landfill Site. The latter data are graphically displayed in Figure 4. Whilst the rainfall shows a similar seasonal trend than at Karwyderskraal Landfill Site, the amount of rain at Afdaksrivier is generally a bit higher than at Karwyderskraal. The annual rainfall over the last 6 years at Afdaksrivier varied from a minimum of 451 mm during 2008 to a maximum of 737 mm in 2007 (Table 4).

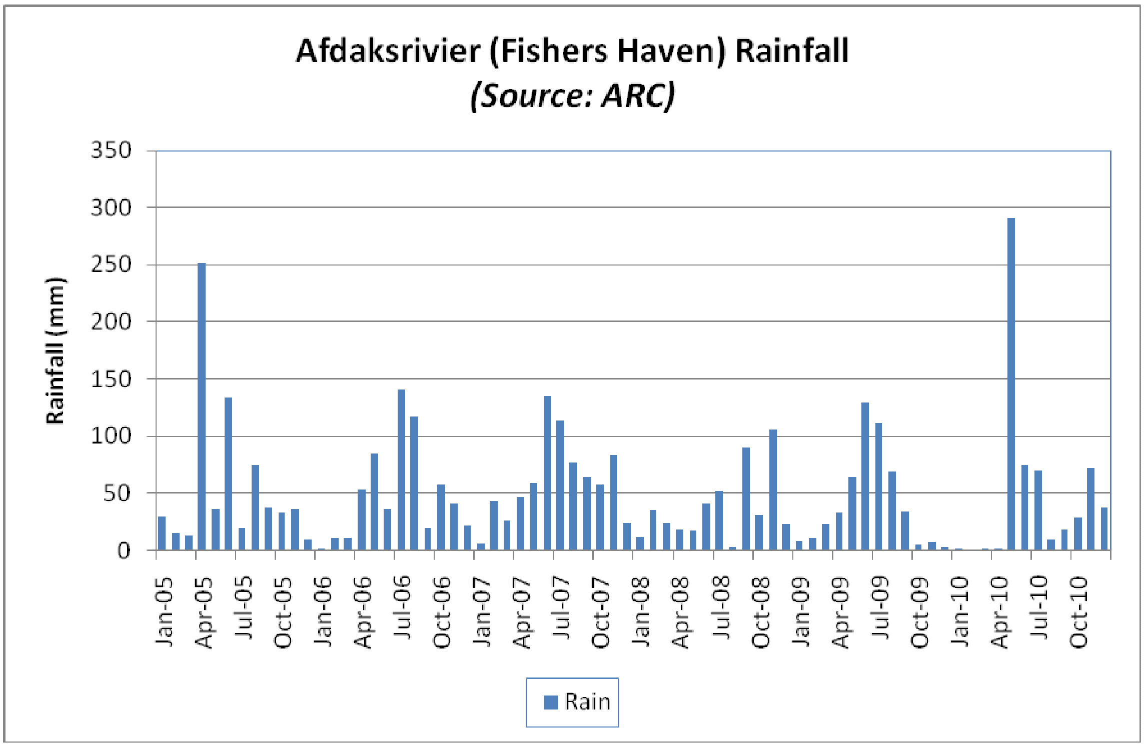

Figure 4: Monthly Rainfall of Afdaksrivier

Table 4: Annual Rainfall of Afdaksrivier

Year	Annual Rainfall (mm) Afdaksrivier
2004	412
2005	688
2006	594
2007	737
2008	451
2009	498
2010	604

The annual rainfall data for Karwyderskraal and Afdaksrivier rainfall stations are shown in Figure 5. Since the amount and timing of peak rainfall vary for both rainfall stations, it can be concluded that the rainfall is spatially and temporally variable throughout the study area. However, for the purpose of this study, the Karwyderskraal rainfall will be used for the analyses.

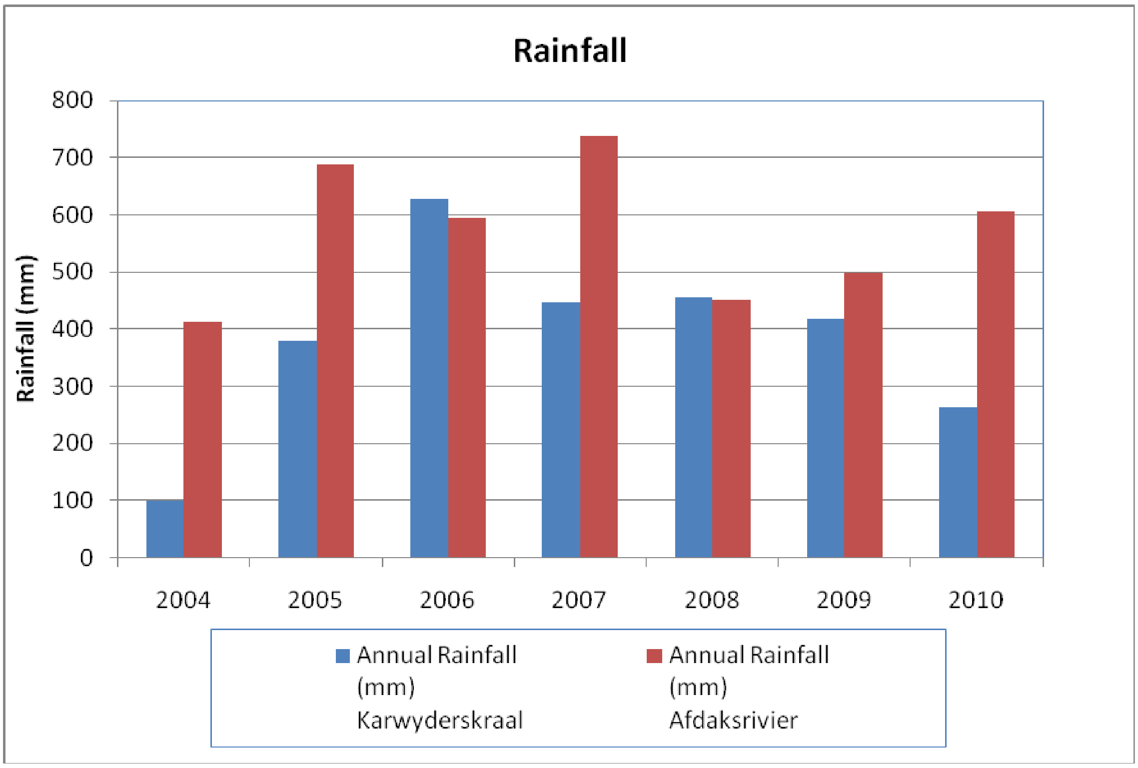

Figure 5: Annual Rainfall for Karwyderskraal and Afdaksrivier

5. WATER LEVEL ANALYSES

The time series water level data of boreholes BH3, BH4, BH5 and BH7 are graphically displayed in Figure 6. From 1998 to 2010, the water levels at BH3, BH4 and BH5 show similar trends. The water levels at the latter boreholes showed a steady decline from 1998 to 2005 (i.e. 3 – 6 m), followed by a steady recovery period from 2005 to 2010 to above the 1998 level. BH7 has a slightly different trend. Whilst the water level at BH7 also shows an initial downward trend of about 5 m from 1998 to 2005, this was followed by a period of stable water levels (i.e. at about 20 mbgl) from 2005 to 2009, as well as a further water level decline of about 2 m from 2009 to 2010.

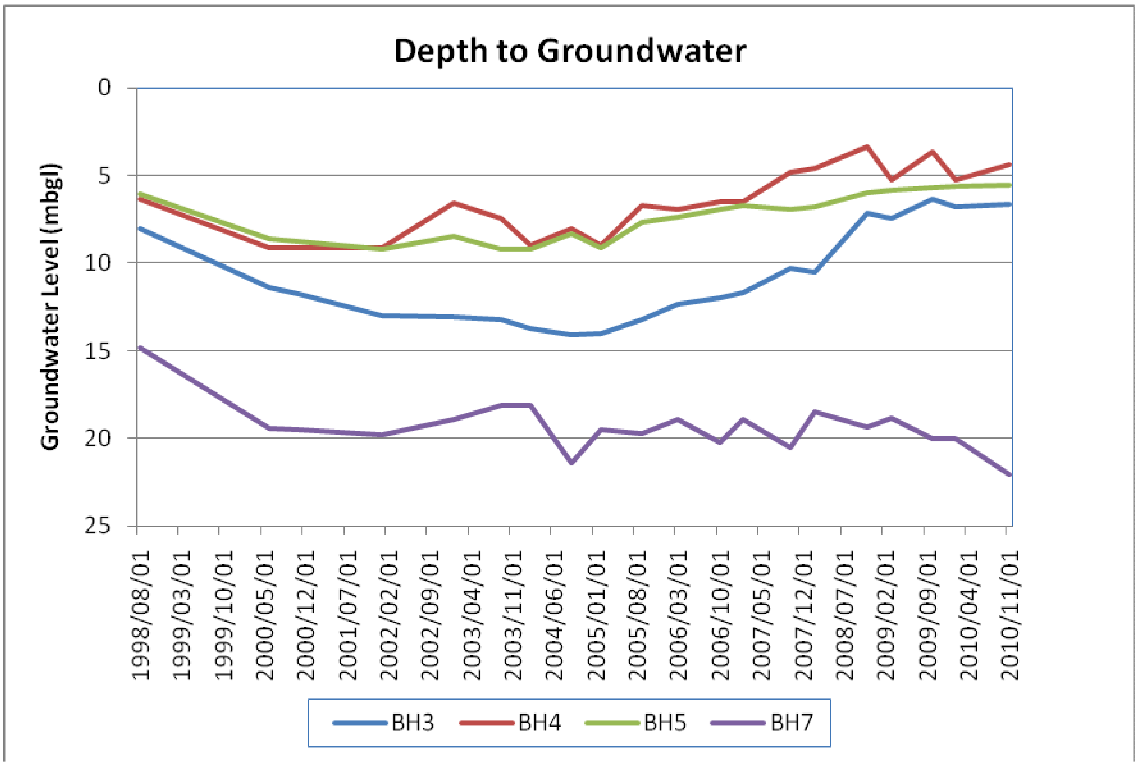

Figure 6: Groundwater Level Depth

BH7 is situated upgradient of the Karwyderskraal Landfill Site and represents the pristine condition monitoring. BH3, BH4 and BH5 are situated downgradient of the Karwyderskraal Landfill Site. Figure 7 shows the groundwater level elevations for the 4 boreholes visited. Note that these groundwater level elevations are based on surface elevation measurements taken with a handheld Garmin GPS device. Generally, the basic handheld Garmin GPS's don't record accurate surface elevations (i.e. measurements could be out by 3 – 5 m), but they are useful for comparison between different areas. From Figure 7, an interesting observation is that since about November 2009 the groundwater elevation at BH7 (42 mamsl) has declined to about 2 m below the groundwater elevation at BH3 (44 mamsl) and BH5 (44 mamsl). As a result of this, a groundwater mound has developed in the vicinity of the Landfill Site, which will further result in a reversal in the groundwater flow direction from the Landfill Site towards BH7. The reasons for the groundwater mound developing are:

- Artificial leachate recharge from the Karwyderskraal Landfill Site along preferred pathways (transmissive zones).
- Artificial recharge from the surface stream along preferred pathways (transmissive zones).
- A combination of the two above.

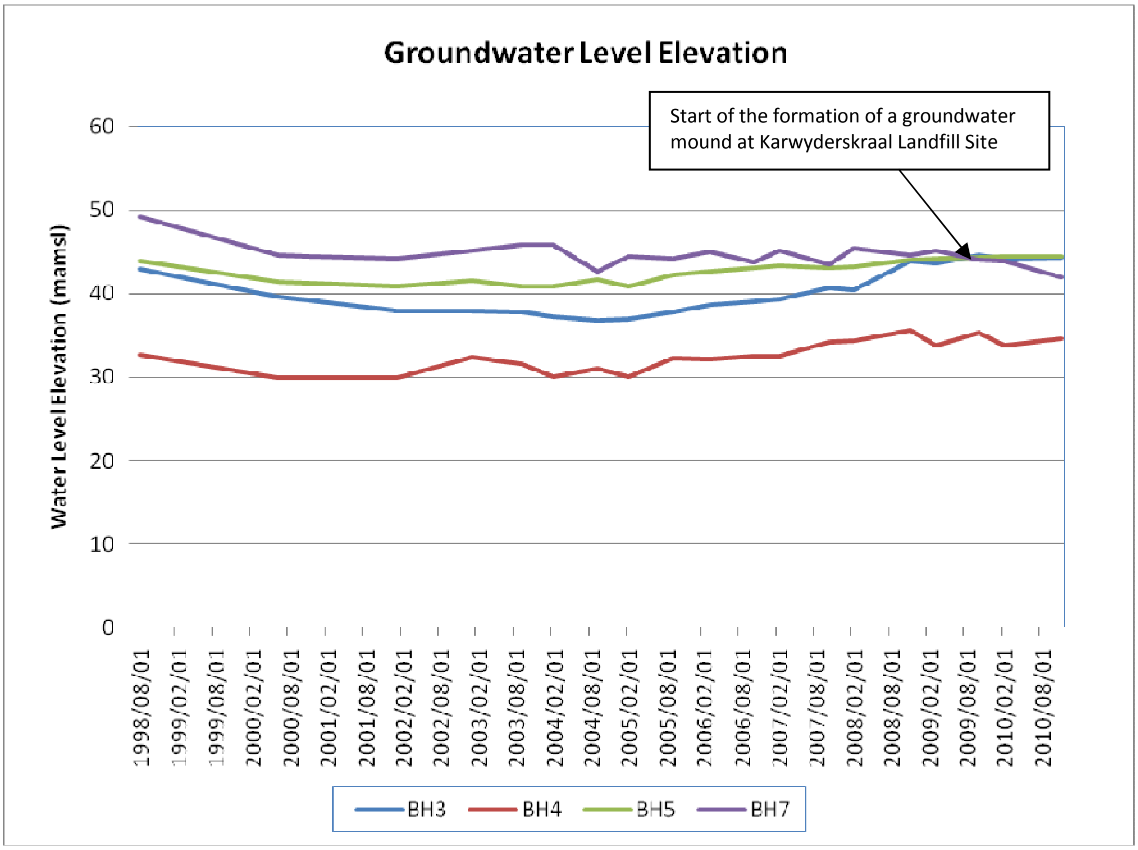

Figure 7: Groundwater Level Elevation

Figure 8 shows the groundwater level elevations in comparison with the rainfall at Karwyderskraal Landfill Site. The higher rainfall received during 2006 (628 mm), 2007 (447 mm) and 2008 (456 mm) respectively resulted in significant groundwater level recovery at BH3, BH4 and BH5, whilst at BH7 the groundwater level remained stable.

The low rainfall (i.e. 263 mm/annum) received in 2010 did not result in any major groundwater level decline at BH3, BH4 and BH5. The only groundwater decline was observed at BH7, where the groundwater level declined by about 2 m from end – 2009 to end – 2010. The groundwater levels at BH3, BH4 and BH5 have been very stable since September 2008.

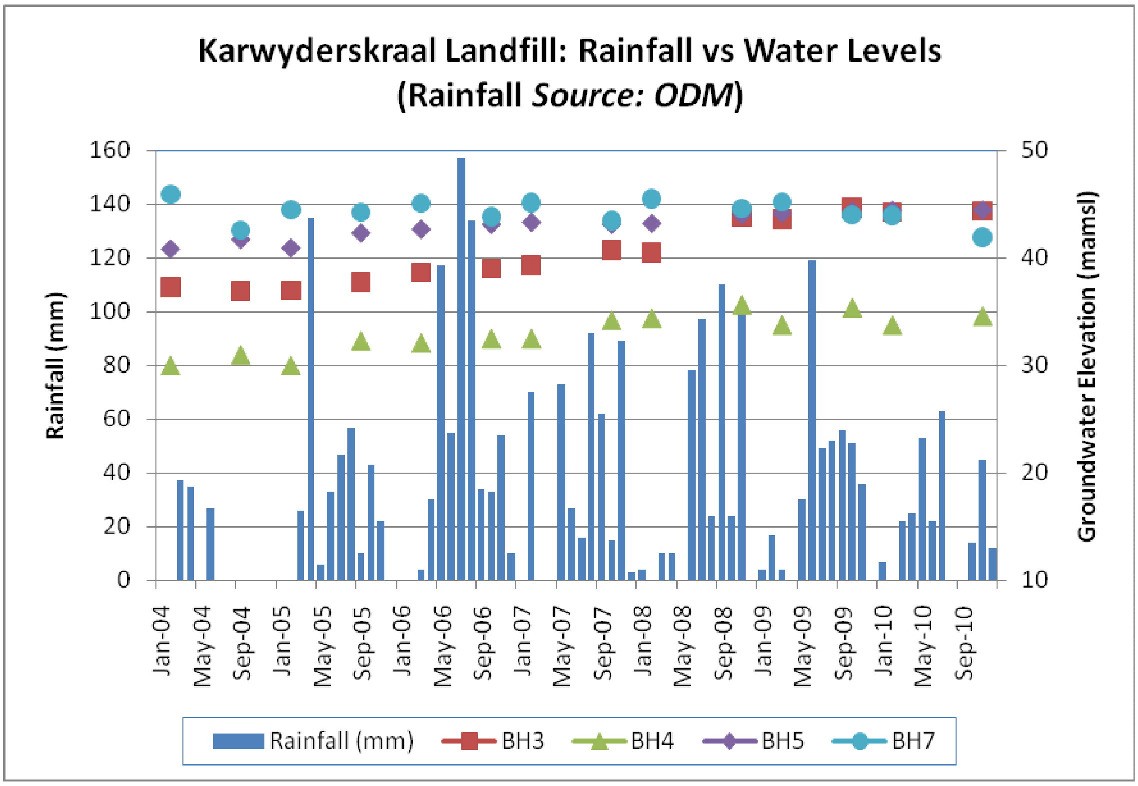

Figure 8: Rainfall vs Water Level Elevation

6. WATER CHEMISTRY

All the available groundwater chemistry data (historical and new data) were sorted in a WISH (Windows Interpretation System for Hydrogeologists developed by the Institute for Groundwater Studies at the University of the Free State) format. The groundwater chemistry data include the major cations and anions, metals and trace elements. The latest chemistry data analysed by Bemlab in Somerset West are shown in Appendix A.

Trends in the electrical conductivity (EC), pH, nitrate (NO_3), ammonia (NH_4), iron (Fe) and manganese (Mn) were assessed. Generally the EC is used as an overall groundwater quality indicator, whilst the concentrations in NO_3, NH_4, Fe and Mn are collectively used as potential pollution indicators.

6.1 Groundwater Sites

The water chemistry of the 4 boreholes sampled at the Karwyderskraal Landfill Site is shown in Figure 9. Boreholes BH4, BH5 and BH7 have similar water chemistries, i.e. sodium (Na) and chloride (Cl) dominant ions. The latter boreholes are completely deficient in bicarbonate (HCO_3). BH3 has a slightly different chemistry. Whilst BH3 also has sodium (Na) and chloride (Cl) dominant ions, it is also slightly more bicarbonate enriched than the other boreholes, which is generally indicative of a fresher water type.

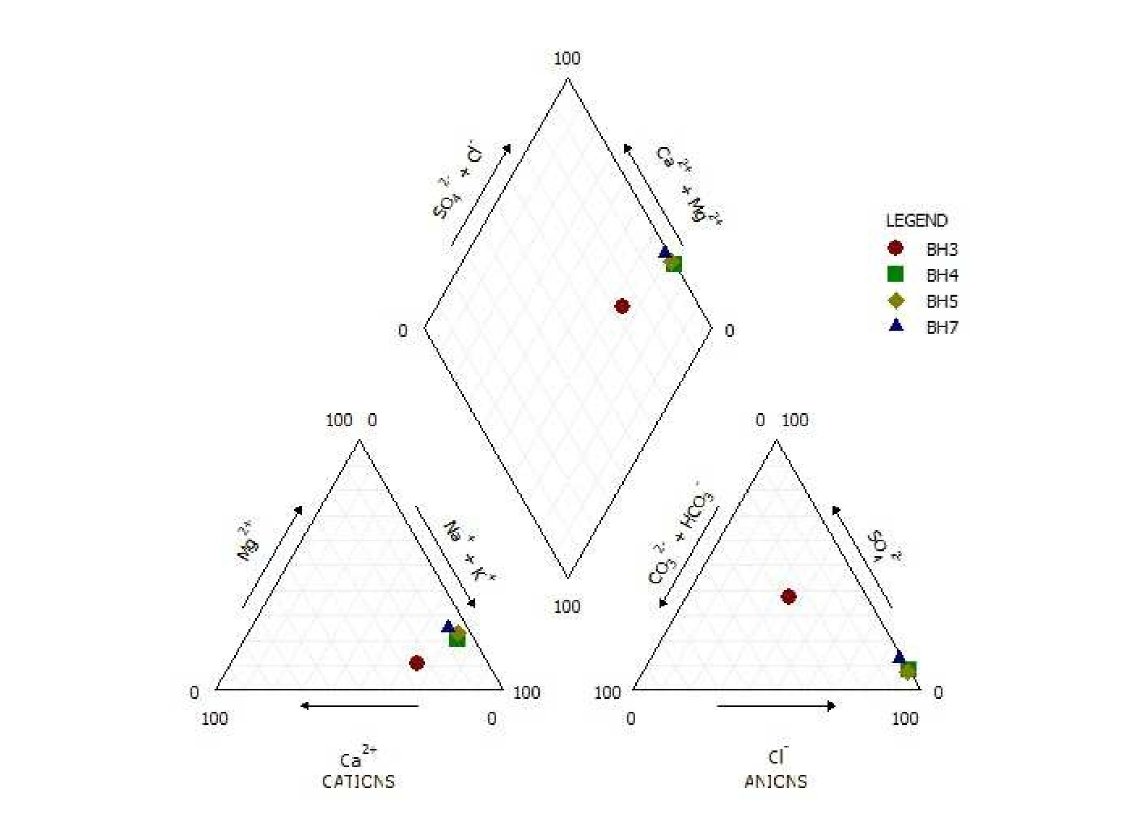

Figure 9: Piper Diagram of Borehole Sites

The time series EC graph in Figure 10 shows the variation in EC over time. BH3 has the lowest and most stable EC of the 4 boreholes sampled, i.e. between 60 – 70 mS/m. The EC at BH7 varies between 100 mS/m and 300 mS/m. Since 2005 a gradual increase in EC has been observed at BH7. The EC at BH4 and BH5 are significantly higher and have greater variability than at BH3 and BH7. The EC at BH4 varies between 800 – 1200 mS/m, whilst the EC at BH5 varies between 100 – 1100 mS/m.

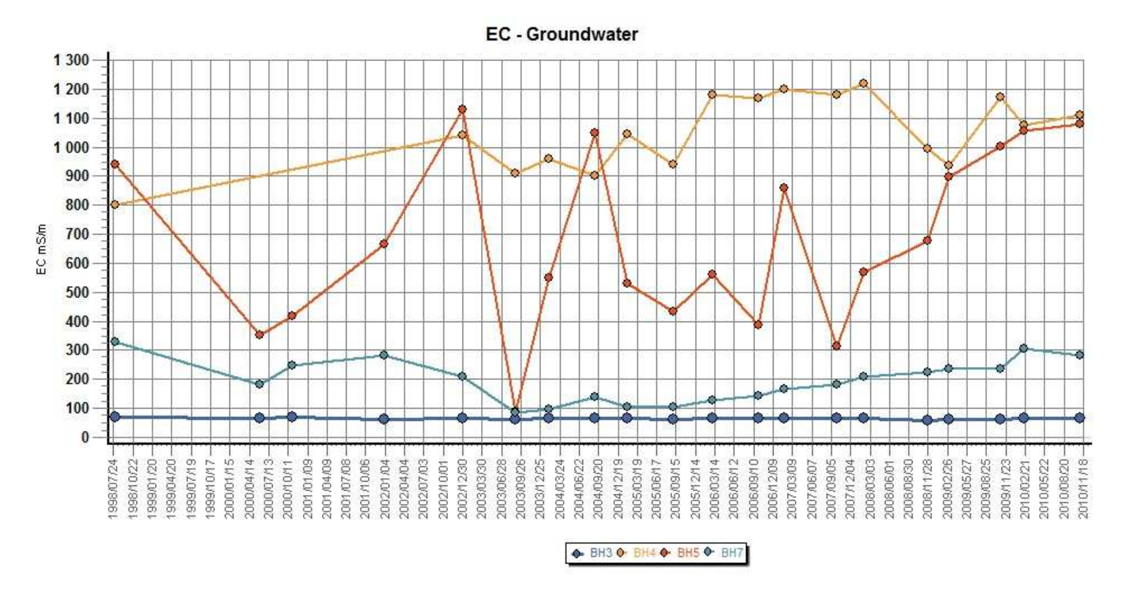

Figure 10: EC of Borehole Sites

The pH at BH3 is relatively stable between 7 and 8.5 (Figure 11). In contrast, greater variations in pH are observed at BH4 (i.e. 3 – 7.5), BH5 (i.e. 3.5 – 8) and BH7 (i.e. 5.5 – 8). BH4 and BH5, in particular, show sharp periodic variations in pH, particularly since 2007.

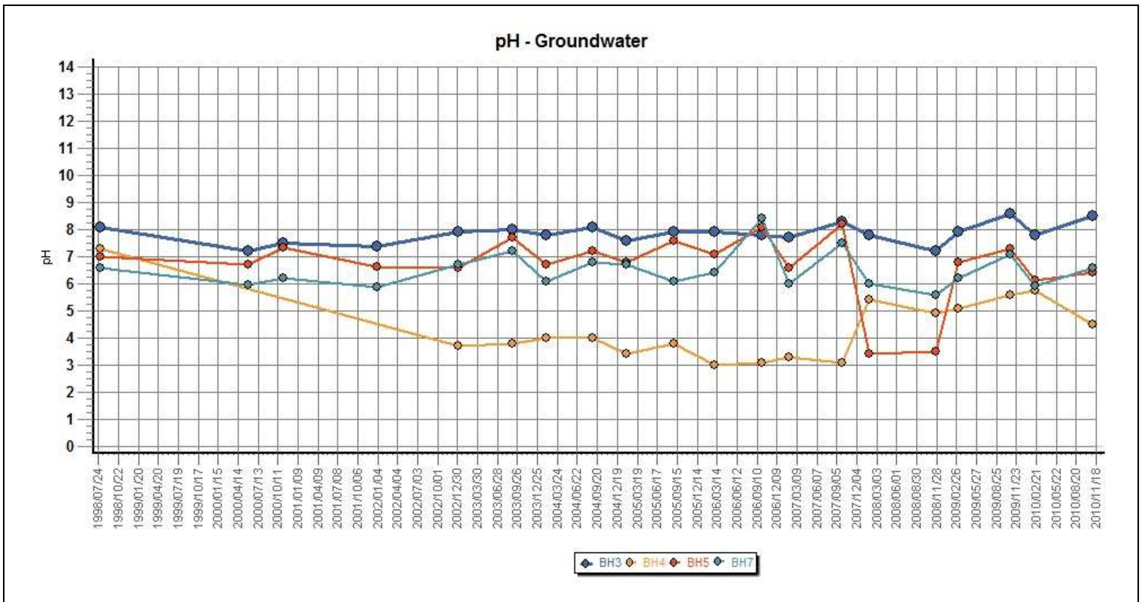

Figure 11: pH of Borehole Sites

In terms of the heavy metal content, the latest Fe and Mn concentrations are high at BH5 (i.e. 24.0 mg/l and 0.4 mg/l respectively) and extremely high at BH4 (137.0 mg/l and 3.0 mg/l respectively) (Figures 12 and 13). Generally, water used for domestic purposes should have Fe and Mn concentrations of < 1.0 mg/l and 0.1 mg/l respectively (DWA, 1999). The exceptionally high Fe and Mn concentrations observed at BH4 and BH5 are likely to be related to a pollutant source from the Karwyderskraal Landfill Site. At BH7, slightly elevated Fe and Mn concentrations are recently observed, i.e. 1.6 mg/l and 0.7 mg/l respectively. However, note that the Fe and Mn concentrations at BH7 were > 10.0 mg/l and 0.99 mg/l respectively in February 2010, which could be indicative of leakage of poorer quality groundwater. At BH3 the latest Fe and Mn concentrations are 0.09 mg/l and 0.14 mg/l respectively. However, it must be noted that higher Fe concentrations of > 5.0 mg/l were observed in February 2008 and February 2010 respectively.

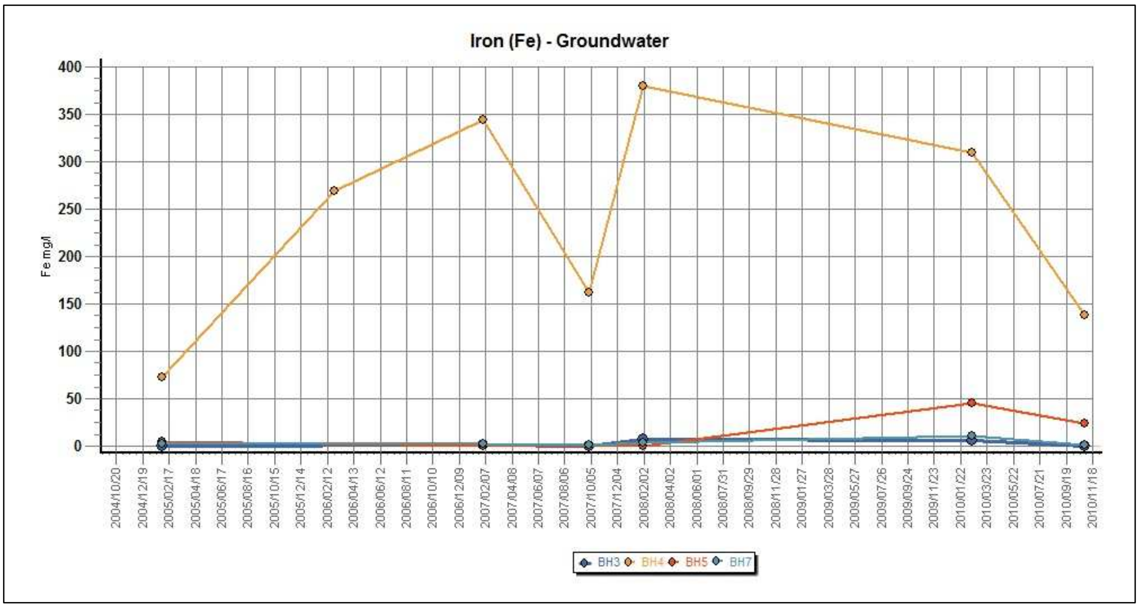

Figure 12: Iron (Fe) in Groundwater

Figure 13: Manganese (Mn) in Groundwater

The time series NO_3 and NH_4 data are graphically displayed in Figures 14 and 15. At all boreholes the NO_3 concentrations have been below the recommended 6.0 mg/l prescribed by DWA for drinking water standards (DWA, 1999). Generally the NO_3 concentrations are relatively stable throughout the monitoring record. An occasional spike occurred at BH5 during 2007 and 2008, where the NO_3 concentration increased to > 5.0 mg/l. However, the latest NO_3 concentrations at all the boreholes are < 1.0 mg/l.

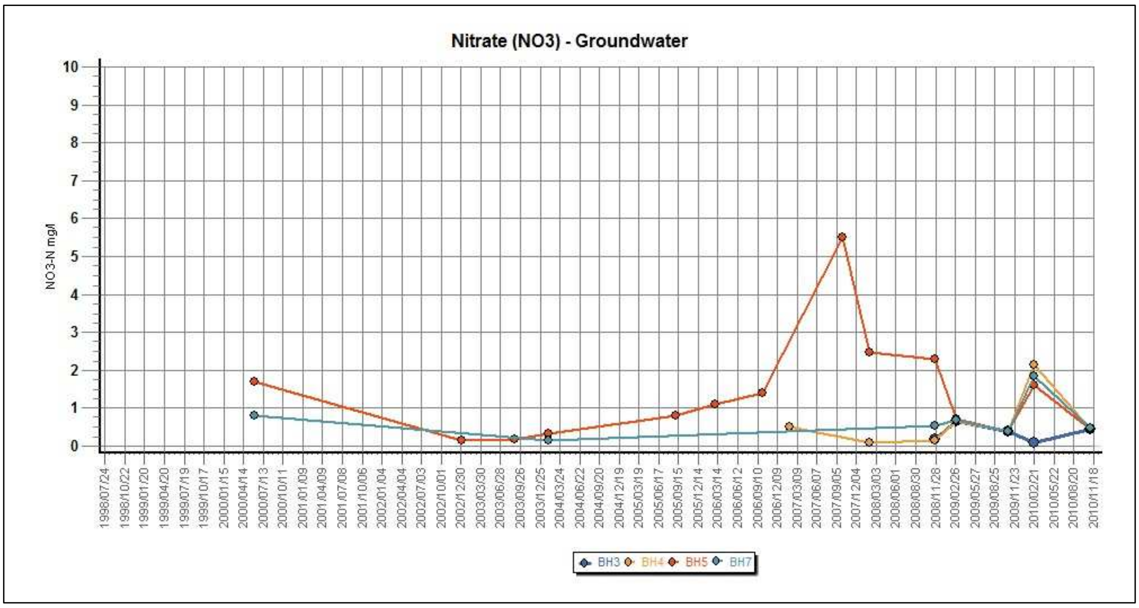

Figure 14: Nitrate (NO_3) in Groundwater

The NH_4 concentrations at BH4, BH5 and BH7 have similar recent (2009 – 2010) trends. Prior to 2009, the NH_4 concentrations at all boreholes were generally < 1.0 mg/l. However, in 2009 a sharp increase in NH_4 concentration was observed at BH4, BH5 and BH7 to about 3.0 mg/l, whilst that of BH3 remained < 1.0 mg/l. The latest NH_4 concentration at BH4, BH5 and BH7 is < 1.0 mg/l, whilst that of BH3 has increased to > 1.5 mg/l.

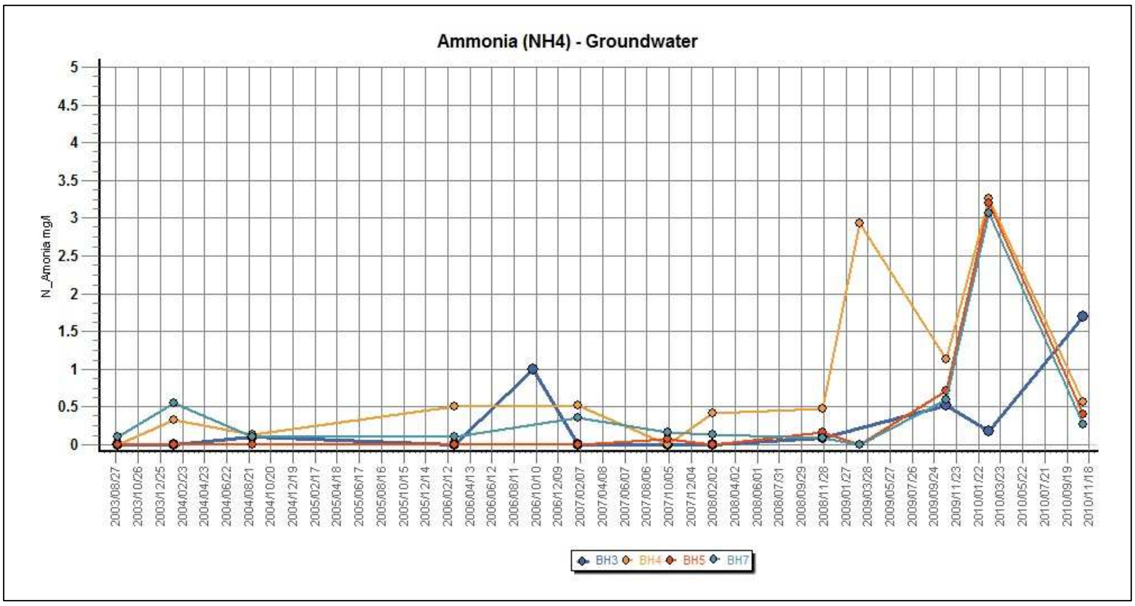

Figure 15: Ammonia (NH_4) in Groundwater

6.2 Leachate Sites

The water chemistry of the 3 leachate sites at the Karwyderskraal Landfill Site is shown in Piper Diagram (Figure 16). Of these 3 sites, only LT1 was sampled during the November 2010 sampling run. LD1 could not be sampled due to an obstacle in the downpipe, whilst C3 was dry. The data reflected in the Piper Diagram is based on the latest measured dataset at these 3 sites.

As expected the 3 leachate sites have different chemistries, mainly due to their different settings. LT1 monitors the leachate above the clay liner, whilst LD1 monitors the leachate below the clay liner (GEOSS, 2010). C3 monitors the overland flow from a stormwater compost window (GEOSS, 2010). LT1 is exclusively sodium (Na) – chloride (Cl) dominant water type, depleted in calcium (Ca), magnesium (Mg) and bicarbonate (HCO_3). LD1 has predominantly sodium (Na) – chloride (Cl) dominant water type, but is more enriched in calcium (Ca) and magnesium (Mg) than LT1. LD1 plots very close to BH3 (See Section 6.1) and could reflect the natural water type in the aquifer. C3 has a calcium (Ca), magnesium (Mg) and chloride (Cl) water type.

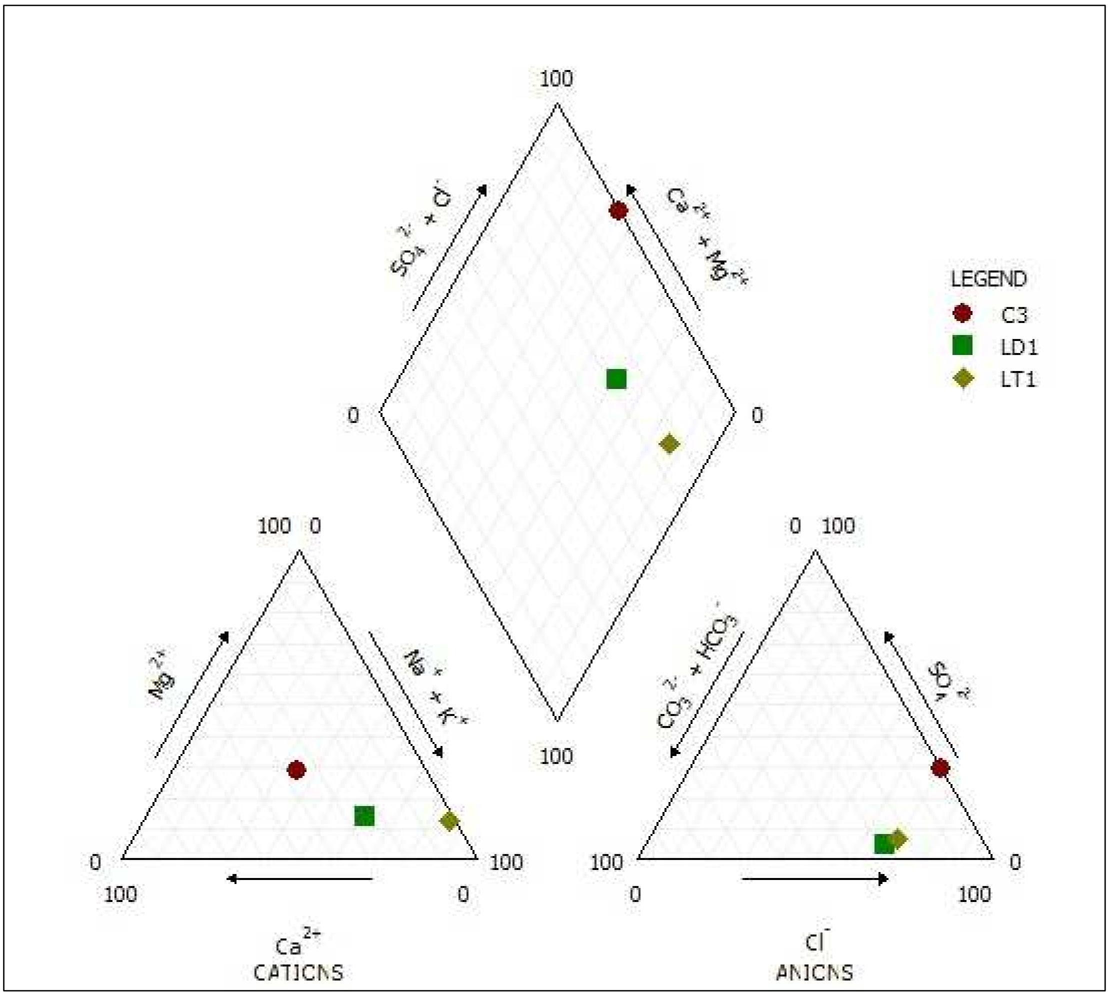

Figure 16: Piper Diagram of Leachate Sites

The EC graph for the leachate sites is shown in Figure 17. The EC at LT1 varies significantly between 1000 – 4500 mS/m. The EC at LD1 varies between 170 – 550 ms/m, but more importantly, there has been a consistent decrease in EC since 2004 to the latest 187 mS/m level. C3 was only sampled twice before and no clear trend in EC can be observed. The latest EC, measured in 2007, was > 500 mS/m.

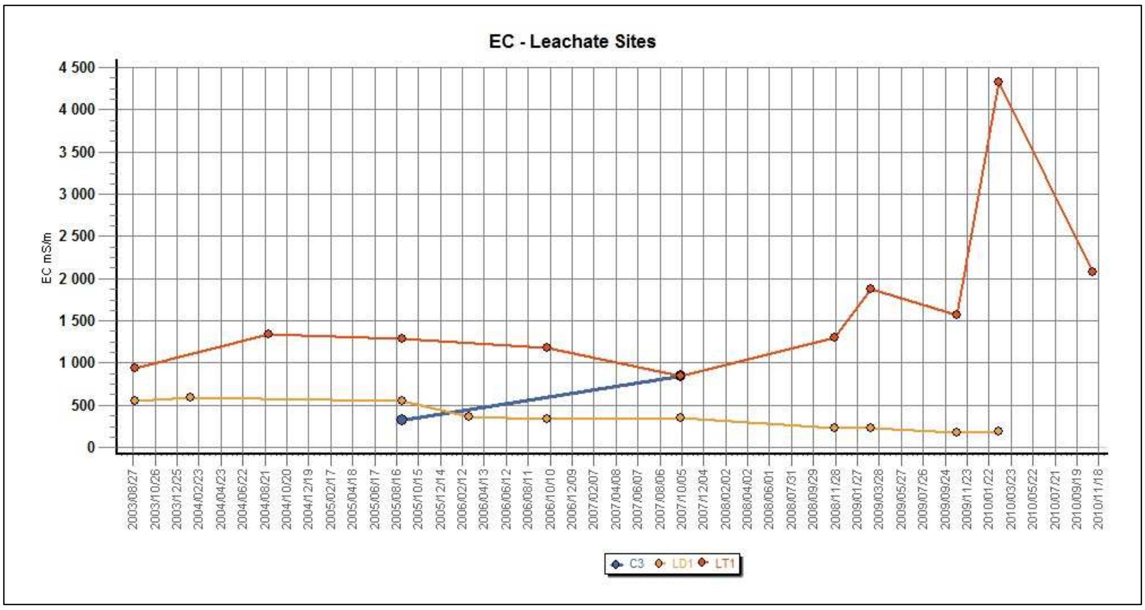

Figure 17: EC of Leachate Sites

The long – term trend in pH between LT1 and LD1 is similar (Figure 18). However, the pH at LT1 is consistently higher than that of LD1. The pH at LT1 varies from 8.0 – 9.5, whilst the pH at LD1 varies from 6.5 – 8.0.

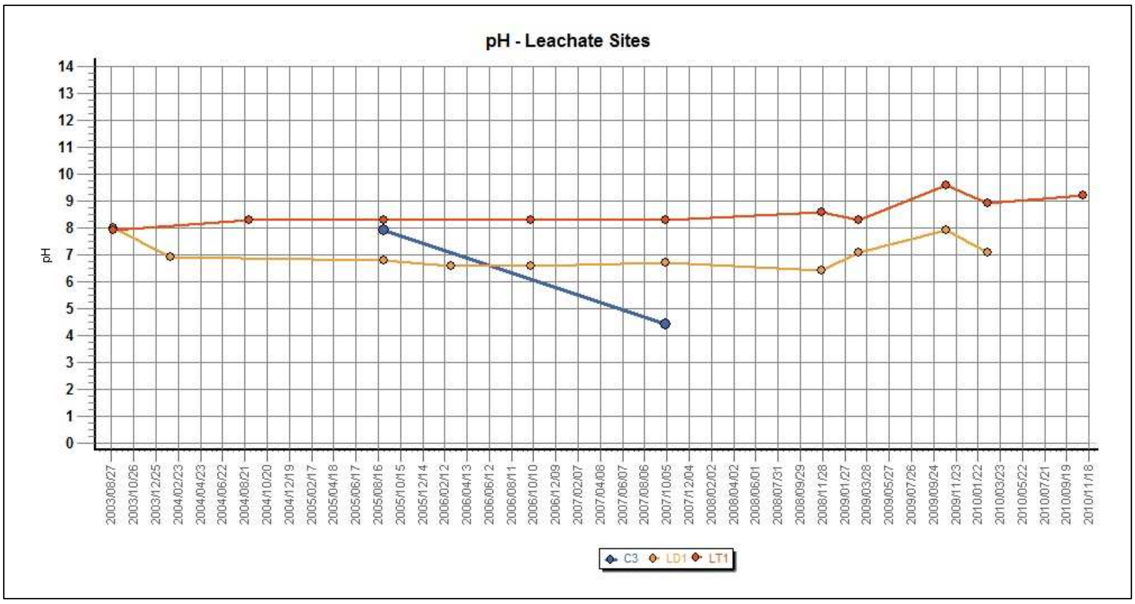

Figure 18: pH of Leachate Sites

The observed Fe and Mn concentrations correlate well with that of the borehole sites (Figures 19 and 20). At LD1 the Fe and Mn concentrations are between 5 – 60 mg/l and 0 – 0.80 mg/l respectively, whilst at LT1 the Fe concentrations are between 2 – 30 mg/l. Similar ranges in Fe and Mn concentrations were observed at BH5 and to a lesser extent BH7. The exception is at C3, where the Fe concentration of > 150 mg/l was recorded in 2007. However, Fe at BH4 was also > 150 mg/l during this period, which suggests that leakage from the stormwater compost window (C3) into the groundwater is occurring.

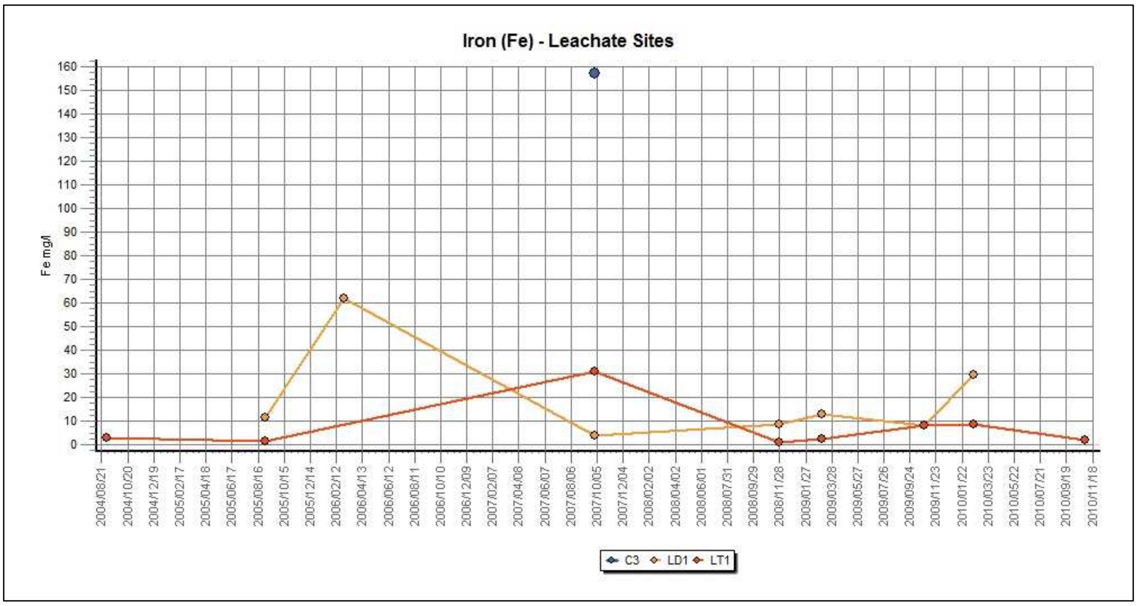

Figure 19: Iron (Fe) at Leachate Sites

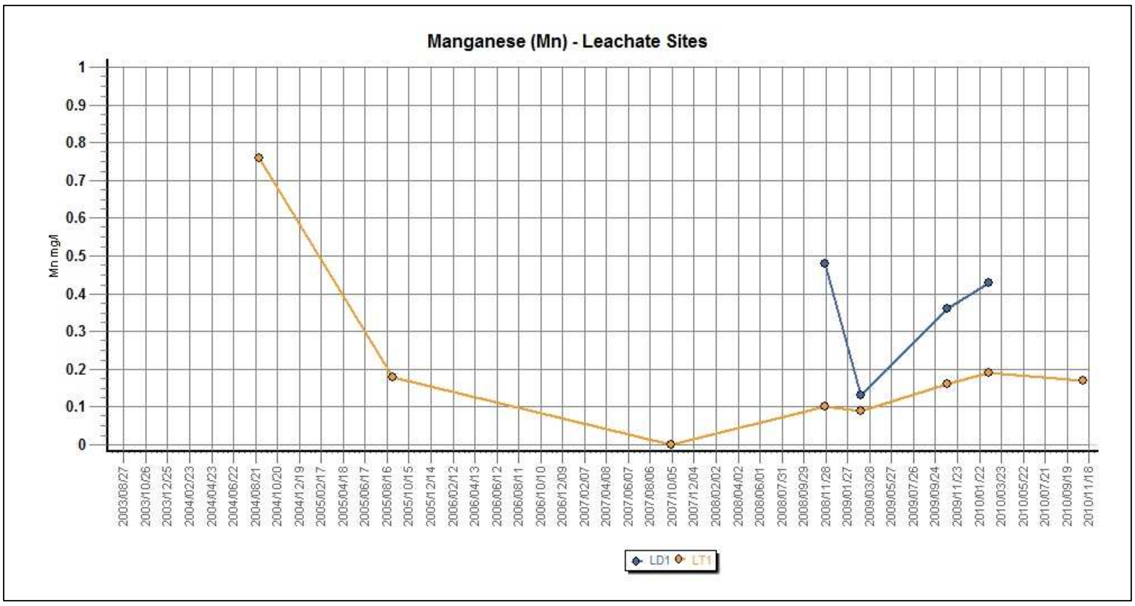

Figure 20: Manganese (Mn) at Leachate Sites

The NO_3 and NH_4 concentrations tend to fluctuate significantly at LT1, where a peak NO_3 and NH_4 concentrations of > 70 mg/l and 550 mg/l respectively were recorded in February 2010 (Figures 21 and 22). The NO_3 concentration at LD1 was only once over the 10 mg/l (i.e. maximum allowable concentration for domestic water purpose) mark during February 2009, whilst the NH_4 concentration is showing a steady decline to its latest level of < 10 mg/l.

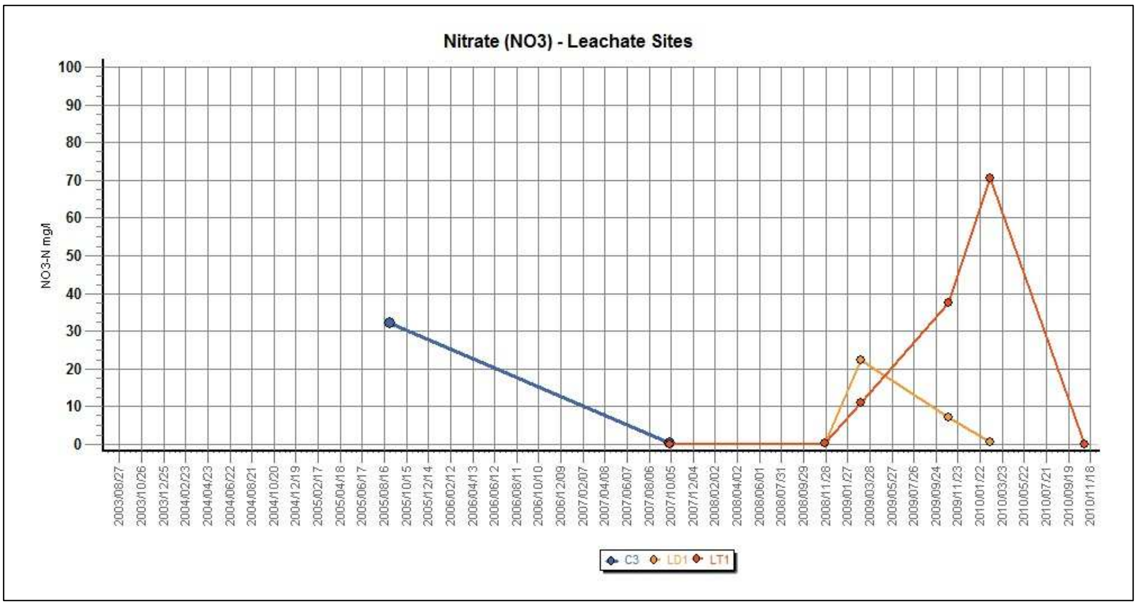

Figure 21: Nitrate (NO_3) at Leachate Sites

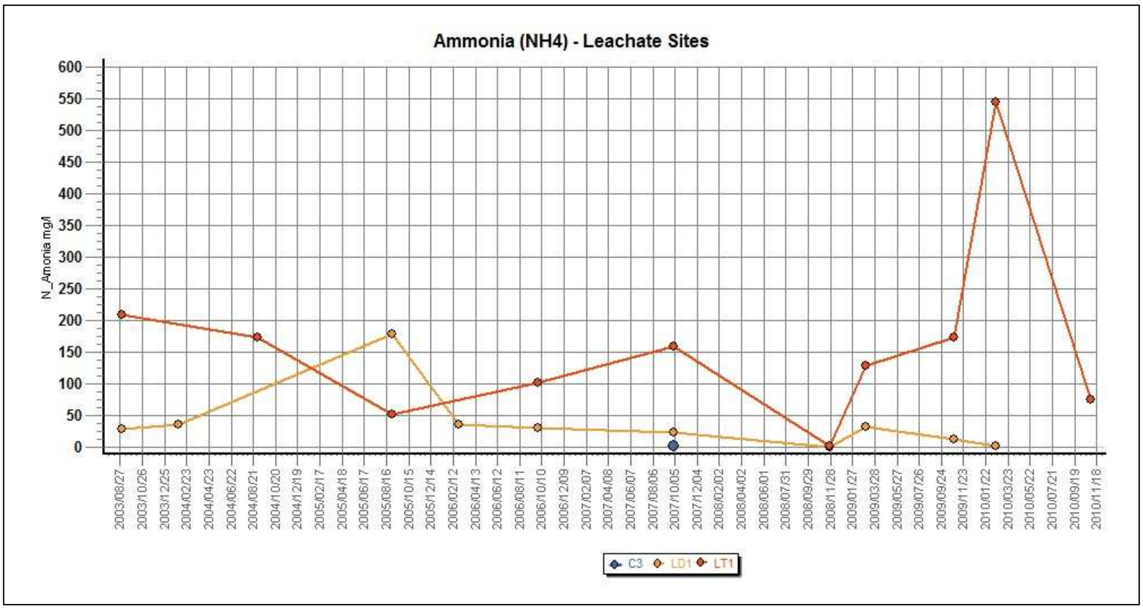

Figure 22: Ammonia (NH_4) at Leachate Sites

6.3 Surface Water Sites

The water chemistry of the 5 surface water sampling sites sampled at the Karwyderskraal Landfill Site is shown in Figure 23. SW1, SW4, SW5 and SW8 have similar water chemistries, i.e. sodium (Na) and chloride (Cl) dominant ions. The latter sites are almost completely deficient in bicarbonate (HCO_3). SW3 has a slightly different chemistry. Whilst SW3 also has sodium (Na) and chloride (Cl) dominant ions, it is also slightly bicarbonate enriched, which is generally indicative of a fresher water type. SW3 has a similar water chemistry than BH3 (see 6.1) and LD1 (see 6.2).

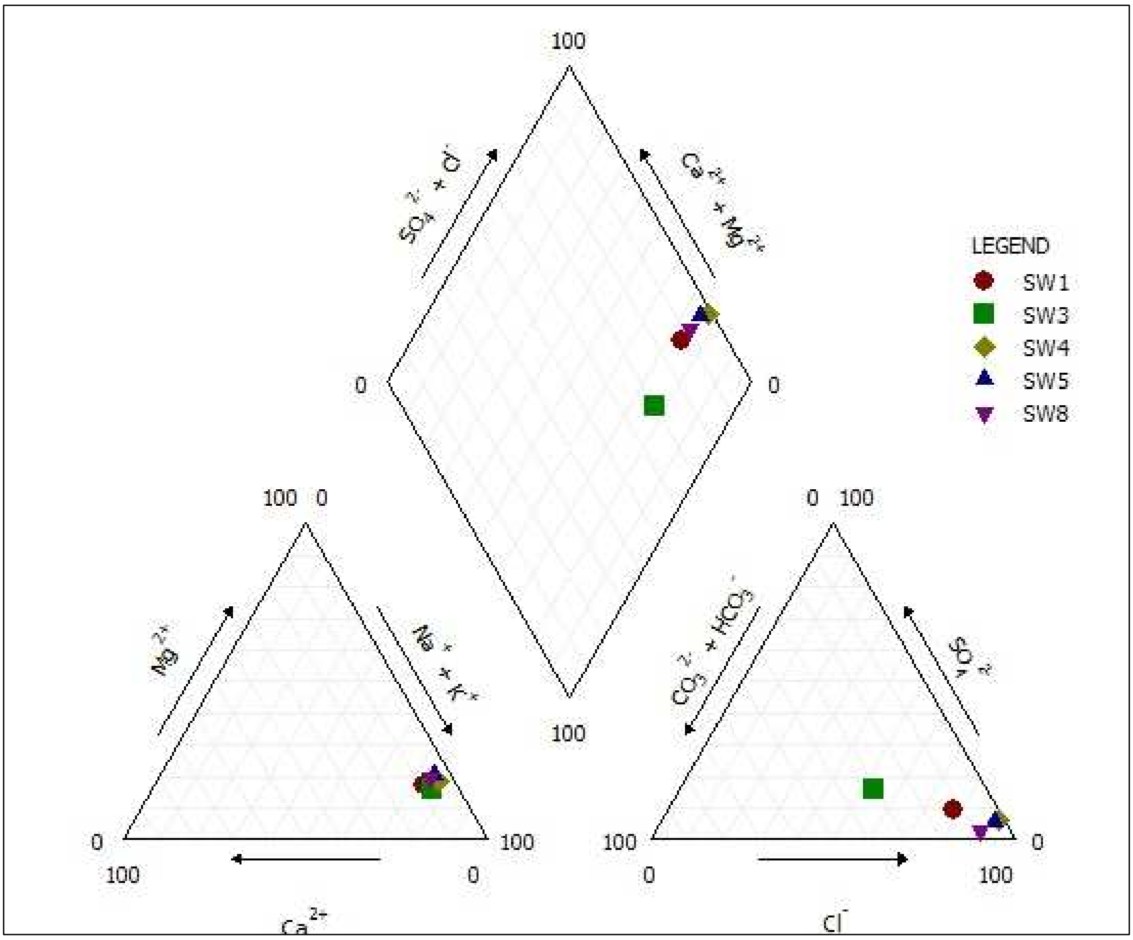

Figure 23: Piper Diagram of the Surface Water Sites

The EC at most of the surface water sites have similar trends (Figure 24). The only exception is at SW8. The EC at SW8 is generally at least 2 – 3 times greater than at all the other surface water sites. Since 2006, the EC at SW8 has increased steadily from about 200 mS/m to 450 mS/m. Note that the ECs at SW1, SW3, SW4 and SW5 vary between about 50 mS/m to 200 mS/m, but in some instances the EC might have been impacted by cattle grazing at these sites.

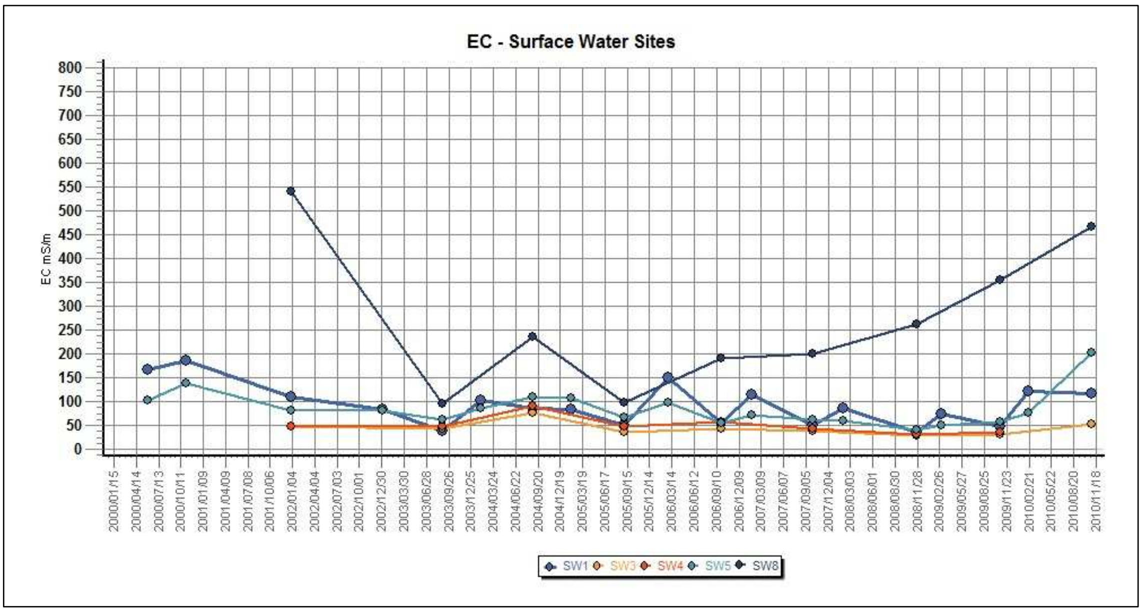

Figure 24: EC at Surface Water Sites

The pH at the surface water monitoring sites varies between 5 and 9 (Figure 25). The lowest pH of between 5.0 and 6.0 can be observed at SW3 and SW4, which is situated downstream of the Karwyderskraal Landfill Site. The pH at SW5 is slightly elevated at between 6.0 and 7.5. The pH at SW1 (upstream of Karwyderskraal Landfill Site) and SW8 (directly below the main Landfill area) are generally between 7.0 and 9.0.

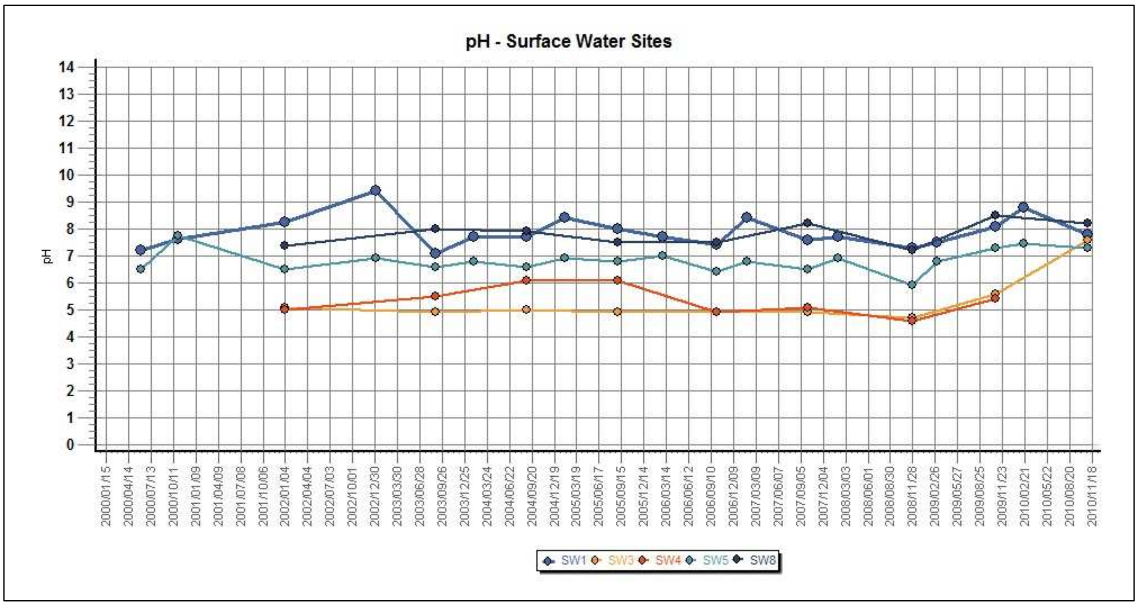

Figure 25: pH at Surface Water Sites

From Figures 26 and 27, the Fe and Mn concentrations are highest at the upper and lower most surface water monitoring points, i.e. SW1 (22 mg/l) and SW5 (16 mg/l) respectively. Ironically both these sites are enclosed water bodies (most if not all of the time) or non – flowing monitoring points, which could be prone to pollution from other sources such as cattle and human/farming activities. At the other monitoring sites, i.e. SW2, SW3 and SW8, the Fe and Mn concentrations are well below 5.0 mg/l. Hence, the periodic increase in the Fe and Mn observed at SW1 and SW8 are more likely to be related to another pollutant source other than the leachate from the Karwyderskraal Landfill Site.

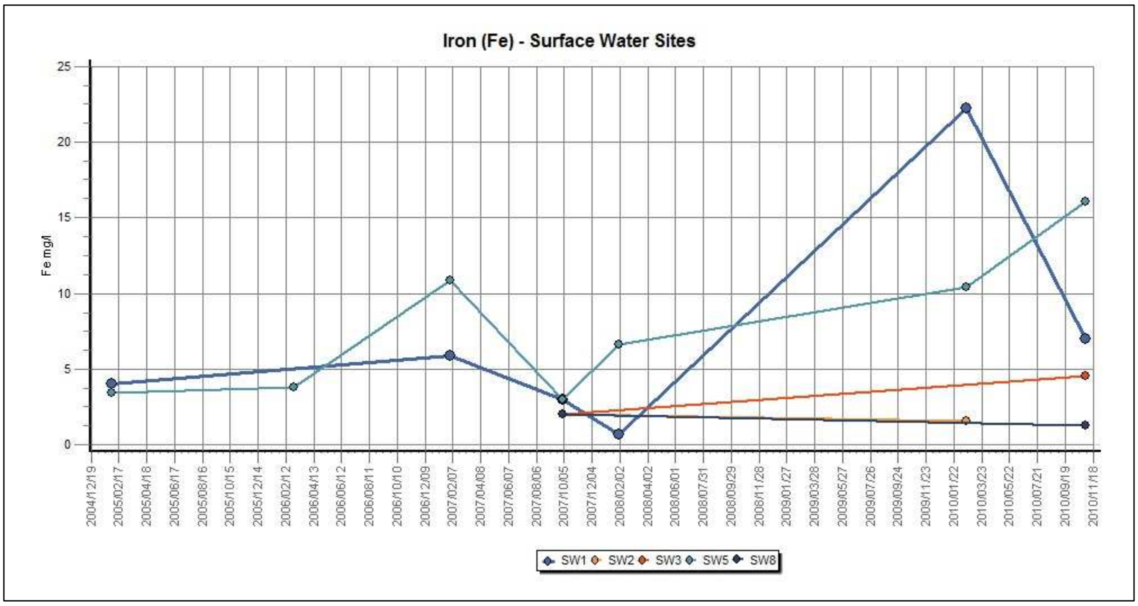

Figure 26: Iron (Fe) at Surface Water Sites

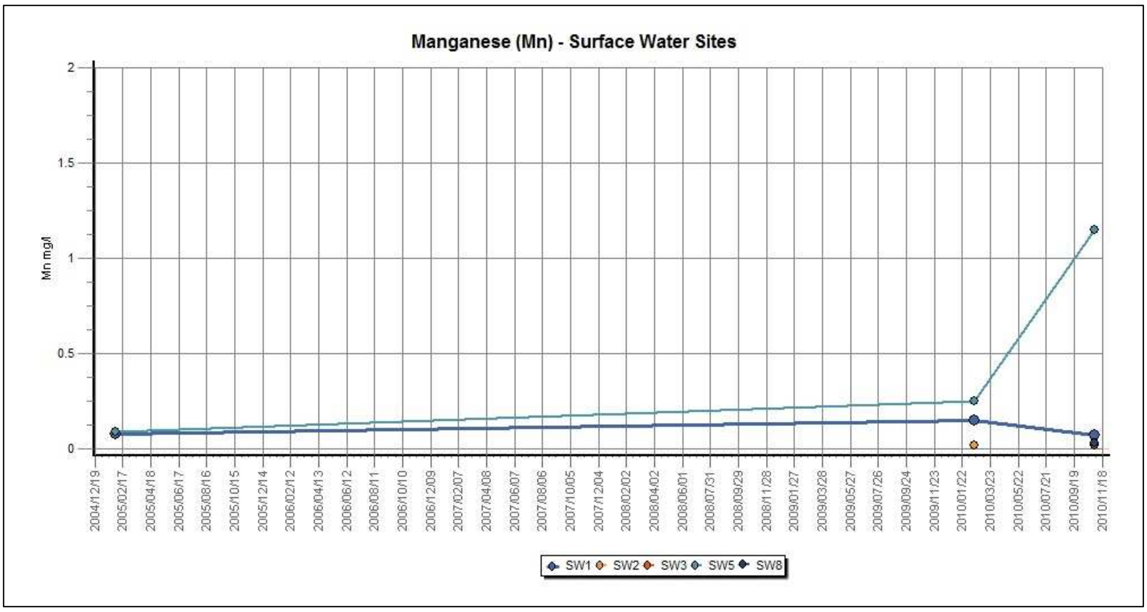

Figure 27: Manganese (Mn) at Surface Water Sites

A similar trend observed with the heavy metals (Fe and Mn) are observed with the NO_3 and NH_4 concentrations at the surface water sites (Figures 28 and 29). A periodic increase in the NO3 and NH4 concentrations were observed at SW1 and SW8 from end – 2009 to end – 2010. At all the other monitoring sites the NO_3 and NH_4 concentrations are both below 1.0 mg/l. The latter confirms that the surface water monitoring sites SW1 and SW5 could periodically become polluted by either cattle or human/farming activities, which is entirely independent from the Karwyderskraal Landfill Site. Closer to the Karwyderskraal Landfill Site, the monitoring sites SW2 and SW3 are not showing signs of any pollution. Surprisingly, SW8 is also not showing signs of significant NO_3 and NH_4 pollution since it is situated close to and downgradient of the main Landfill area.

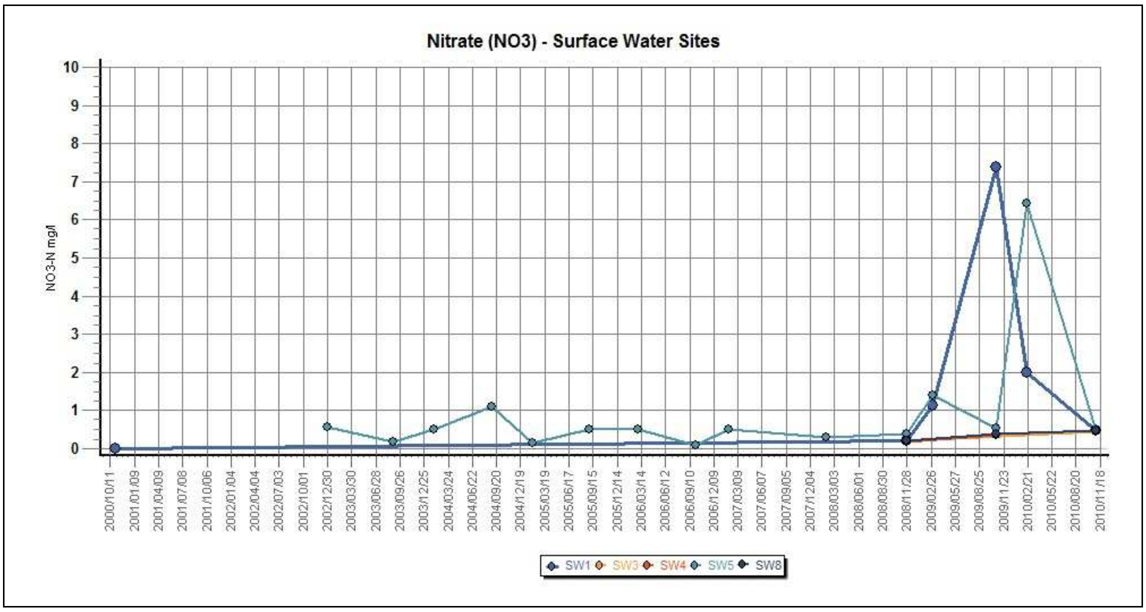

Figure 28: Nitrate (NO_3) at Surface Water Sites

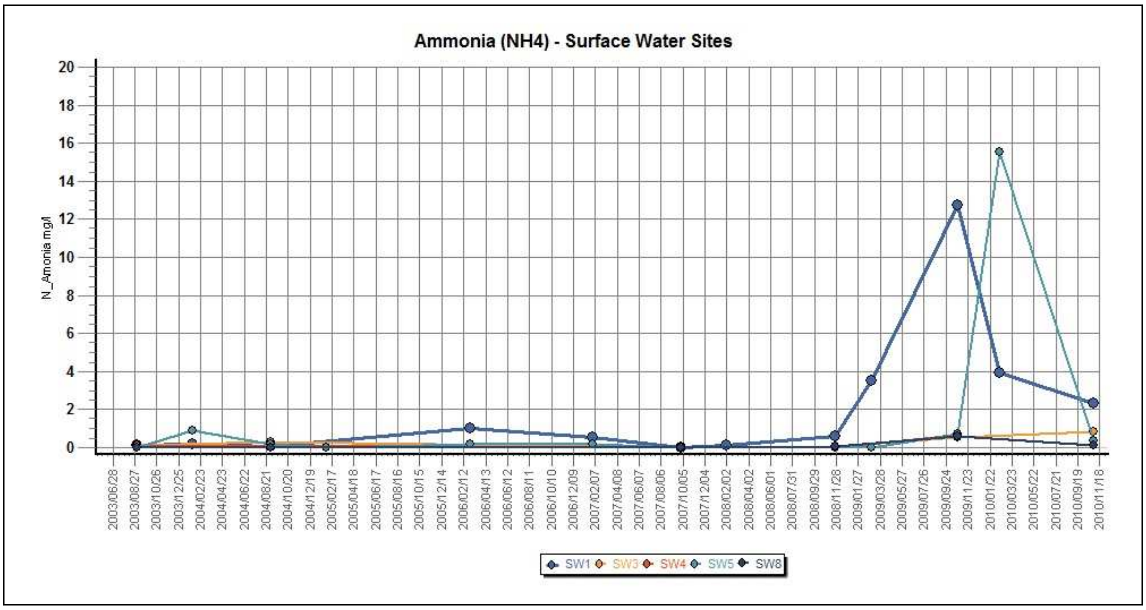

Figure 29: Ammonia (NH_4) at Surface Water Sites

7. CONCLUSIONS

An assessment of the groundwater levels suggests that a groundwater mound has developed below the main Landfill area since about November 2009, which has resulted in a reversal of the natural groundwater flow. Prior to the groundwater mound developing at the Karwyderskraal Landfill Site, the natural groundwater flow direction was from south (BH7) to north (BH4). Currently at the Karwyderskraal Landfill Site, the groundwater flow is now diverted in a southerly (towards BH4) and northerly direction (towards BH7) from the main Landfill area. The reason for the development of the groundwater mound is likely to be the artificial recharge of polluted water (leachate) from the Karwyderskraal Landfill Site since the latter is consistent with observations of the groundwater chemistry.

Evidence of low transmissivity and low storativity conditions at BH7 was observed during field sampling, when the borehole was pumped dry after < 5 minutes. The fact that there is a reversal of the natural groundwater flow upstream towards BH7 is not a major concern since the area in the vicinity of BH7 can be regarded as a non – aquifer. Since BH3, BH4, BH5 were able to pump for much longer than BH7, they are likely to have higher transmissivities than BH7. The latter implies that the water level at BH7 is likely to respond quicker to peak rainfall events and droughts, whilst the water levels at BH3, BH4 and BH5 have longer response periods (inertia). Since BH3, BH4 and BH5 are situated on more transmissive zones compared to BH7, they are more vulnerable to contamination from the Karwyderskraal Landfill Site than BH7. During the drilling of BH3, strong water was intersected at this borehole, which confirms the presence of a highly transmissive geological zone (possibly a fault). The spatial extent of the higher transmissive zone is difficult to delineate or visualise (even with the latest aerial photography) since the area at the Landfill has been modified. However, through pump testing it is possible to determine the magnitude and the approximate spatial extent of the higher transmissive zone/s.

The water chemistry results were used to determine the current status of each monitoring site and to assess whether the monitoring sites are being impacted by activities at the Karwyderskraal Landfill Site. For the groundwater monitoring sites, BH4, BH5 and to a lesser extent BH7 seems to be impacted by the on – site leachate pollution. BH4 and BH5 in particular have extremely high ECs (> 1000 mS/m over the last year), high concentrations in Fe and Mn, as well as elevated NO_3 and NH_4 concentrations. BH4 has a similar Fe concentration (footprint) than at stormwater compost site C3 (> 150 mg/l), which further implies a cumulative pollution effect at BH4 (leachate and occasional compost infiltration during overland flow conditions). BH5 and BH7 have similar Fe concentrations (footprint) than at LT1 and LD1. The fact that the EC at BH7 is steadily increasing, as well as the fact that the NH_4 concentrations are similar to that of BH4 and BH5 (i.e. about 3.0 mg/l), seems to suggest that BH7 has become impacted by on – site leachate pollution. BH3 seems to be unimpacted by leachate pollution since the ECs are low and stable (60 – 70 ms/m), and the Fe, Mn, NO_3 and NH_4 concentrations are relatively low. BH3 is likely to reflect the natural aquifer conditions and could be linked to an actively recharged fault system.

The surface water monitoring sites seems relatively unimpacted by the on – site leachate pollution. With the exception of SW1 and SW5, where minor localised pollution occasionally occurs through cattle and human/farming activities, only SW8 shows signs of leachate pollution. This is evident in the ECs, which generally tend to be between 2 – 3 times more than at the other surface water monitoring sites. Surprisingly, SW8 are not showing any signs of significant heavy metals or NO_3/NH_4 pollution. This could well be due to the effectiveness of the reeds in “purifying” the water.

Further to this, SW3 has similar water chemistry than BH3 and LD1. The area’s natural water chemistry is likely to be represented by the water at these 3 sites. BH3 and LD1 could also be hydrologically linked. It is likely that a positive hydraulic gradient exists from BH3 towards the Landfill Site, which could be the reason why BH3 is not showing signs of leachate contamination. A reversal in this hydraulic gradient (caused by pumping at BH3) could result in severe leachate contamination at BH3.

It is imperative that the monitoring at the Karwyderskraal Landfill site is continued to broaden the knowledge base of this integrated monitoring system.

A very comprehensive monitoring database has now been established, which is vital to our understanding of the systems.

8. RECOMMENDATIONS

The following recommendations are provided:

- Drill replacement boreholes for BH1 and BH2.
- Survey accurate borehole elevations for all current and future boreholes.
- Compile a groundwater flow net based on accurately surveyed borehole and water level elevations to assess the extent of the groundwater mound below the main landfill area.
- Future monitoring at LD1 and BH3 must be handled with care. Any significant signs of contamination at LD1 must be mitigated immediately to prevent the leakage of contaminants to BH3.
- BH3 must not be used as a production borehole as this could reverse the groundwater flow direction from the Landfill Site towards BH3.
- Pump BH5 to reduce the groundwater mound below the main landfill area and restore the natural flow of groundwater.
- Test the suitability of BH5 for plant composting or irrigation purposes.
- Remove blockage from downpipe at LD1.
- Expand the monitoring network to the west of the main Landfill area.
- On – site monitoring must be continued and must include the maintenance of a monitoring database.
- Leachate removal must be continued.
- Include the flow monitoring of surface water sites where possible.

9. ACKNOWLEDGEMENTS

The following people are gratefully thanked for their input and assistance during this project:

- Mr. Francois Kotze of ODM.
- Mr. Dudley Rowswell of ARC.
- Mr. Ivor Wolmarans (Independent GIS Consultant).

10. REFERENCES

DWAF (1999). Department of Water Affairs and Forestry, Department of Health, Water Research Commission, 1998. Quality of domestic water supplies, Volume 1: Assessment Guide.

GEOSS (2010). Karwyderskraal (GMB+) Landfill Facility Groundwater and surface water monitoring report - Sampling 18 February 2010. GEOSS Report No. 2010/03-07

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APPENDIX A: WATER CHEMISTRY

Report No.: **NR15521/2010**

ANALYSES REPORT

Regan
BMK Engineering Consultants
P.O. Box 13581
N1 City
7463

Date received: 08/11/2010
Date tested: 10/11/2010

Reference No.	Lab. No.	Alkalinity mg/l	NH4-N mg/l	HCO3 mg/l	Ca mg/l	Cl mg/l	EC mS/m	F mg/l	Fe mg/l	Mg mg/l	Mn mg/l	NO2-N mg/l	NO3-N mg/l	pH	P mg/l	K mg/l	Na mg/l	SO4 mg/l	COD mg/l	DOC mg/l	Cu mg/l	Cr mg/l
LT1	15521	2886.500	75.30	4746.41	39.06	4877.91	2070.00	6.10	2.065	164.90	0.17	1.21	0.00	9.2	6.33	1041.22	1626.67	619.42	4450	395.00	0.006	0.183

Reference No.	Lab. No.	Pb mg/l
LT1	15521	0.000

Sample conditions
Samples in good condition.

Statement
The reported results may be applied only to samples received. Any recommendations included with this report are based on the assumption that the samples were representative of the bulk from which they were taken. Opinions and recommendations are not accredited.

Dr. W.A.G. Kotzé
....
for BemLab

12-11-2010
....
Date

Technical Signatory: Dr. W.A.G. Kotzé
Arrie van Deventer (Chemical Analyses)
Annerina Esterhuyse (Microbiology)

Report No.: **NR15522/2010**

ANALYSES REPORT

Regan
BMK Engineering Consultants
P.O. Box 13581
N1 City
7463

Date received: 08/11/2010
Date tested: 10/11/2010

Reference No.	Lab. No.	Alkalinity mg/l	NH4-N mg/l	HCO3 mg/l	Ca mg/l	Cl mg/l	EC mS/m	F mg/l	Fe mg/l	Mg mg/l	Mn mg/l	NO2-N mg/l	NO3-N mg/l	pH	P mg/l	K mg/l	Na mg/l	SO4 mg/l	COD mg/l	DOC mg/l
BH3	15522	114.958	1.70	211.29	32.22	89.87	64.90	0.74	0.089	8.21	0.14	0.00	0.46	8.5	0.03	14.35	88.79	123.64	7	9.60
BH4	15523	2.008	0.56	7.66	88.53	3520.98	1111.00	0.63	137.946	202.47	3.30	0.03	0.46	4.5	0.00	8.77	1419.45	414.77	51	7.20
BH5	15524	55.220	0.40	75.02	75.26	3418.77	1079.00	0.30	23.422	236.49	0.41	0.12	0.46	6.4	0.01	5.45	1436.24	365.91	49	9.70
BH7	15525	27.610	0.27	49.00	34.43	841.48	281.00	15.50	1.610	76.58	0.77	1.02	0.49	6.6	0.04	5.82	403.10	159.30	1055	12.20
SW1	15526	87.348	2.31	131.67	20.44	307.51	116.30	0.90	7.006	23.14	0.07	0.06	0.47	7.8	0.13	28.85	173.25	48.14	137	26.90
SW3	15527	128.010	0.81	52.06	8.74	128.64	52.30	0.24	4.516	11.33	0.02	0.10	0.46	7.6	0.00	6.36	101.51	51.93	60	16.60
SW5	15528	35.140	0.35	68.90	15.42	612.38	202.00	0.95	16.068	41.62	1.15	0.08	0.48	7.3	0.05	7.81	295.84	46.76	144	28.40
SW8	15529	218.370	0.13	369.00	49.60	1356.93	467.00	1.27	1.295	94.84	0.03	0.02	0.48	8.2	0.01	59.84	655.06	59.42	115	27.10

Sample conditions
Samples in good condition.

Statement
The reported results may be applied only to samples received. Any recommendations included with this report are based on the assumption that the samples were representative of the bulk from which they were taken. Opinions and recommendations are not accredited.

Dr. W.A.G. Kotzé
....
for BemLab

11-11-2010
....
Date

Technical Signatory: Dr. W.A.G. Kotzé
Arrie van Deventer (Chemical Analyses)
Annerina Esterhuyse (Microbiology)

(Last page)