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Chemical and Biological Hazards
Report CR/06/201N

BRITISH GEOLOGICAL SURVEY

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Foreword

This report is the published product of a study by the British Geological Survey (BGS) to assess whether or not the Houghton Quarry Landfill is impacting on groundwater quality.

Acknowledgements

A number of individuals in BGS have contributed to the project. This assistance has been received at all stages of the study. In addition to the collection of data, many individuals have freely given their advice, and provided the local knowledge so important to improving the conceptual model for the site. Of the many individuals who have contributed to the project we would particularly like to thank the following: Martin Culshaw, Ben Klinck and Helen Taylor. We would also like to extend our thanks to J.R. Maxwell (Biffa Waste Services Limited Site Manager, Houghton Quarry Landfill) for arranging permission to include the Biffa Waste Services Limited borehole location plan.

Contents

FIGURES

TABLES

APPENDICES

Summary

This report describes a groundwater investigation and monitoring audit of the Houghton Quarry Landfill, Houghton-le-Spring, Northumberland. The investigation was undertaken to establish whether there is any evidence of landfill contamination from Houghton Quarry polluting groundwater. In addition to achieving this aim the investigation has identified groundwater contamination focused on the area of Borehole J2.

Having established that the groundwater contamination in this isolated area of the site does not appear to emanate from the landfill, the source-pathway-receptor paradigm was applied to the results of the investigation and the findings indicate:

1) Sources: Potential sources of contaminants include contaminants resulting from activities associated with the concrete batching and soil recycling areas; the significant thickness of made ground that underlies at least part of the area and the presence of a former colliery yard to the south of the site entrance. Additional potential sources of contamination include minor sources from road salting and the agricultural application of herbicides and pesticides outside the landfill boundaries.

2) Pathways: Pathways are likely to be guided by the zones of recharge, the occurrence of faults and the regional hydraulic gradient. Pathways may also be influenced by dissolution of the limestone.

3) Receptors: The groundwater aquifers, with particular concern for the public water supply at Stoneygate Pumping Station and the outer sources protection zone. The site is situated in the total catchment protection zone. In addition, the hydrogeological risk assessment (ESI, 2003) identified a hypothetical receptor, comprising an agricultural abstraction well on the boundary of the site.

A number of recommendations arise from the audit of the monitoring being carried out by Biffa Waste Services Limited. These are primarily focused on improving the reliability of the data generated during monitoring, in order to achieve earlier refinement of the monitoring suites for the site. They include recommendations with respect to field sampling procedures, laboratory testing and data interpretation.

A number of recommendations also arise from the analysis of the results of the investigation. These are primarily focused on the identification of point sources of contamination, including the occurrence of pesticides at specific locations, including the location of Stoneygate Pumping Station, the suspected occurrence of road salt contamination in specific boreholes and the potential sources associated with the area of Borehole J2.

Consideration has been given to the potential for refining the conceptual model for the site. However it is concluded that this would be unlikely to impact on the current conclusions with respect to the impact of the landfill site on groundwater quality.

Examination of both the findings of this groundwater investigation and the results of historical monitoring has not identified any measurable impact of the landfill on groundwater quality.

1 Introduction

The British Geological Survey was commissioned by the Environment Agency to undertake a groundwater investigation to assess the extent of any impact of the Houghton Quarry Landfill. This work was required to address allegations from a local pressure group: Residents Against Toxic Sites (RATS), that the site is polluting groundwater. Located at National Grid Reference NZ 342507, Houghton Quarry Landfill is an engineered site, which is operated by Biffa Waste Services Limited and is licensed to accept non-hazardous wastes.

Following preliminary discussion with the Environment Agency and the submission of a bid for the work, six tasks were identified to both assess the impact of the site on groundwater and verify the quality of the existing data sets:

- To identify a laboratory that could carry out the required range of tests and achieve specified lower detection limits
- Review the existing procedures for leachate sampling and groundwater sampling and undertake a sampling audit
- Arrange sample analysis
- Assess historical temporal concentration characteristics of the groundwater
- Review the existing hydrogeological risk assessment
- Provide an interpretative report

This report presents the work associated with each of these tasks and also identifies additional activities that could be considered to further the understanding of the site.

It is understood that Houghton Quarry Landfill has been subject to a number of phases of investigation. However, the BGS has not been furnished with all of the preceding information, because the Environment Agency requirement was for an independent view of the site.

1.1 REPORT STRUCTURE

The first part of the report introduces the project and the context in which it was undertaken. The report continues with a consideration of published information with respect to the site, and then describes the fieldwork, audit and laboratory testing that was carried out. The results of the laboratory testing are described in terms of both the data quality and in terms of leachate and groundwater characterisation. A conceptual model for the hydrogeology of the site has been derived from the assessment of both the current and historic monitoring undertaken at the site. The conceptual model has enabled a number of conclusions with respect to the impact of the site to be made and the reporting of these is followed by recommendations for further work, which could potentially contribute to a greater understanding of the site.

2 Site Context and Published Data

2.1 GEOGRAPHY AND TOPOGRAPHY

As the name suggests, Houghton Quarry Landfill occupies a former quarry that was worked for limestone and was operated by ARC. The former quarry lies immediately to the north of the northern extent of the developed area of Houghton Le Spring in County Durham, in the order of 6 km to the south-southwest of Sunderland. The quarry is situated (National Grid Reference NZ 342507) immediately to the north of Houghton Hill. The hill is formed between two southwesterly-trending valleys. It is interesting to note that the alignment of the valleys is coincident with fault alignment (subsection 2.2). The regional topography is gently undulating, with a number of valleys, accommodating surface drainage and following a similar alignment, trending northeast towards the coast.

Houghton Quarry Landfill is an active site, which occupies an approximately rectangular area in the order of 500 m by 390 m, with the long axis orientated approximately northeast to southwest, parallel to the valley axes. Examination of the 1: 25 000 Ordnance Survey sheet indicates that the natural surface drainage is in a westerly direction towards Moors Burn and Lumley Park Burn to the River Wear. However, there does not appear to be any surface expression of the drainage in this area, which suggests that it is carried away via a system of artificial drainage. There is also a stream that is referred to as Grasswell Burn in a valley immediately to the north of the site. This drainage, via an open ditch, also flows in a westerly direction towards Moors Burn.

A Sitescope report was obtained for the preparation of the PPC application site report (Enviros Consulting, June 2003). This identified eight former landfill sites located within a 1 km radius of the site (centred on National Grid Reference NZ 342507), primarily to the north, southeast and northwest of the site. The location and waste type associated with each of these sites is detailed in the site report (Enviros, 2003).

2.2 SITE HISTORY

The limestone quarry was formerly operated by ARC (Enviros, 2003). It is understood that the landfill has been in operation since 1997 (Environmental Simulations International Limited, 2003). Prior to the issue of the PPC permit in August 2004 The waste management licence (TW 134SL) permitted the disposal of hazardous and non-hazardous wastes. Since the issue of the PPC permit the site has only been licensed for the disposal of non-hazardous wastes.

2.3 GEOLOGY

The 1: 50,000 scale British Geological Survey Sheet 21 *Sunderland* (Solid and Drift edition) shows the area to be covered with a superficial covering of undifferentiated Boulder Clay (till) and Drift, with Glacial Sand and Gravel Deposits closely associated with the valleys. The excavation of the quarry has exposed the solid geology, which the geology sheet (British Geological Survey, 1978) shows to be Lower Magnesian Limestone (with Marl Slate at the base) underlain by Basal Permian (Yellow) Sands, in turn resting unconformably on Westphalian strata (Coal Measures). Surface distribution of the solid geology indicates an easterly dip (in the order of 2 degrees) of the strata. As a consequence of the easterly dip of the strata the Basal Permian Sands form the bedrock exposed immediately to the west of the site and reaching an increasing depth beneath the site, to the east.

Lower Magnesian Limestone, which in the area of Durham is referred to as the Raisby Formation, generally occurs as a buff coloured, bedded, fine grained calcitic dolomite, which shows evidence of slumping and has been interpreted as an offshore and basin slope deposit (British Geological Survey, 1978). Where the Marl Slate is present it comprises buff to dark grey unevenly laminated silty carbonaceous dolomite, with thin limestone and dolomite beds, interpreted as an offshore and basin-slope deposit (British Geological Survey, 1978). Smith (1994) describes a lower unit of dark grey to black, bituminous finely laminated, silty argillaceous dolomite or dolomitic shale, overlain by a thicker unit of less finely laminated, slightly bituminous, silty, dolomite. The thickness of the Marl Slate ranges between 0.8 and 2.6 m, but locally it is absent.

The Basal Permian Sands comprise medium to fine-grained sands with some calcite and dolomite cement. They are coarsely cross-laminated, except at the top where planar bedding occurs and have been interpreted as the product of a desert dune environment.

Analysis of the stress field of the district is incomplete. It lies to the east of the Alston Block, with uplift being influenced by the Weardale Granite, which lies to the west of the region. The structure of the Carboniferous rocks is more complex than that of the overlying Permian rocks and the faulted displacement of Permian strata is generally considerably less and simpler than that of the Carboniferous strata. Faulting of the Carboniferous rocks has largely been interpreted from mining record plans. Faulting is dominated by normal faulting that falls within three main groups: NNW-SSE, SW-NE and W-E. The NNW-SSE faults are the least continuous and the displacement tends to be greatest on the E-W faults (Smith, 1994). The site is situated between two major faults, the Seaham Fault, which is an E-W trending fault situated immediately to the north of the quarry and the Houghton Cut to the south. In correspondence with Sunderland Council (23 November 2000) the District Geologist noted that there is evidence of "*some hitherto unrecorded smaller scale faulting within the area of the present quarry*".

2.4 HYDROGEOLOGY

At the time of the preparation of this report there was no hydrogeology sheet available for the area of Durham. The following description of the properties of the strata is largely derived from Allen et al. (1997).

Magnesian Limestone forms an essentially unconfined, major aquifer. Recharge areas predominate along the western outcrop of the aquifer, however some recharge also occurs through the drift deposits, where flow paths associated with surface water sources have developed (Cairney and Hamill, 1977). The regional hydraulic gradient is to the east (Younger, 1994). The boundary between the Magnesian Limestone and the underlying Yellow Sand coincides with the western side of the site. A plot of water levels indicates the groundwater level to be in the order of 60 m AOD in the vicinity of the site, reducing to sea level at the coast. Younger (1994) reported that there has been a general rise in groundwater levels in the area of Durham, which has occurred over the last twenty to thirty years as abstraction along the coast has been reduced. In addition, dewatering of coal workings has also been reduced, thereby contributing further to the rise in groundwater levels. Characteristically, the Magnesian Limestone is heavily fractured and in the area to the east of Durham cavernous; as a consequence the hydraulic conductivity (and transmissivity) of the limestone is variable. There is very little published information available with respect to the analysis of core samples, or field-testing; the data that is available confirms the variability in hydrogeological properties, with transmissivities ranging between 2200 m^2/day and 11 m^2/day (Allen et al., 1997). The highest transmissivity values are associated with fault zones. Allen et al. (1997) report that the hydraulic conductivity of the Lower Magnesian Limestone aquifer is less than 5 m/day and that there is a variation in hydraulic conductivity with depth, suspected to reflect the presence of more massive and sometimes calcitic beds at the base of the formation.

The glacial drift generally comprises stiff, stoney clays of low vertical permeability, which can be up to 80 m in thickness. The presence of a thick unsaturated zone combined with a deep water table may impart a significant influence on recharge.

3 Existing Site-Specific Data

3.1 GROUNDWATER MONITORING WELLS

There have been a number of phases of groundwater monitoring well construction, however BGS is not in receipt of all the associated documentation. It is understood that early installations were carried out by WEEKS (Consulting Engineers and Environmental Scientists), who were responsible for the design of the landfill. The latest phase of well installations was carried out under the supervision of ESI Ltd and a summary of the detail with respect to the monitoring wells has been prepared by Biffa Waste Services Limited in response to a request made by the British Geological Survey (Appendix 1). Locations are shown in Appendix 10.

3.2 HYDROGEOLOGICAL RISK ASSESSMENT

A hydrogeological risk assessment of the landfill site was undertaken by Environmental Simulations International Limited (ESI, 2003). Modelling was carried out using the ESI software package RAM, a spread sheet-based quantitative stochastic risk assessment model, combining contaminant transport pathway analysis with Monte Carlo based parameter uncertainty modelling.

The leachate quality that was assumed in the modelling was that of another Biffa Waste Services Landfill site, namely Howley Park Landfill. Derived from this, three List 1 substances (pentachlorophenol, tributyltin and mercury) were selected for modelling, as well as chloride and ammonium. This phase of monitoring has identified that the List 1 substances have not been recorded in the current leachate chemistry. The majority of the base of the site has been lined with a basal flexible membrane and 1 m thick clay seal, however the entirety of the base of Phase 1 is not lined with the flexible membrane, more specifically an area that is referred to, as the extension of Phase 1 has not been lined with the flexible membrane, although the clay seal has been installed across the entirety of the landfilled area. The design of the steep sidewall engineering for Phase 1 also differs to that of the other phases in that the flexible membrane abuts polystyrene that is backed by a compacted granular backfill, rather than a clay seal, which has been used for the other phases. Receptors used in the model are theoretical agricultural wells abstracting water at 20 m^3/day at the site boundary and abstracting from both the Raisby Formation and the underlying Yellow Sand Formation.

A conservative approach to the design has been taken in the sense that no unsaturated zone processes have been incorporated in the model and dilution is assumed to be the only attenuating process that is in operation. The model assumes that the Raisby Formation is isolated from the Yellow Sands Formation by the Marl Slate, which is a conservative measure because it restricts the potential for dilution in the aquifer. Furthermore, the modelling was based on leachate strength and composition derived from mature leachate analyses from other sites, without any provision for leachate management to maintain leachate levels to the maximum 1 m head of the site design. It has also been assumed that the leachate can move freely within each component of the landfill. Although Construction Quality Assurance Procedures are being followed during the installation of the site sealing systems, the model also includes a representation of defects in both the cap and the liner.

The area of greatest uncertainty with this model probably lies in the hydraulic properties that have been assumed. The values that have been used are based on limited hydraulic testing that was carried out by WEEKS. For the Raisby Formation a hydraulic conductivity of 0.086 m/day was adopted, which falls marginally outside the test results (0.034 to 0.08 m/day) and for the Yellow Sands Formation a triangular distribution of results in the range 0.00864, 0.0864 and 273 m/day. The literature review identified a hydraulic conductivity of less than 5 m/day for the Magnesian Limestone (Allen et al., 1997), so the arithmetic mean of the measured values indicates a high hydraulic conductivity. A hydraulic gradient of 0.01 has been adopted for the Raisby Formation and 0.08 for the Yellow Sand Formation. Gradients calculated from the current data set are approximately 0.01 for the Raisby Formation and 0.005 for the Yellow Sand Formation.

Another area of uncertainty, but one that lies outside the assumed model boundaries is the understanding of the influence of the faults on the groundwater regime of the site (subsection 6.5).

3.3 GROUNDWATER MONITORING

Environmental Simulations International Limited (ESI), acting for Biffa Waste Services Limited prepared a protocol for monitoring surface and groundwater at Houghton-le-Spring Landfill (ESI, 2004). At the time of reporting ESI noted that as a working document the protocol should be subject to revision in accordance with: up-dates to Environment Agency guidance (Environment Agency, 2001); and also one year after the preparation of the initial report, following consultation with the Environment Agency. Although this does not appear to have been carried out, Biffa Waste Services advised BGS that there were practical differences between the protocol and the actual site procedures and provided a list of amendments to the protocol (Appendix 2).

Ten new boreholes were installed in January 2004 and ESI (2004, Table 3.1) details all of the boreholes that are currently scheduled for monitoring. These include: GW9; RJ1; J2; K1; GW8; L1; L2; H1; H2; M1; M2; F1; F2; A1; A2; B1; RB2; N1; N2; BH2 (re-drill); G1; G2; BH1 (re-drill); RI1; I2 and GW10. The complexity of the numbering system reflects the various phases of borehole installation. Biffa Waste Services Limited has another unique, consecutive numbering system (commencing with 58502001), however the old numbering systems have remained in use. Some of the detail presented in Table 3.1 (ESI, 2004) is not correct, for example the diameter of the installations in boreholes H1 and H2 are 50 mm, rather than 110 mm. BGS requested that Biffa Waste Services provide a revised table of boreholes, which includes the response zones of each of the wells. This table has been presented in Appendix 1.

The monitoring schedule for the boreholes and surface water monitoring points (the pool in the base of the quarry and Grasswell Burn) was agreed with the Environment Agency. This includes monthly determination of groundwater level, pH, Electrical Conductivity, Chemical Oxygen Demand, Dissolved Oxygen, ammonia and chloride and quarterly determination of a more extensive range of determinands. Mercury, cadmium and cyanide are analysed annually.

The number and position of the boreholes would appear to give good coverage in terms of the potential flow vectors. However, the plot of groundwater contours indicates that it is difficult to confidently define up-hydraulic gradient boreholes (subsection 6.3 and 7.4). BGS was not provided with the information that relates to the positioning or the scheduling of the depths of the boreholes and does not have access to information with respect to the recharge processes operating in the limestone, therefore cannot comment on these aspects of the monitoring regime. However discussion with the Environment Agency has identified that some of the latest phase of boreholes were positioned to try and identify the influence of faulting on the groundwater regime of the site.

3.4 REPORTING OF GROUNDWATER DATA

Groundwater levels are reported to the Environment Agency in electronic format. More recently the data has been reported in a time-series format, which is beneficial for analysis.

Historic groundwater level monitoring data was provided by the Environment Agency. Some of the data had been subject to alteration, owing to errors associated with the interpretation of the datum level. Upon examination, it became evident that there were also differences in ground levels reported by Biffa Waste Services Limited and those reported by ESI (2004) and that there are differences in the Biffa Waste Services datum level data-sets (BEDS, recent survey, ESI data and BHL datum level, Appendix 1). Furthermore, the ground levels presented in these data-sets do not correspond with the ground levels determined at the time of boring. Accurate datum levels are essential for analysing the hydraulic gradient and the difficulties associated with the data that was provided is evident in the plots of groundwater contours presented in Appendix 4. It should be noted that the ground level at borehole positions M1 and M2 had not been recorded in the recent survey dataset, instead it was noted that the datum level was raised in January 2006. The Environment Agency were advised of the problems associated with the datum levels and in response to a request from the Environment Agency, Biffa Waste Services Limited arranged for a level survey to be carried out. Accordingly, it is understood that the values presented in Appendix 5 are correct.

The chemical data is reported to the Environment Agency in an electronic AGS format, which makes temporal monitoring of the data clumsy, selected parameters were converted to a time series format. Since this work was carried out Biffa Waste Services Limited have re-issued much of the data in a time-series format, which is essential for temporal analysis and the on-going assessment of future monitoring of the site.

3.5 ADDITIONAL SOURCES OF INFORMATION

Reference has been made to the BGS Research and Development Project Report W6/i722/7 (Brewerton and Edmunds, 1997) for baseline groundwater quality for the Magnesian Limestone of Northumbria (Section 6.1). Where appropriate reference has also been made to drinking water standards, Environmental Quality Standards and to the Internet-based resources as a source of information with respect to specific determinands.

The British Geological Survey has been involved in a number of phases of research with respect to the faulting in the area of Houghton-le-Spring. More specifically, investigation of fissuring which has caused damage to the carriageway within Houghton Cut on the A690 road, immediately to the east of Houghton Quarry Landfill, has been carried out (Cuss and Beamish, 2002; Cuss and Thompson, 2003; Young and Culshaw, 2001; Young and Lawrence, 2002; and Young, 2003). Fieldwork and examination of the abandonment plans of coal workings beneath the area indicated a close spatial relationship between the occurrence of structural damage and the position of faults, both in the Magnesian Limestone and the underlying Coal Measures. The evidence was consistent with ground movement resulting from reactivation of pre-existing faults. The results of the geophysical investigation indicate that the fissuring is heterogeneous along its length, i.e. in some places it has opened; whilst in other places the fissure is closed. The results of the geophysical surveying, in particular comparison of surveys carried out in May and November 2003, indicate that the fissuring is active.

Young (2003) reported that the results of current investigations indicate that fissuring within the Magnesian Limestone is widespread in the area and that it is typically most abundant in the hanging wall zone of known faults, particularly those with an east-west trend.

Evidence from the fissuring in the A690 carriageway indicates that fissures may appear suddenly. Detailed investigation to the west of the Houghton Cut (Young and Lawrence, 2002), which identified that the surface features discovered in this area are “some of the most striking found in this investigation" (Young and Lawrence, 2002, p3 and Table 1), suggests that the line of the most recent phase of fissuring lies immediately to the south of the landfill site.

Young (2003) makes reference to a network of GPS monitoring equipment installed in the Houghton-le-Spring area by the School of Civil Engineering and Geosciences, University of Newcastle upon Tyne. Potentially this could be a useful source of information on the ground movement and may contribute to the interpretation of the risk of ground movement in the area of the landfill.

Table 1: Surface effects of fissuring in ground west of Houghton Cut, recorded by Young and Lawrence, 2002.

National Grid Reference	Observation
NZ 34350 50464	Prominent gully extending several metres west from western edge of cutting. Open fissure up to 1.1 m wide and up to several metres deep at its eastern extremity immediately above cutting. Paired fissures separated by approximately 1.0m of limestone. Clear evidence of very recent collapse with disrupted soil, turf and displaced mature hawthorn bush. Substantial collapses since June 2000 investigation
NZ 34345 50465	Prominent linear fissure approximately 4.0m long, up to 1.0m wide and at least 2.4m deep. Fissure exhibits clean vertical sides. Adjoining topsoil and turf freshly broken giving clear evidence of very recent collapse. Although this fissure lies along course of depression recognised during June 2000 investigation, this prominent open fissure was not observed at that time.
NZ 34308 50461	Very recent collapse of topsoil along small south-facing scar approximately 1.0m long and approximately 0.5m high on north side of shallow linear depression. Linear depression observed during June 2000 investigation.
NZ 34304 50454	Open linear fissure up to approximately 3.0m long, 0.5m wide and at least 1.2m deep. Clean limestone walls, vertical or locally very steeply inclined to the north. Freshly collapsed turfs in base of opening give clear evidence of very recent collapse. Although this fissure lies along course of depression recognised during June 2000 investigation, this prominent open fissure was not observed at that time.
NZ 34285 50445 – NZ 34304 50454	Prominent, very recently subsided linear depression bearing 273º, up to 2.0m wide and 1.25m deep. Abundant evidence of very recent collapse in form of fresh scars in turf and topsoil on either side of depression forming graben-like feature. Although this fissure lies along course of depression recognised during June 2000 investigation, this prominent open fissure was not observed at that time.
NZ 34199 50430 – NZ 34255 50439	Linear depression up to 1.0m wide and approximately 1.0m deep. Abundant evidence of very recent collapse in form of fresh scars in turf and topsoil on either side of depression. Locally appears to exhibit displacement to south of up to 1.0m, though generally appears as trough, or graben-like feature. Although this fissure lies along course of depression recognised during June 2000 investigation, there is evidence of very considerable recent movement.

4 Fieldwork

4.1 INTRODUCTION

A representative of the British Geological Survey accompanied Biffa Waste Services Limited Waste personnel on a routine sampling round of the Houghton Le Spring landfill Site during the week of June 12, 2006. One of the objectives of the BGS presence was to observe the sampling protocol employed at the site. A second objective was to collect groundwater samples using the Biffa Waste Services Limited protocol for analysis at independent laboratories for direct data comparison, the key objective being to obtain samples commensurate with the determination of the extensive suite of determinands detailed in section 5.1, in order to enable an assessment to be made regarding any measurable impact of the site on groundwater.

As noted in subsection 3.3, in August 2004 a groundwater sampling protocol was prepared for Biffa Waste Services Limited by Environmental Simulations International Ltd (ESI) and described in the ESI Report 6373D, August 2004. Subsequently a number of sections of the protocol have been amended by Biffa Waste Services Limited (Appendix 2).

For quality control purposes blank samples are prepared using deionised water supplied to Biffa Waste Services Limited by VWR International. Sample bottles are filled directly from the deionised water supply and are collected approximately every 10 standard samples. Random duplicate samples are also collected to verify laboratory accuracy. The BGS also collected two blank samples using deionised water, one poured directly into sample bottles the other transferred to the bottles through a clean inertial pump set-up to mimic those used in the monitoring wells. In addition the BGS collected three duplicate groundwater samples (N2A, L1A, M1A) and one duplicate leachate sample (Phase IIBA).

The deionised water that was used was supplied to the site in standard plastic barrels. The deionised water is stored in laboratory conditions in the Biffa Waste Services Limited site offices. The Waterra tubing that was used for sampling purposes was also stored in the Biffa Waste Services Limited site offices.

A ‘base-line’ sample was collected from Stoneygate Pumping station as an indicator of the current groundwater quality at the pumping station. Sample bottles were filled directly from a tap inside the pumping station that is continually running.

4.2 GROUNDWATER PURGING AND SAMPLING

A total of 28 groundwater monitoring wells, 3 leachate and 2 surface water samples are collected during each round of sampling. Inertial pumps (lengths of HDPE tubing fitted with either stainless steel or HDPE foot valves) are dedicated to each monitoring well. The pumps are left in the well in order to preclude the potential for contamination from other sources. When maintenance of the pumps is required Biffa Waste Services Limited staff ensure that there is minimal contact of the tubing with the ground. Ideally there would be no contact at all. However, these are deep wells and on occasions it is necessary to remove the entire length of tubing in a given borehole.

Water level measurements are taken prior to purging the well and are measured to the recorded datum point. Borehole identification, datum points and well depth are recorded on laminated cards attached to each well.

Purge volumes are calculated prior to pumping the well. The volumes are calculated from the measured water level and borehole depth, using the formula: Volume = $\Pi r^2 h$. Biffa Waste Services Limited limits the calculated standing water volume to that derived from using the diameter of the well liner (50 mm or 110 mm). This approach does not take into account the annulus between the well liner and the bored hole, which is backfilled with gravel and will store a significant amount of groundwater, however the Biffa Waste Services Limited approach is consistent with the EA Guidance (Environment Agency, 2001). Calculated purge volumes are recorded in a field notebook.

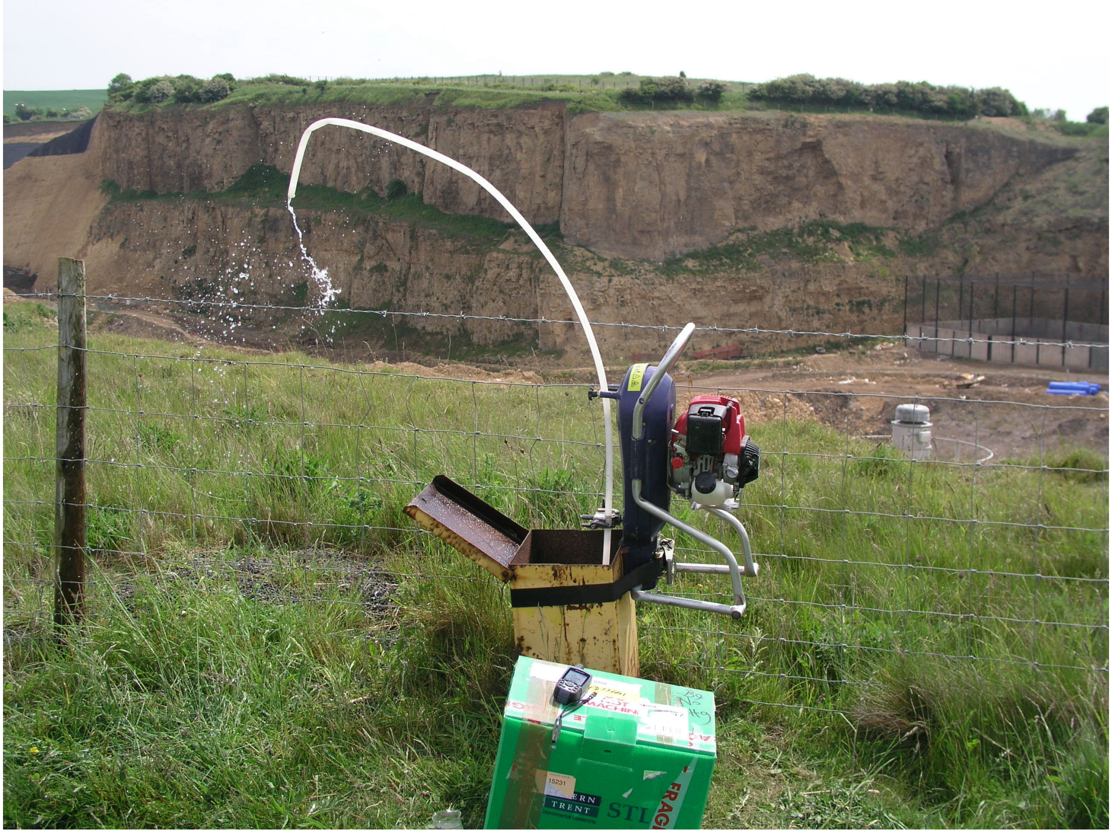


Figure 1: Powerpack pump control with inertial pump

A flow rate is calculated by timing the collection of one litre of groundwater and the purge time is calculated by dividing the purge volume required by flow rate (L per minute). The pump is then started and left for the time required to remove three borehole volumes. As the inertial pumps are being operated close to their design limits they are subject to frequent failure. This is usually recognised by a reduced or zero discharge from the tubing. If this occurs the pump is stopped and the pipe is removed to identify and rectify the problem. The period of all stoppages is added to the calculated purge time. Purge water is allowed to flow back to ground and is not collected or disposed of off site. The pump tubing often extends above the power pack and the reciprocal motion of the inertial pump sprays groundwater over quite a wide area (Figure 1). This makes it difficult to fill sample bottles and, if the water were found to be contaminated would constitute a significant health hazard. Measurements of water quality indicator parameters such as Electrical Conductivity (EC), pH, Dissolved Oxygen (DO) are not taken during or after the purge.

Sample bottles provided by the analytical laboratory prior to each sampling round are labelled using pre-prepared labels. Monitoring points are assigned two unique identification codes; the first being the borehole name e.g. BH10, the second being an 8 digit identifier starting 5850 and it is this number that is added to the bottle label. Sample bottles are filled either directly from the end of the pump tubing or via a beaker, which is discharged to the relevant bottle. Sample bottles that contain chemicals for sample preservation are not rinsed prior to sample collection, nor however, are any of the other bottles, which is at odds with the sampling protocol (ESI, 2004). Sample bottles are transferred to a refrigerator daily, prior to courier transportation to the laboratory. Samples are then transported in corrugated boxes provided by the analytical laboratory, these are not cool boxes and the couriers do not use refrigerated trucks. However, refrigerated vehicles transported the samples taken by the BGS.

There are three monitoring wells (G1, I2, RI1) that routinely do not produce a sample; G1 and I2 have insufficient sample and RI1 is reported to be difficult to sample due to high levels of silt in the well screen. This suggests that high groundwater levels in this area could be associated with localised recharge, particularly given that the borehole log indicates a cover thickness of just 1.0m. Borehole J2 yielded insufficient sample for the entire testing schedule. The sample that was obtained was sufficient to supply Biffa Waste Services' laboratory and the requirement for the Scientifics component of the testing. However there was insufficient sample to meet the analytical requirements of Mountainheath Services Limited. At the time of the June 2006 sampling round it was found that Borehole M2 had been damaged and could not be sampled.

With respect to the current sampling and monitoring procedures, the sampling method employed by the Biffa Waste Services Limited staff does not correspond to any of the three methods described by ESI (2004), instead all boreholes are fully purged of three borehole volumes before sample collection. This is in accordance with Environment Agency Guidance (2001) for representative sampling of short screen wells and is an acceptable method for this site although some wells require significant volumes of water to be purged, which not only takes a long time but also creates a discharge issue. ESI (2004) recommends purging the wells for a minimum of 10 minutes and until the Electrical Conductivity (EC) readings of the water stabilise, the report also recommends measuring pH, Dissolved Oxygen (DO) and temperature (T) using a flow-through cell. These parameters are not determined as field parameters by Biffa Waste Services Limited; instead the analytical laboratory receiving the samples determines them. This is considered unsatisfactory in carbonate aquifers where the groundwater chemistry can change during transport as a result of precipitation, or dissolution of minerals, resulting also in changes in the pH.

Field measurements of each of the field water quality indicator parameters specified in the sampling protocol (ESI, 2004) and additionally reduction/oxidation potential (Eh) were taken by the BGS every five minutes during the purge and finally after sample collection for the majority of boreholes sampled. Continuous measurements were not collected in wells that were bailed or when more than one well was being purged at a time. It can be seen from examples of the results presented in Appendix 3 that relying on EC data alone does not necessarily indicate stabilisation of water quality parameters and thus ensure a representative sample. Electrical conductivity is known to stabilise quite quickly and it is DO and Eh that are the last indicators to stabilise. Examination of the results presented in Appendix 3 also indicates that the results are not always easy to interpret. Some boreholes showed much clearer curves than others, the results for boreholes F2 and 10 being much more amenable to interpretation than those for Borehole M1. The characteristics of the curves differ, for instance the results for Borehole F2 (with a response in the Raisby Formation) show an increase in pH and decrease in electrolytic conductivity as the formation water is drawn into the borehole and Borehole 10 (with a response zone in the Yellow Sand Formation) shows an initial decrease in pH and increase in electrolytic conductivity. The lithological description associated with the response zone in Borehole M1 was of a calcarenite, which shows a different response to the other boreholes. Discharging at the rate of approximately 2 l/min, Borehole 10 appears to have taken two borehole volumes [approximately 3.5 hours and as recommended by ESI (2003)] to stabilise (although the dissolved oxygen did not appear to stabilise even after five hours of purging). It is considered that greater stability of the results would possibly be achieved by directing the discharge through a flow-through cell. Borehole F2 also appears to have stabilised after two borehole volumes had been discharged [24 minutes of purging, ESI (2004) recommended 26 minutes].

Figure 2: Phase 2 Leachate sampling point

A summary of field observations is included as Appendix 3.

4.3 LEACHATE SAMPLING

Leachate sampling was carried out in order to characterise the leachate to inform the assessment of groundwater quality. Samples of leachate were collected from Phase I, Phase II and Phase IIB of the landfill. In each case the sample bottles were filled directly from the recirculation pump tap. Access to the Phase II pump is difficult, comprising a descent down a steep slope of loose cover material with a significant drop below. This is made all the more difficult when carrying a box full of sample bottles (Figure 2).

4.4 SURFACE WATER SAMPLING

Two surface water samples are collected from the site:

(1) Grasswell Burn, a field drain/stream that runs through a field to the north of the site, sampled at approximately NZ 342510. In June 2006 there was insufficient flow at the time of sampling to obtain a sample.

(2) Standing water at the base of the quarry, which is likely to be groundwater. This is sampled using a telescopic rod to which a beaker is attached. The sample is transferred directly from the beaker to sample bottles (Figure 3).

Figure 3: Standing water at base of quarry

4.5 HEALTH AND SAFETY CONSIDERATION

The very nature of the site makes access to a number of monitoring wells difficult, some wells have vehicular access others are foot access only. To collect representative samples the sampler needs to carry a lot of equipment to the wellhead and improved access in some areas would enable better samples to be collected. For example a gate in the fence to the north of the site would allow easier access to wells H1, H2, F1, F2 and Grasswell Burn. Furthermore, security is considered to be a problem outside the perimeter boundary, where equipment cannot be left unattended. The reason given by Biffa Waste Services Limited to account for why water quality parameters are not routinely measured on-site is that of well access and difficulty associated with getting the necessary equipment to each of the wells. As mentioned previously (sub-section 4.3) access to the Phase II leachate pump is dangerous and should be looked at as a matter of urgency. Sampling using two operatives would also improve the safety aspects of the monitoring; minimise the problems of security; and reduce the time required for a full round of sample collection.

5 Laboratory Testing

5.1 LABORATORY TESTING SCHEDULE

The scope of the testing (Appendix 6) was instructed by the Environment Agency, in accordance with their methodology for monitoring groundwater under the Water Framework Directive. This approach comprises the selection of suites of determinands from a comprehensive catalogue of contaminant suites, thereby enabling the selection of groups of determinands that characterise the sources that are associated with current and historical land use within a given catchment. Although this is an internal catalogue, it was compiled through a national collaboration. It is understood that the lists are not fixed and are subject to modification to reflect the growth of knowledge associated with various contaminants (Sally Gallagher, Environment Agency, verbal communication September, 2006). Following discussion with the Environment Agency suites 09 and 010 were excluded from the testing schedules and diethylhexylphalate and tributyl tin were added.

The required detection limits were also specified by the Environment Agency in accordance with the same list. However, a number of issues have arisen with respect to the specified detection limits. It would appear that the detection limits that have been set reflect the limit of on-going improvements in analytical methods and that they reflect what is achievable in a minority of the commercial laboratories. Considerable difficulty was experienced identifying a laboratory that could carry out the entire suite of tests to the detection limits that were scheduled by the Environment Agency. Accordingly the British Geological Survey sub-contracted the laboratory testing to two laboratories, namely Scientifics Limited and Mountainheath Services Limited. Mountainheath Services Limited was able to offer a lower detection limit for the organic component of the testing and thus was appointed to carry out the organic testing. It should be noted that difficulty was experienced reaching the lower detection limits for a number of determinands. The reasons for this included: the difficulty of achieving low detection limits in leachate and contaminated groundwater, which require significant dilution factors and the difficulty of maintaining the air conditioned cooling of the laboratory during the prolonged period of hot climatic conditions that prevailed at the time of the laboratory work.

The results of the laboratory testing, as provided by the respective laboratories, are presented on a CD-ROM attached to this report.

5.2 QUALITY CONTROL

In addition to the field procedures described above, sample transport was managed by a procedure of chain of custody forms. The British Geological Survey experienced a field-sampling problem because Mountainheath Services Limited sample bottle supplier failed to deliver the required bottles in time for the majority of the sampling campaign. Fortunately, Biffa Waste Services Limited had a supply of bottles that was made available to the British Geological Survey.

Both of the laboratories appointed by the BGS have NAMAS accreditation, however it should be noted that this does not cover all of the tests that were carried out. Details of the Mountainheath Services Limited UKAS accreditation can be obtained from their website: www.mountainheath.com and the tests for which Scientifics Limited is accredited are indicated on the spreadsheet included in the CD-ROM.

In accordance with the accreditation scheme both laboratories were able to provide measurements of uncertainty, based on ANOVA analysis (Ramsey, 1998). Scientifics Limited stated that *Measurement of uncertainty for those results significantly above the LoD is estimated to be +/- 20% for all analyses except total cyanide, which is +/- 30%. Results within an order of magnitude of the LoD have a higher uncertainty*. Scientifics also generated a duplicate measurement for laboratory quality control purposes. This sample is suffixed D in their results (Appendix 6). Mountainheath Services Limited provided tables of expanded uncertainty, which have been reproduced below for reference purposes.

Table 2: Uncertainties in *N*-methyl carbamate determination calculated to a 95 % level of confidence

N-methyl carbamates in water	Standard Uncert. (Precision & Accuracy)	Standard Uncert. (Dilution & Purity)	Combined Standard Uncert. ($\sqrt{\sum x^2}$)	Expanded Uncert. (%)
aldicarb sulfoxide	0.0181	0.0738	0.0760	15
aldicarb sulfone	0.0103	0.0738	0.0745	15
oxamyl	0.0077	0.0738	0.0742	15
methomyl	0.0129	0.0738	0.0749	15
3-hydroxycarbofuran	0.0155	0.0738	0.0754	15
aldicarb	0.0129	0.0738	0.0749	15
propoxur	0.0129	0.0738	0.0749	15
carbofuran	0.0129	0.0738	0.0749	15
bendiocarb	0.0232	0.0738	0.0774	15
carbaryl	0.0103	0.0738	0.0745	15
methiocarb	0.0129	0.0738	0.0749	15
aldicarb & metabolites	0.0129	0.0738	0.0749	15

In addition to the quality control that is provided by the laboratories the BGS submitted both duplicate and blank samples to the laboratories for analysis. Duplicate samples generate information on errors in the entire sampling/ analysis process, however they generally detect random rather than systematic errors (Environment Agency, 2001). The blank samples should provide information on errors associated with the analytical processes and they may detect both random and systematic errors (Environment Agency, 2001). Duplicate samples were obtained from: Borehole L1, M1, N2 and from the leachate sampling point in Phase 2B. Each of these samples was suffixed A. The blank samples were labelled BA and BB.

The following were detected in blank sample BA: 1.50 µg/l diethylhexyl phthalate (DEHP), 0.03 µg/l o-cresol, 0.04 µg/l p-cresol, 0.14 µg/l phenols and 1.12 µg/l monolinuron. The following were detected in blank sample BB: 0.64 µg/l DEHP, 0.03 µg/l m-cresol, 0.02 µg/l o-cresol, 0.13 µg/l p-cresol, 0.12 µg/l phenol and 0.01 µg/l of 1,3,5-trichlorobenzene.

Table 3: Uncertainties in OCL Determination calculated to a 95 % level of confidence

	Standard Uncertainty (precision)	**Std. Uncert. (repeats)**	**Std. Uncert. (other)**	**Combined Standard Uncertainty ($\sqrt{\sum x^2}$)**	**Expanded Uncertainty (%)**
trifluralin	0.0348	0.0300	0.006	0.0463	9 %
a-HCH	0.0221	0.0535	0.006	0.0582	12 %
HCB	0.0348	0.0417	0.006	0.0546	11 %
beta-HCH	0.0158	0.0407	0.006	0.0441	9 %
gamma-HCH (lindane)	0.0221	0.0827	0.006	0.0858	17 %
delta-HCH	0.0285	0.1002	0.006	0.1043	21 %
heptachlor	0.0316	0.0294	0.006	0.0436	9 %
aldrin	0.0221	0.0193	0.006	0.0299	6 %
isodrin	0.0253	0.0096	0.006	0.0277	6 %
heptachlor epoxide	0.0285	0.0059	0.006	0.0297	6 %
chlordane 1	0.0348	0.0123	0.006	0.0374	7 %
o,p'-DDE	0.0253	0.0097	0.006	0.0278	6 %
alpha-endosulfan	0.0221	0.0370	0.006	0.0435	9 %
chlordane 2	0.0285	0.0224	0.006	0.0367	7 %
dieldrin	0.0411	0.0214	0.006	0.0467	9 %
p,p'-DDE	0.0285	0.0214	0.006	0.0361	7 %
o,p'-TDE	0.0285	0.0182	0.006	0.0343	7 %
endrin	0.0379	0.0686	0.006	0.0786	16 %
beta-endosulfan	0.0285	0.0381	0.006	0.0480	10 %
p,p'-TDE	0.0316	0.0805	0.006	0.0867	17 %
o,p'-DDT	0.0221	0.0743	0.006	0.0777	16 %
p,p'-DDT	0.0348	0.1081	0.006	0.1137	23 %

Average expanded uncertainty for OCLs in water is 11 %.

There are a number of issues relating to the occurrence of DEHP. In the environment transport of DEHP in the air is the major route for phthalates to enter the environment and in rivers and lakes concentrations of up to 4 µg/l have been detected in association with industrial discharge points. (International Programme on Chemical Safety, Public data, Environmental Health Criteria 131). It is the most widely used of the plasticizers required to soften the resins used in plastics and may account for 40% (w/w) of plastic. The widespread use of phthalates indicates that there are many potential sources of DEHP in both the sampling and the laboratory environment. For example, glass bottles were used for sampling, however the tops of the bottles were made of plastic and had plastic inserts, therefore this is a potential source of phthalates, others include laboratory gloves and plastic connectors within the analytical system. During field sampling there were occasions when, for reasons of practicality, the samples were discharged from a plastic jug. The fact that the DEHP has been detected in the blank samples indicates that the DEHP is most likely to be derived from the sample bottles, the source bottle for the de-ionised water, or the laboratory procedures. The occurrence of DEHP in the blank samples places a considerable degree of uncertainty associated with values of 1.50 µg/l or less.

Although cresols are derived from crude oil and coal tars and they are commonly used as solvents, disinfectants, resins, wood preservatives and are important in the production of herbicides and insecticides, it is interesting to note that they are also used in flame retardant plasticizers for polyvinyl chloride and other plastics. This suggests that there is a potential for the DEHP and the cresols to have a shared source.

Phenols could also be associated with the potential DEHP sources that have been listed above, as the largest single use of phenol is the production of phenolic resins. Phenols are also used in antiseptics, disinfectants, paint, rubber, dyes, perfumes and soaps and therefore could also be associated with another contaminant source.

Consideration was given to the inertial pump tubing that is used for sampling the majority of the groundwater wells as a source of phthalates, in addition it was noted that plastic base valves were being utilised in a number of the inertial pumps. Contact was made with Peter Dumble, Managing Director of Waterra UK (supplier of the inertial pump systems). It was established that the Waterra tubing is constructed of HDPE and does not contain plasticizers, which are associated with polyvinylchloride products (PVC). The ball valves are constructed of Delrin, which is also free of phthalates. It was also noted that the cling film used to wrap the pump tubing comprises LDPE that is also free of phthalates.

Mountainheath Services Limited was asked to comment on various aspects of the testing and a comprehensive response to these queries was received. With respect to the DEHP Mountainheath Services Limited reviewed their laboratory blank sample and identified that it contained significant concentrations of DEHP. It was established that the technician who had carried out the sample extractions had used distilled water from a plastic container as the blank. Although the standards had not been in contact with this water it has been suggested that the technician probably used this water to rinse the glassware and therefore this is suspected to be the source of the DEHP. Mountainheath Services Limited also confirmed that a typical source of phenols in samples is through contact with plastics and that low levels of phenol and p-cresol were also detected in the in-house blanks and the results were not blank corrected, so it was considered that the samples *"contain a contribution from laboratory contamination (as well as from any other potential sources prior to receipt at the laboratory)."*

Monolinuron is a herbicide and its presence is unlikely to be associated with the sampling process. 9.18 μg/l of monolinuron was determined in one of the samples of leachate from Phase 2B. It was not detected in any of the other samples, therefore this suggests cross-contamination of the blank sample BA during the analytical procedure.

Similarly, the presence of the pesticide 1,3,5 trichlorobenzene is unlikely to be associated with the sampling process. This chemical is used as: an intermediate used in the agricultural and pharmaceutical industries, an insecticide, a solvent, a coolant, a lubricant and heat-transfer medium. A concentration of 0.15 μg/l was determined in each of the leachate samples (Phase 1, 2 and 2B), as with the monolinuron, this suggests cross-contamination of the blank sample BB during the analytical procedure.

Mountainheath Services Limited was asked to comment on the issue of cross-contamination during the laboratory testing procedures. The quality manager was of the opinion that cross-contamination is unlikely to be a significant factor during the analysis of extracts and that if there had been cross-contamination; it was most likely to occur during the extraction of the samples. The quality manager pointed out that glassware used for the extractions is rinsed thoroughly between samples, but the laboratory cannot guarantee that no cross-contamination would have occurred. The laboratory did not keep a list of the order of the sample extractions, but it is most likely to have been carried out in numerical order of the laboratory numbering system.

Mountainheath Services Limited made two additional points that have been made elsewhere in the report, but are worthy of consideration. Firstly that *"across the board, the levels of most analytes observed in the samples were extremely low and of questionable significance."*

Secondly that "*those results which are particularly close to the limit of detection for the method have increased uncertainty associated with them which is very hard to quantify*" and that "*some of the reporting limits that you requested are unusually low and do stretch the limits of the method.*"

The results of the duplicate samples were tabulated and calculations of the difference, mean and difference as a percentage of the mean were carried out. These analyses have been presented in Appendix 7. The information supplied by Scientifics that relates to uncertainty states that values of 20% might be anticipated for results that are not close to the detection limit and that this is likely to increase as concentrations approach the detection limit. The increase in uncertainty close to the detection limit is typical of all laboratory data sets. It is evident in the determination of beryllium in the leachate in Phase 2B, where the difference in the results was 0.001, but taken as a percentage of the mean this is 66.67%. Clearly therefore, the proximity of the result to the detection limit and the value of the detection limit needs to be taken into account in the assessment of these results. Taking due account of these considerations the following appear to show a greater difference than would be anticipated: thallium and selenium in the leachate from Phase 2B; faecal colliform in the leachate from Phase 2B; barium and iron in the groundwater from Borehole M1; antimony, lead and tin in the groundwater from Borehole N2. As suggested above these appear to be random "errors", they could reflect an error in laboratory procedures: differences resulting from laboratory sub-sampling, error associated with the field sampling, or real variability in the water quality. It is suspected that each of the differences reflects different sources of error. For instance the difference in faecal colliform could be either a sub-sampling or sample variation; and it is interesting to note that the variation in the metals in Borehole N2 is in groundwater that is derived from a karstified zone in the Raisby Limestone, which suggests that the sampling could have encountered differing flow paths, such an effect may also be exaggerated by the inertial pump method of sampling, which by virtue of the movement can collect sample from differing components of the water column.

With respect to the results supplied by Mountainheath Services Limited the majority of the determinands, if present, were at concentrations below the lowest limit of detection. With respect to the remainder the duplicate differences expressed as a percentage of the mean were generally lower. The following differences warrant further consideration: m-cresol, phenol, fluorine, anthracenene, naphthalene in the leachate from Phase 2b; o-cresol in the groundwater from M1; p-cresol in the groundwater from Borehole N2. For each of the duplicate analyses the variation in the reported values of DEHP is higher than might be expected. Difficulties with the DEHP and phenols (including the o- and p-cresols) have been described above. With respect to the polyaromatic hydrocarbons Mountainheath Services Limited considered that the result variation was within the range of experimental error.

Despite the considerable care that has been taken with the sampling and laboratory testing it is clear that there is still scope for uncertainty in the results. Therefore the quality-controlled data that has been collected is very valuable in aiding the interpretation of the groundwater analyses.

5.3 COMPARISON WITH BIFFA WASTE SERVICES LIMITED (SEVERN TRENT) DETERMINATIONS

For comparative purposes the results for boreholes L1, M1 and N2 and the analysis of the leachate from Phase 2b were compared with the duplicate sample results. The table of comparative values is included in Appendix 8. Generally there is good agreement between the two sets of results. There are some differences, which result from differences in: the test method, the reporting method and also the lowest detection limits. Differences in testing method appear to account for the difference in the reported ammonia concentration in the leachate in Phase 2b and possibly account for the marginally higher values of uranium that are consistently detected by Severn Trent. The differences in the nitrate concentration can be accounted for by the difference in reporting methods (Severn Trent report as Nitrogen). The analyses presented in

Appendix 8 indicate that some of the cations, in particular lead, but also barium and at low detection limits manganese and iron are consistently higher in the Severn Trent analyses and this observation is typical of the data sets as a whole. This may reflect the use of a different analytical procedure, although it should be noted that because of the rate of improvements to the various analytical techniques the type and age of the equipment in use, might also impact on the quality of the results. Another contributory factor is the way in which the laboratories operate, if the equipment is set-up for routine through put it may not be possible to accurately achieve the low detection limits that have been specified for the audit. It should be noted that although the high specification was required of the BGS laboratory analyses, it is not a requirement of the routine analyses required by Biffa Waste Services under the existing site licensing arrangements.

6 Groundwater Quality

6.1 INTRODUCTION

As surface water moves from the ground surface to and through an aquifer it chemically reacts with the minerals with which it has contact. These reactions determine the chemical characteristics of the groundwater at a given location. By virtue of the chemical composition of the Magnesian Limestone, cations in the groundwater are dominated by calcium and magnesium (derived from the dolomite) and anions by bicarbonate (HCO_3) and sulphate (derived from carbonate minerals and gypsum respectively).

Brewerton and Edmunds (1997) presented a statistical summary of groundwater quality in the Magnesian Limestone of Yorkshire and Northumbria. The data for Northumbria was derived from analyses from thirty boreholes in Northumbria. The majority of data was derived from the Environment Agency. The baseline data includes a median value (less likely to be affected by outliers in the data than the mean) and an upper baseline value (calculated on the basis of the 95 percentile), which have been reported below, for reference.

Table 2 Background water quality for the Magnesian Limestone of Northumbria (taken from Brewerton and Edmunds, 1997)

Determinand	Units	Median	Upper Baseline
Filtered Samples			
Temperature	° C	10.2	12.9
pH (field)		7.3	8.1
Eh	MV	-71.0	45.0
Calcium	mg/l	91.75	178
Magnesium	mg/l	42.5	83.6
Sodium	mg/l	27.25	61.0
Potassium	mg/l	2.33	6.69
Chloride	mg/l	33.5	93.5
Sulphate	mg/l	105	375
Bicarbonate	mg/l	355	451
Nitrate as N	mg/l	0.86	15.0
Nitrite as N	µg/l	<20	30
Ammonium as N	µg/l	<50	213

Determinand	Units	Median	Upper Baseline
TOC	µg/l	0.56	7.4
DOC	µg/l		
Aluminium	µg/l	<10	11
Arsenic	µg/l	<1	1.16
Boron	µg/l	<80	249
Barium	µg/l	51.7	186
Cadmium	µg/l	<0.1	<0.1
Chromium	µg/l	<1	4.65
Copper	µg/l	1.89	5.21
Total iron	µg/l	<30	525.0
Mercury	µg/l	<0.02	0.04
Manganese	µg/l	<10	186.0
Nickel	µg/l	<1	3.38
Total phosphorus	µg/l	<50	535.0
Orthophosphorus	µg/l		
Lead	µg/l	<1	12.7
Antimony	µg/l	<2.5	<2.5
Selenium	µg/l		
Silicon	µg/l	3900.0	4100.0
Strontium			
Zinc	µg/l	5	141
Unfiltered samples			
Aluminium	µg/l	9.6	82.0
Arsenic	µg/l	<0.2	0.9
Boron	µg/l	31.1	153
Barium	µg/l	64.0	245.0
Cadmium	µg/l	<0.1	0.105
Chromium	µg/l	0.7	3.8
Copper	µg/l	1.68	11.0
Fluoride	µg/l	695.0	1520.0
Mercury	µg/l	0.057	0.360
Total iron	µg/l	36.8	1690.0
Manganese	µg/l	13.3	200.0
Nickel	µg/l	<1	4.22
Lead	µg/l		
Antimony	µg/l	<0.4	1.3
Selenium	µg/l		
Strontium	µg/l		
Zinc	µg/l	13.0	99.8

Brewerton and Edmunds (1997) reported that in the Northumbria waters, in the order of 20% had significant contributions from agricultural nitrate, and that "nitrate concentrations in excess of 5 mg/l can be used safely to divide natural waters from those with an anthropogenic contribution".

6.2 HYDRAULIC GRADIENT

ESI (Table 7.10, 2003) suggested that it was possible to allocate the boreholes into up and down hydraulic gradient monitoring wells. The up-gradient wells were defined as: J1; J2; I1; I2; G1; G2; BH8, G9 (GW9) and C. The down-gradient wells were H1; H2; BH6; BH7; F1; F2; A1; A2; B1 and B2. In order to check this, the groundwater levels were plotted and contoured using the software package SURFER. As described in subsection 3.4, previous datum levels have been shown to be unreliable and a completely new set of levelling data was provided by the Environment Agency on 4 October 2006. A groundwater contour map has been prepared from the results of the revised levelling data (Appendix 5). Groundwater levels correspond with the levels presented in the regional groundwater contours presented by Younger (1994), with a hydraulic gradient to the east.

The map shows the contours of groundwater levels in both the Raisby Formation and the Yellow Sands Formation. In the Yellow Sand Formation the contours suggest an easterly hydraulic gradient in the southern part of the site, becoming a northerly gradient to the north. A similar pattern is seen in the Raisby Formation.

Groundwater levels in the Raisby Formation (67.5 to 78.5 m AOD) are generally higher than those in the Yellow Sand Formation (67.4 to 72.2 m AOD). The difference is greater to the southwest and it is considered that this reflects the presence of the Marl Slate, which becomes an increasing leaky aquitard to the northeast. The borehole records for a number of boreholes in the northeastern part of the site do not make any reference to the Marl Slate, suggesting that it is absent from these boreholes. Additionally, consideration needs to be given to the influence of the faults on the groundwater regime (section 6.5).

ESI (2003) considered the response of the hydrographs to hydrologically effective rainfall and demonstrated that groundwater levels respond to changes in the effective rainfall. They also suggested that the hydrographs show a subdued annual variation, noting that they would have expected more rapid responses in the limestone and therefore they concluded that the response represents aquifer conditions, rather than an immediate recharge response. It is possible that this is attributable to the influence of faulting in the area (subsection 6.5).

Upon examination of the plot of the groundwater contours (Appendix 5) it is apparent that the definition of the "up-hydraulic gradient" boreholes is difficult, particularly given the extent of the apparent contamination associated with Borehole J2 (subsection 6.3). The following are considered to be "up-hydraulic gradient" in the Yellow Sand Formation: boreholes 1, 10, RI1 and G2; and in the Raisby Formation: boreholes I2 and G1.

6.3 GROUNDWATER QUALITY DURING JUNE 2006

As described in Section 5, the leachate and groundwater samples were analysed for an extensive range of determinands, many of which were either absent from the samples, or present in concentrations that were below the analytical detection limit. The summary below is based on the results of the laboratory testing that was commissioned by the British Geological Survey and has been limited to the anions and cations that characterise the water, or are present in apparently elevated concentrations; and to the organics that occur in concentrations above the respective lower detection limit. Selective reference has been made to drinking water standards where it is considered that this benefits the interpretation of the results.

1. Chloride concentrations in the groundwater were found to range between 27 and 220 mg/l and the WHO guideline for drinking water quality is 250 mg/l. The highest concentrations were recorded in boreholes BH2 (220 mg/l) and G2 (210 mg/l), with response zones in the Raisby Formation and Yellow Sand Formation respectively. In each case sodium concentrations were also elevated: 120 mg/l in borehole G2 and 130 mg/l in borehole BH2. Concentrations of the other anions and cations were not elevated in these boreholes. This suggests dissolution of sodium chloride. The boreholes were situated towards the southeastern boundary of the landfill.

2. Sulphate concentrations were found to range between 38 and 1000 mg/l and the WHO guideline for drinking water quality is 500 mg/l. The highest concentrations were determined in boreholes J2 (1000 mg/l), GW9 (400 mg/l), RJ1 (370 mg/l) and GW8 (350 mg/l). Sulphate is naturally occurring in carbonate rocks, where it results from the dissolution of gypsum or anhydrite and can also be attributable to the dissolution of pyrite in oxidised groundwater. The concentration determined in Borehole J2 is particularly elevated, the upper baseline value presented by Brewerton and Edmunds (1997) was 375 mg/l. Yet it is considered unlikely that the source of the sulphate is the landfill leachate, because concentrations of sulphate in the leachate are in the range 3.2 to 22 mg/l (Table 2) and sulphide concentrations are in the range <0.1 to 0.3 mg/kg. Furthermore, these boreholes are situated on the western side of the site, in an area that is not considered to be down hydraulic gradient of the landfill.

3. Although the Magnesian Limestone is a carbonate aquifer, it is considered that the concentrations of calcium determined in boreholes J2 (400 mg/l), GW9 (200mg/l) and GW8 (150 mg/l) and the concentrations of magnesium determined in Borehole J2 (290 mg/l) and Borehole RJ1 (240 mg/l) are elevated. In support of this it has been noted that the upper baseline values for these determinands were 178 mg/l for calcium and 83.6 mg/l for magnesium (Brewerton and Edmunds, 1997). Furthermore, the Total Hardness and Alkalinity determined for boreholes J2, RJ1 and GW9 are also considered to be elevated.

4. Dissolved silica concentrations were in the range 2.1 to 5.5 mg/l, these concentrations are considered to fall within the range that might typically be expected in carbonate aquifers, although Brewerton and Edmunds (1997) reported median and upper baseline values of 3.9 and 4.1 mg/l respectively. Furthermore, it was noted that that highest values were determined in boreholes J2 (5.7 mg/l), GW9 (5.5 mg/l), and RJ1 (4.5 mg/l).

5. The highest concentration of nickel (4 µg/l) was determined in the groundwater sample from Borehole J2 and 3 µg/l was determined in the groundwater sample from Borehole GW9. Both of these values are well below the provisional drinking water guideline value, which is 20 µg/l.

6. Nitrate concentrations were found to range between 13 and 290 mg/l. The highest concentrations were determined in boreholes J2 (290 mg/l), RB2 (83 mg/l), GW9 (80 mg/l) and RJ1 (71 mg/l). It is noted that these boreholes are all situated on the western side of the site. The guideline value for nitrate in drinking water is 50 mg/l. Nitrates comprise oxygenated nitrogen, which can be derived from ammonia. Therefore the presence of nitrates can be indicative of contamination associated with landfill leachate (sub-section 6.4), however Borehole J2 is situated on the western side of the site, in an area that is not considered to be down hydraulic gradient of the landfill. Thus consideration has been given to other sources of nitrate contamination, which include fertilizers, animal wastes, septic tanks and decaying plant debris (sub-section 7.4). The elevated nitrate concentrations are reflected in the total oxidised nitrogen (TON) determinations.

7. Potassium concentrations were found to range between 0.5 and 28 mg/l. The highest value recorded was in Borehole J2. This and the concentrations determined in boreholes RJ1 (12 mg/l), GW9 (14 mg/l) and GW8 (5.3 mg/l) were considered to be elevated. The upper baseline value determined by Brewerton and Edmunds (1997), which was 6.69 mg/l, would appear to confirm this observation.

8. Uranium concentrations were found to range between < 0.07 µg/l and 4.5 µg/l. Again the maximum concentrations were associated with boreholes J2 (4 µg/l), RJ1 (4.5 µg/l) and GW9 (3.2 µg/l). Although these concentrations appear elevated relative to the background, they are well below the provisional drinking water standard, which is 15 µg/l.

9. Selenium was particularly elevated in the groundwater from Borehole J2, where 110 µg/l of selenium was detected. This concentration significantly exceeds the provisional guideline drinking value (10 µg/l). The analytical laboratory was contacted and asked to check this result, which they did and confirmed that it was correct. Elevated concentrations (20 µg/l) were also determined in boreholes RJ1 and GW9.

10. The pesticide metazachlor has been determined in a number of the groundwater samples including those from boreholes 1 (0.11 µg/l) , 10 (0.015 µg/l), F1 (0.19 µg/l), H1 (0.007µg/l), H2 (0.013 µg/l) and most significantly in Stoneygate Pumping Station. It should be noted that this pesticide was not detected in the leachate samples. The concentration was highest in the water from the pumping station (0.91 µg/l), where it is very close to the drinking water standard for pesticides (1 µg/l). The potential for cross-contamination of the organic contaminants during laboratory testing has been demonstrated in the analysis of the blank and duplicate samples. Accordingly it might be considered that the lowest values that were detected (groundwater from boreholes H1, H2 and 10) could be indicative of cross-contamination, however the remaining values would appear to be indicative of the use of pesticides. Borehole F1 is situated in an area of arable land and Borehole 1 in an area of open grass land. It is likely that there is on-going pesticide use in the vicinity of these locations. The pesticide primicarb was detected at the detection limit in a single sample (the groundwater sample from Borehole B1), but was not detected in any of the leachate samples. The pesticide 1,3,5-trichlorobenzene was present in concentrations of 0.15 µg/l in each of the leachate samples (although it was not determined in the duplicate sample taken in Phase 2B). The presence of this contaminant in the Blank sample BB was described in sub-section 5.2. This sheds some uncertainty on the low concentrations (<0.1 µg/l) of 1,3,5-trichlorobenzene that were determined in boreholes K1 (0.02 µg/l), N1 and N2 (0.01 µg/l), A1 (0.02 µg/l), M1 (0.01 µg/l), the duplicate of L1 (L1A with a concentration of 0.04 µg/l), 10 (0.07 µg/l), G2 (0.05 µg/l), 1 (0.03 µg/l) and 2 (0.02 µg/l). All of these values, including those determined in the leachate fall below the drinking water guideline for pesticides (1 µg/l).

11. The herbicide 2,4-DP was detected in the leachate taken from Phase 1 (0.98 µg/l), Phase 2 (0.47µg/l) and Phase 2B (0.62 µg/l and 0.52 µg/ in the duplicate sample). It was also detected in the groundwater sample obtained from Borehole GW 8 (0.24 µg/l). The herbicides 2,4-DB and MCPA were determined in the sample from Borehole GW8 (0.24 µg/l and 0.28 µg/l respectively), but not in any of the other samples, including the leachate. The herbicide 2,3,6-TBA was detected in the leachate in Phases 1 and 2 (0.20 and 0.38 µg/l respecively), but not in any of the groundwater samples and 2,4,5-TP was detected in the leachate from each of the phases (with concentrations in the range 0.08 to 0.92 µg/l), but not in the groundwater samples. The herbicide mecoprop, which is a herbicide used for broad-leaved weed control in cereals and grassland was determined in the leachate samples from each phase (9.2 µg/l in Phase 1, 0.06 µg/l in Phase 2 and 0.07 µg/l in Phase 2B). Mecoprop was also detected in the groundwater obtained from boreholes A1 (5.8 µg/l), A2 (6.0 µg/l), 1 (1.0 µg/l), 2 (5.90 µg/l); with low concentrations that, based on the result of the duplicate analysis for Borehole N2, could result from cross-contamination in M1 (0.07 µg/l), B1 (0.04 µg/l) and GW9 (0.03 µg/l).

12. 9.18 µg/l of monolinuron was detected in the leachate from Phase 2B, although it was not detected in the duplicate sample. 0.06 µg/l of diflubenzuron (a crop insecticide) was detected in the groundwater from Borehole GW9, but it was not detected in either the leachate, or in the other groundwater samples.

13. A number of phenols were detected in the leachate samples. The detection of cresols and phenols in the blank sample BB was noted in sub-section 5.2. These results were considered to be indicative of cross-contamination and suggest that concentrations of similar orders of magnitude in the groundwater samples could also be the result of cross-contamination. Significant concentrations of phenols were determined in the groundwater from boreholes F1 (0.98 µg/l) and 2 (0.98 µg/l). A concentration of 0.06 µg/l and 0.07 µg/l of o-cresol was determined in boreholes GW8 and M1 respectively.

14. The volatile organic carbon (VOC) determinations identified the presence of low concentrations of benzene, MTBE, o-xylene, and m and p-xylene in the leachates. 13.4 µg/l of MTBE was also detected in the pond water. MTBE is an additive to petrol, its presence in the pond water suggests a former spillage or leakage of fuel. There were no VOCs detected in the groundwater samples.

15. The polynuclear aromatic hydrocarbon (PAH) analyses identified low levels of a number of PAHs in the leachate samples. With the exception of 0.02 µg/l of anthracene in Borehole GW8, these were not evident in the groundwater samples.

16. The problems associated with phthalates have been described in subsection 5.2. Diethylhexyl phthalate (DEHP) was detected in all of the samples. Concentrations ranged between 0.22 µg/l in borehole GW9 and 3.10 µg/l in the duplicate of the sample of leachate taken from Phase 2B. However, it should be noted that the concentration determined in the sample from Phase 2B was 0.91 µg/l.

The results of the analysis of the water from the Stoneygate Pumping Station do not show any indications of contamination by landfill leachate. It has already been stated that there was an elevated concentration of metazachlor in the water from the pumping station (0.91 µg/l), but this pesticide was not detected in the leachate samples.

6.4 LEACHATE CHARACTERISATION

Following detailed consideration of the laboratory test results a number of determinands have been selected to characterise the leachate (Table 2). For comparative purposes and where available, a range of values for leachate from household wastes (Robinson, 1995) have also been tabulated.

Determinand (units mg/l, unless otherwise defined)	**Leachate Phase 1**	**Leachate Phase 2**	**Leachate Phase 2b** **Reported value mean of results reported for sample and duplicate**	**Range of values for leachate from household wastes (Robinson, 1995)**
pH	7.9	7.9	7.4	5.8 – 7.5
COD	2280	2350	2140	100 – 62 400
DOC	690	670	665	
Alkalinity	6000	6000	4450	
Ammoniacal Nitrogen	1500	1400	870	5 - 1000
Nitrate-N	<0.5	<0.5	0.645	<0.5 – 5
Nitrite-N	<0.3	<0.3	4.0	<0.2 – 2
Ortho-Phosphate (as P)	1.4	11	<0.5	<0.02 - 3
Bromide	19	9.9	11	
Chloride	1870	2050	1565	<100 - 3000
Iodide (µg/l)	2700	1700	2700	
Sulphate	9.1	22	1.7	<60 - 460
Arsenic (µg/l)	34	60	16	

Determinand (units mg/l, unless otherwise defined)	Leachate Phase 1	Leachate Phase 2	Leachate Phase 2b Reported value mean of results reported for sample and duplicate	Range of values for leachate from household wastes (Robinson, 1995)
Boron	6	4.7	3.45	
Cadmium (ug/l)	0.3	0.2	0.35	<5 – 10
Calcium	90	120	225	<20 – 165
Chromium	0.083	0.17	0.0625	<1.0 - 1
Cobalt (ug/l)	47	39	21.5	
Iron	7.9	5.5	24.5	<0.1 - 2050
Lead (ug/l)	2	19	14.5	50 - 600
Magnesium	160	160	220	<10 – 480
Manganese	0.2	0.21	0.55	0.3 - 250
Molybdenum (ug/l)	9.6	5.8	3	
Potassium	580	710	470	<0.05 - 2050
Sodium	1400	1600	1200	40 - 2800
Mecoprop	9.2	0.06	<0.02	
Total PAH	1.3	3.02	0.30	

Table 3: Leachate Composition

The table of results indicates that the composition of the leachate is typical of household waste leachate, although particularly elevated concentrations of ammoniacal nitrogen have been determined in the leachate from Phases 1 and 2. When compared with the leachate quality reported in 2003 (Enviros, 2003) the leachate appears to have strengthened. The strengthening of the leachate with time was anticipated by ESI (2003) in their hydrogeological risk assessment.

ESI (2003, Table 7.11) determined control and trigger levels for the determinands that were modelled in the Hydrogeological Risk Assessment (tributyltin, mercury, pentachlorophenol (list 1 substances); and chloride, ammonium and nickel (list 2 substances). List 2 substance control levels are defined from the mean plus two standard deviations and trigger levels on mean plus three standard deviations. The control and trigger values for chloride have been set at a higher value for boreholes G1 and G2 to reflect the higher background concentration in these boreholes. The list 1 substances continue to remain below the detection limit and the list 2 substances have remained below the respective control levels. The list 1 substances were not detected in the leachate. It was noted in subsection 6.4 that the concentrations of ammonia are high for landfill leachate and although ammonia is a reactive contaminant it is considered that it would be a good indicator of any leakage from the landfill site.

6.5 RESULTS OF TEMPORAL MONITORING

Groundwater monitoring records were supplied by the Environment Agency. It is clear from the issues that surround the plots of groundwater contours that this data cannot be relied upon. Not only do the ground levels need adjusting in the light of the revised set of ground levels (Appendix 5), but also there are inconsistencies in the data that require consideration. The borehole designated 58502128 is initially referred to as RJ2, then subsequently as RJ1 (it is suspected that the latter is correct). There are sudden rises in some of the groundwater levels that are not consistently apparent in other boreholes measured on the same date. From the data that was supplied, which covers the period March 2003 to June 2005, hydrographs were plotted for the majority of the boreholes. The resultant hydrographs appear to fall into two categories, namely:

1. Boreholes that show a systematic variation in groundwater levels, typical of these are boreholes 1 (Raisby Formation), A1 (Yellow Sand Formation), A2 (Raisby Formation), F2 (Raisby Formation), G1 (Raisby Formation), G2 (Yellow Sand Formation), H1 (Yellow Sand Formation), H2 (Raisby Formation), K1 (Yellow Sand Formation), L1 (Yellow Sand Formation), L2 (Raisby Formation), M1 (Yellow Sand Formation), M2 (Raisby Formation), N1 (Yellow Sand Formation) and N2 (Raisby Formation).

2. Boreholes that are flashier, typical of these are boreholes 2 (Raisby Formation), F1 (Yellow Sand Formation), RI2 (Raisby Formation) and RJ2 (Raisby Formation).

This difference in response does not appear to correspond to the variation in cover thickness, which is quite considerable, ranging from zero cover in Borehole A1, to 9.3m of Drift in Borehole N1 and 16.8m of made ground in Borehole J2. The less marked response in some of the boreholes would be more typically associated with high storage and high permeability. It is possible that these boreholes correspond with fault zones. In support of this, comparison of the logs for Boreholes F1 and F2 revealed that the Magnesian Limestone in Borehole F1 is dolomitised and contains jointing with abundant voids lined with calcite, with thin veins of calcite throughout, but these observations were not recorded for Borehole F2. The extensive dolomitisation noted in boreholes A1 and A2 could also be associated with faulting in the area of Borehole F1. The groundwater levels associated with these boreholes are all in the range of approximately 68 to 70 m AOD. Each of the boreholes does show what appears to be an occasional, large, flashy response to recharge. Of particular note is a peak in September 2004, which appears to be common to each of these boreholes. Although Borehole 2 could also be associated with faulting there is no specific evidence to suggest that this accounts for the groundwater levels in Borehole RJ2. It is considered more likely that the groundwater level in this borehole reflects a response to recharge and reflects the perched conditions offered by the Marl Slate. A particularly significant thickness of the Marl Slate was encountered in Borehole 9 and this is another of the boreholes that shows this flashy response.

The more systematically responsive boreholes show a lower total range in groundwater levels, but greater month-to-month variation. For each pair of boreholes (one with a response zone in the Raisby Formation and the other with a response zone in the Yellow Sand Formation) the groundwater levels show similar responses.

Examination of the borehole logs suggests that a number of other boreholes fall within fault zones. However, these boreholes show the more systematic variation in groundwater levels that has been described above. It is considered that this could reflect the stress field associated with the faults, with more open, or tensional sections of the faults providing zones of greater storage and therefore a more flashy response than the compression faults.

Groundwater chemistry data for the period January 2004 to April 2006 was also supplied by the Environment Agency. The data was re-entered as time series data and plots of the data were generated using EXCEL. Six of the plots were selected for inclusion in Appendix 9, namely:

i) Borehole G2 (Yellow Sand Formation), a borehole with elevated chloride concentrations, which are suspected to be derived from road salt contamination (subsection 7.4).

ii) Borehole J2 (Raisby Formation), a borehole that shows elevated groundwater levels and consistently shows evidence of contamination (suspected to be associated with one or more of: the considerable thickness of made ground that was encountered in the borehole, historic contamination associated with the former colliery yard to the south of the site entrance, or with either the soil recycling, or concrete batching activities being carried out, immediately to the west of the landfill operations (subsection 7.4).

iii) Borehole 10, which is most likely to be an "up-hydraulic gradient" borehole in the Yellow Sand Formation.

iv) Borehole F1 (Yellow Sand Formation), one of the boreholes showing a more "flashy" response, suspected to be associated with faulting.

v, vi) Boreholes K1 and GW8 (Borehole 9) boreholes with more systematic groundwater level changes in the Yellow Sand Formation and Raisby Formation and associated with the suspected location of an east-west -trending fault immediately to the north of the quarry.

The groundwater levels in Borehole G2 appear to show a seasonal fall of approximately 0.8m during the period March to June 2003. This is followed by a recovery in groundwater levels during the period July 2004 to June 2005. In order to assess the reason for the elevated conditions during summer 2005 reference needs to be made to the effective rainfall figures for the monitoring period and also to the patterns of groundwater dewatering from the Durham coalfield. The rise in groundwater levels is not reflected by systematic changes in the groundwater chemistry. The fact that the lowest sodium concentration was recorded in May 2005 suggests that elevated concentrations could be attributed to the use of road salt on the A690 as suggested in subsection 6.3. There do not appear to be any identifiable seasonal trends to the other determinands. However, this may be due to the apparent rise in groundwater levels in this borehole. The hydrograph for Borehole G1 follows a very similar pattern, with an overall rise in levels during the period July 2005 to May 2006.

Groundwater levels in Borehole J2 are consistently in the order of 78.05 to 79.07m AOD, with significant peaks in September 2004 and January 2005. The full suite of chemical determinands was not carried out on these occasions, so observations regarding the impact of the fluctuations in the groundwater levels on the groundwater chemistry cannot be made. The sulphate concentrations, which are elevated, do not appear to be correlated with the other determinands. Magnesium and calcium appear to be more closely correlated, but there is not enough data to investigate correlations with changing groundwater levels, i.e. to assess seasonality.

Groundwater levels in Borehole 10 are consistently in the order of 69.06 to 69.72m AOD, but show a very significant peak in May 2004, similar peaks have not been identified for this date in the other "flashy" response boreholes, suggesting that this could be an error of measurement. A considerably smaller peak, which does correspond with peaks in other boreholes was recorded in September 2004, however the peak of January 2005, which is evident in other boreholes was not evident in this borehole. The full suite of chemical determinands was not carried out in May or September 2004; therefore observations regarding the impact of the fluctuations in the groundwater levels on the groundwater chemistry cannot be made. The sodium and chloride concentrations in this borehole appear to be relatively consistent. However, a peak in sulphate concentrations (nearly 600 mg/l) was associated with elevated calcium and magnesium concentrations in February 2005. This could be due to elevated groundwater levels in Borehole J2 at this time, causing a change in the hydraulic gradient such that Borehole 10 received recharge from the area of Borehole J2. The gradual increase in concentrations (April to February) and fall (February to August) cannot be correlated with fluctuations in groundwater levels, or with the electrolytic conductivity. More monitoring data is required to assess the significance of the fluctuations in the groundwater chemistry.

Groundwater levels in Borehole F1 were considerably elevated in May and August to October 2003; no obvious reason for this has been identified. Based on the evidence that has been presented, the elevated levels could be attributable to a blockage in the borehole, alternatively it is possible that groundwater levels in the fault zones rise prior to the sudden ground movements that have been reported and are known to have occurred between May and November 2003 (subsection 3.5). The groundwater levels appear to show a gradual increase since November 2003. The elevated levels pre-date the groundwater chemistry data set, so observations regarding the impact of the fluctuations in the groundwater levels on the groundwater chemistry cannot be made. Meteorological data is required to interpret both the groundwater levels and the groundwater chemistry more fully. Furthermore, the current number of groundwater chemistry data sets limits the extent of any reliable interpretation. Nevertheless, the evidence from the data that have been presented indicates elevated concentrations of calcium and magnesium during the winter months, possibly reflecting higher energy recharge events.

The trend in Borehole K1 is one of rising groundwater levels (to October 2005), associated with increases in the concentration of calcium, sodium and to a lesser extent magnesium. The groundwater levels in Borehole GW8 (Borehole 9) appear to show seasonality. Groundwater levels generally fluctuate between 64.63 and 66.62 m AOD. However, the data shows two distinct peaks of 107.66 in September 2004 and February 2005. The reason for these peaks is not known. The September 2004 peak appears to be common to a number of boreholes. Meteorological data is required for further interpretation. The peak in February 2005 is associated with a lowering of the concentration of the major cations and anions, with the exception of chloride. Further data collection is required for more detailed assessment of seasonality in the data associated with this borehole.

7 Conceptual Model for Houghton Quarry Landfill

7.1 SOURCES

The initial hypothesis was that landfill leachate is the prime source of contamination from the site. Following consideration of the analytical results a number of other potential sources have been identified, as detailed below.

- With active plant operating on the site there are additional potential sources of mineral oil contamination.
- In addition to the activities that are directly related to the landfill there is a concrete batching plant and soil recycling area on the site. It is understood (Mr D Browell, Environment Agency, personal communication 1-9-06) that there is only limited surface sealing in the vicinity of the concrete batching and soil recycling areas.
- Examination of borehole records held by the BGS has identified that there was a former colliery yard to the southwest of the site entrance (NZ 337 504).
- A thickness of 16.2m of made ground was identified in Borehole J2. This could be indicative of a source of contaminated made ground, with a potential for leaching and consequential impact on groundwater quality. Unfortunately, the made ground is not described on the borehole log.
- There is arable land immediately to the north of the site and any crop spraying associated with the farming of this land would provide a potential source of herbicides and pesticides. Land to the south of the site is maintained as open access grassland and it is feasible that this is also subject to spraying activities, particularly associated with the public footpaths.
- ESI (2003) identified proximity to the A690 as a potential source of road salt contamination.

7.2 RECEPTORS

The key receptors have been defined in section 2 of this report. They comprise:

- The groundwater aquifers with particular concern for the public water supply at Stoneygate Pumping Station and the associated source protection zone, the site lies within the total catchment protection zone.
- The outer source protection zone associated with Stoneygate Pumping Station, which is situated in the order of 1200 m to the northeast of the site. The shape and position of the outer protection zone, to the west of the Stoneygate pumping station is indicative of an easterly hydraulic gradient. It should also be noted that the Stoneygate pumping station abstracts water from the Coal Measures.
- The hydrogeological risk assessment (ESI, 2003) identified a hypothetical receptor, comprising an agricultural abstraction well on the boundary of the site.

7.3 PATHWAYS

The proximity of the site boundary to the boundary between the Raisby Formation and the underlying Yellow Sand Formation suggests the likelihood of recharge to the Yellow Sand along the western boundary of the site. The boundary between the Raisby Formation and the underlying Yellow Sand Formation swings round to the south of the site and therefore recharge to the south of the site is also very likely. This is reflected in the results of the plotting of the groundwater contours (Appendix 5), which suggest an easterly hydraulic gradient in the southern part of the site, becoming a northerly gradient to the north (subsection 6.2).

The groundwater levels indicate that there is a recharge zone associated with the western side of the site, in the vicinity of Borehole J2. The groundwater levels at this location are also elevated by the perching effect of the Marl Slate.

Reference has been made to the faulting encountered by boreholes F1 and N1. Evidence derived from The GeoInformation Group Image (2006, Google Earth), suggests that from Borehole F1 the fault trends east-southeast from the borehole, but the westerly direction of the fault is not clear. Evidence from the borehole logs for boreholes L1 and A1 suggest the occurrence of a fault zone immediately to the north of the site, with a downthrow to the north. Following discussion with the Environment Agency it has been established that the boreholes were positioned to encounter the fault. Consideration of the likely position of the fault zone suggests that the groundwater contours in the northern part of the site could be modified to reflect the storage associated with the fault. However, the evidence from the hydrographs suggests that the fault zone is in hydraulic continuity with the aquifers. It may act as a partial groundwater divide, resulting in shallower groundwater contours across the site, with an increased gradient to the north of the fault. Recharge associated with the fault zone could also be the source for Northern Spring, the spring that is monitored in Grasswell Burn.

Limestone derives much of its permeability by dissolution and it can be subject to significant impacts resulting from point sources of contamination. The borehole logs indicate that the Magnesian Limestone is a soft limestone or dolomite, with many calcite lined voids being noted in some of the boreholes and with a void being noted in Borehole L1, below the water table at 37.5 to 39.0 m depth (approximately 55.50 to 54 m AOD). The occurrence of these features indicates a potential for the limestone to be a triple porosity medium, comprising matrix, fracture and channel porosity. Furthermore, there is a potential for open features that appear to be associated with a fault line to the southeast of Borehole F1. Therefore there is a potential for conduit flow within the limestone. However, whilst this is likely it has not been identified in the hydraulic testing that has been carried out to date.

7.4 INTERPRETATION OF THE RESULTS

The elevated concentrations of sodium and chloride noted in boreholes BH2 and G2 could possibly be attributable to the dissolution of halite, as reference to elevated chloride concentrations resulting from halite dissolution have been made by Brewerton and Edmunds, however the position of these boreholes, adjacent to the A690 would suggest that it is more likely that the elevated concentrations are derived from road salts. Further evidence for this comes from the temporal monitoring (Appendix 9), which shows that in Borehole G2 lower concentrations are determined during the summer months, albeit that the concentrations are still considered to be elevated. However, in Borehole 2, which is slightly farther to the north the response seems to be delayed. Furthermore, the trend appears to indicate an overall increase in the chloride concentration in this borehole with time.

It has already been stated (Section 6.3) that the source of the sulphate in Borehole J2 is unlikely to be the landfill leachate and that the value determined is unlikely to be naturally occurring. Furthermore, the elevated sulphate is also associated with elevated concentrations of calcium, magnesium, silica, nitrate, boron, potassium, molybdenum, uranium and selenium. Additionally, the calcium: magnesium ratio is significantly lower than that determined in any of the other boreholes. It would also appear that a similar source of contamination has affected the groundwater quality in boreholes RJ1, GW9 and GW8. These boreholes are grouped on the western side of the site. This points to another source of contamination. Brewerton and Edmunds (1997) noted that increases in sulphate are known from areas with significant fertiliser use. It follows from this that the most likely source of contamination in these boreholes emanates either from the soil recycling activities that are carried out in this part of the site, from the concrete batching activities carried out in an adjacent area, or it could be associated with the significant thickness of made ground (>16m) encountered in Borehole J2, which remains an unknown quantity that could be indicative of a more extensive area of landfill. Alternatively it may be associated with the former colliery yard to the south of the site entrance.

There are herbicides that are associated with Borehole G8 specifically and an insecticide associated specifically with Borehole G9, further investigation (contact with farmers and landowners to enquire about past and current land management practices) would be required to identify the actual sources of these contaminants. Even with further investigation it may prove impossible to fully establish the sources. The evidence from this investigation tends to point to local, site-specific applications of the herbicides and pesticides.

8 Conclusions

Mountainheath Services Limited and Scientifics Limited were appointed as independent laboratories to undertake the groundwater and leachate analyses in accordance with the Environment Agency specification.

The existing procedures for leachate sampling and groundwater sampling have been reviewed and a sampling audit was undertaken. A number of recommendations have resulted from this work (section 9). Field monitoring of the determinands that are recommended in the sampling protocol (ESI, 2004), as presented in Appendix 3, has been shown to be useful in the assessment of the purge times required for the groundwater sampling.

A review of the historical data was carried out and the difficulties in groundwater level interpretation associated with the poor quality of datum level data have been considerably reduced by the provision of the new set of datum levels supplied by Biffa Waste Services Limited (Appendix 5). This will be of considerable benefit to on-going monitoring of the site.

A review of the Hydrogeological Risk Assessment has been undertaken. The evidence presented in section 7 indicates that further work is required to develop a more complete conceptual model for the site. Nevertheless, the model that has been adopted for the Hydrogeological Risk Assessment would appear to be a conservative one, in terms of assessing the potential impact of the landfill site on the groundwater aquifers. The modelling approach adopted by ESI (2003) was aligned with current guidance (Leeson et al., 2003) and took a conservative approach to the derivation of parameters. Whilst reference has been made to the weaknesses in specific aspects of the data, such as the hydraulic parameters and the hydraulic gradient, it is considered that the modifications that would be likely to result from further development of the conceptual model (subsection 9.3) would result in a reduced risk to the potential sources. The list 1 control substances continue to remain below the detection limit and the list 2 substances have remained below the respective control levels. The list 1 substances were not detected in the leachate. The concentrations of ammoniacal nitrogen determined in the landfill leachate suggest that ammoniacal nitrogen would be a good indicator of any leakage from the landfill site

Examination of both the findings of this groundwater investigation and the results of historical monitoring has not identified any measurable impact of the landfill on groundwater quality. However, some groundwater contamination has been identified and this is primarily focused on the area of Borehole J2. Potential sources for this contamination include: the significant thickness of made ground identified in Borehole J2, the concrete batching and the soil recycling activities carried out adjacent to the site and the former colliery yard to the southwest of the site entrance.

9 Recommendations

The work that has been carried out has enabled an assessment to be made regarding the impact of the site on groundwater quality. The following recommendations are derived from: the audit of the Biffa Waste Services Limited monitoring procedures; consideration of the Hydrogeological Risk Assessment; the review of the temporal monitoring, and from work that fell outside the original remit of this investigation. The work with respect to the monitoring procedures is important in generating reliable data to facilitate future refinement of the monitoring and testing requirements of the Environment Agency. Recommendations with respect to the Hydrogeological Risk Assessment would improve the conceptual model for the site, but are unlikely to result in a change to the conclusions. Improvements with respect to the interpretation of the temporal monitoring would contribute to future refinement of the monitoring and testing requirements of the Environment Agency.

9.1 FIELD PROCEDURES

Overall the sampling of monitoring wells, leachate and surface water samples at the Houghton Le Spring Landfill is in accordance with good practice and recommended protocols. Biffa Waste Services Limited have deviated from the protocol suggested by ESI in the 2004 report which recommended short purge times based on water quality parameter (WQP) stabilisation, however purging three well volumes is a valid and proven technique and will not affect the representativeness of the samples collected. The short purge times recommended by ESI are based on Low Flow sampling methodologies which work best at flow rates of less than one litre per minute (preferably around 250ml- 500ml / minute) and in short screened wells. Water quality indicator parameter measurements collected by the BGS during long purges indicate that stabilisation may take longer than ten minutes in some boreholes and that the methodology comparison undertaken by ESI should be repeated at lower flow rates and include the full range of parameters i.e. EC, pH, Do, Eh and T. The following recommendations would improve the sampling methodology:

- Field measurement of water quality parameters EC, pH, Do, Eh and T should be undertaken for all samples (multi-probes are now available that have simple calibration procedures, log data and are relatively small).
- A field logbook should be kept for all sampling events that include field sheets for each monitoring well, leachate sample, and surface sample. The field sheet should be completed for each sample and include: time/date, borehole information, water level, purge volume, pump start/finish times, WQP data, observations, analysis requested etc.
- Flexible tubing that attaches to the inertial pump tubing should be fitted to each well to stop potentially contaminated groundwater being sprayed around the well. This will also help when filling sample bottles especially those for VOC analysis. Furthermore, the use of a plastic beaker for filling the sample bottles contributes to the uncertainty associated with the determination of DEHP.
- The analytical laboratory should be asked to provide cool boxes and ice packs for the transportation of samples or alternatively a courier with refrigerated vans.
- Access to the monitoring wells to the north of the site should be improved to enable sampling rounds to be completed within one week.
- An additional staff member would also speed up the sampling round.

- An alternative method of sampling Phase II Leachate should be devised or access improved.
- Reporting of data should be carried out after each sampling round and should include all field data, analytical results, and comparison with previous data and trend analysis.
- Boreholes G1, I2, RI1 should be investigated to determine why samples cannot be collected. The wells should ultimately be reinstated into the sampling round.
- The problems of contamination by DEHP serve to emphasise the requirement for the utmost of care to minimise DEHP contamination at all stages of the sampling and testing procedure. More specifically, consideration should be given to the use of the plastic jug for surface water sample collection and also the use of plastic containers for distilled water storage.

9.2 LABORATORY TESTING

It is clear from this round of sampling that improvements in technology have enabled the achievement of significantly lower limits of detection of a number of determinands and in particular the organic suite of tests. This requires a commensurate improvement in our understanding of the potential for cross-contamination associated with both the sampling and the laboratory testing procedures, for instance Mountainheath Services Limited have identified a requirement to ensure greater control over the extraction process. The use of blank and duplicate samples has been shown to be essential to the interpretation of the results and it is recommended that they should be incorporated within the routine analysis of the results. The Anova data provided by the laboratories has also proved to be useful in the interpretation of the results and it is recommended that the Environment Agency should request this data from the laboratory that is used by Biffa Waste Services Limited for use in the interpretation of the results. It is considered important that on-going interpretation of the results is carried out, in order that any anomalies are identified at the earliest stage. More specifically, monitoring of groundwater chemistry during any investigation of the made ground in the vicinity of Borehole J2 would contribute to the understanding of this area.

The potential problem of cross-contamination could be reduced by advising the laboratory of any samples that are thought to be more likely to be contaminated so that the extraction and testing order can be adjusted to work from “clean” to “contaminated” and the laboratory should be asked to follow this sequence of extraction and testing.

9.3 HYDROGEOLOGY

It is recommended that further consideration be given to the geological detail in order to refine the conceptual model of the hydrogeology of the site. In particular it would be useful to plot the extent of the Marl Slate Formation and contour the top of the Yellow Sand Formation to compare these surfaces with the groundwater levels.

The historic groundwater records need to be reassessed in the light of the revised ground levels.

It is considered that if more rigorous interpretation of the groundwater chemistry is required then a more detailed understanding of the hydrogeology is essential. In particular consideration could be given to the following:

- Reassessment of the data relating to the hydraulic testing in each of the formations.
- Further analysis of the response of groundwater levels in each of the formations to recharge.
- Assessment of temporal changes in the groundwater contours, in particular to investigate whether the “up-hydraulic” gradient boreholes that have been identified remain “up-

hydraulic gradient “, as there is some evidence to suggest occasional recharge from the area of Borehole J2.

- Further information is required to assess the impact of the faulting on the groundwater regime.

9.4 GROUNDWATER CHARACTERIZATION

Clearly the elevated concentration of metazachlor in the water from the Stoneygate Pumping Station requires further consideration. The evidence points to a localised source, possibly associated with either on-going agricultural activities, or with localised pest control. Traces of herbicides and pesticides have also been identified in a number of the other boreholes. Consideration could be given to contacting landowners and farmers to enquire about current and historic pest and weed control practices.

The likelihood of the chloride contamination being associated with the use of road salt has been identified in section 6.3. Anti-caking agents typically comprise sodium ferrocyanide (Yellow Prussiate of Soda) or ferric cyanide (Prussian Blue), which are added in concentrations in the order of 50 to 250 ppm. (Wisconsin Department of Transporation, 2004). Following consultation with the Highways Authority to identify whether or not anti-caking agents are included (or have been included historically) in the road salt that they utilise on the A690, it is recommended that groundwater samples from boreholes G1, G2, 2 and Borehole 10 (as a background control) be analysed for cyanide, or an alternative if a different anti-caking agent is used. In addition, it is considered that a walk-over survey to look at the area of the road drainage in the area immediately to the south of the lay-by on the western side of the A690 and immediately to the east of Houghton Quarry Landfill. Any hollows in this area could be an area in which surface water accumulates following snow melt, ice thawing, or rainfall, all of which offer the potential to mobilise any remnant road salt.

Further investigation is required to identify the source of the contamination that has been identified in Borehole J2. Potential sources for this contamination have been identified in section 7.1 and following an investigation of historic records pertaining to the site a phased investigation of each of the potential sources is recommended. In the first instance characterisation of the made ground associated with Borehole J2 will be required.

Elevated concentrations of uranium have been determined in some of the groundwater samples, again focused on Borehole J2, the source could be natural, or associated with the unknown characteristics of the made ground, the soil processing activities or the concrete batching activities if pulverised fuel ash is utilised. Consideration could be given to isotope analysis for assessing whether the uranium is naturally occurring or derived from an anthropogenic source. If the isotope signatures suggest a natural source gamma logging could be used to identify uranium in the quarry face for petrological analysis.

The temporal datasets require up-dating and on-going analysis.

9.5 ADDITIONAL SOURCES OF INFORMATION

Reference was made to the occurrence of abandoned mines beneath the Houghton Landfill in section 3.5. On-going research, for example Culshaw et al. (2006), has identified that those areas that have been subject to coal mining can be subject both to subsidence as a consequence of collapse of remnant pillars and also to rebound as a consequence of rising groundwater levels following the cessation of dewatering operations. Pillars in coal-mines are inherently unstable, but what is of key concern to the operation of the landfill site is the likelihood of collapse and the occurrence of upward collapse propagation during the design life of the landfill site. It is understood that consideration has previously been given to the potential for subsidence and that this was not considered to be a significant risk. However, research has moved on and therefore it is considered that a review of the current state of knowledge would be beneficial to the project and that this should be followed by further reviews at intervals throughout the design life of the landfill and in particular at the time of proposed closure of the landfill.

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

BRITISH GEOLOGICAL SURVEY. 1978. Sunderland Sheet 21 Solid and Drift Edition. 1:150 000. (Keyworth, Nottingham: British Geological Survey.)

ALLEN, D.J., BREWERTON, L.J., COLEBY, L.M., GIBBS, B.R., LEWIS, M.A., MACDONALD, A.M., WAGSTAFF, S.J. AND WILLIAMS, A.T. 1997. *The physical properties of major aquifers in England and Wales*. British Geological Survey Technical Report WD/97/34. NERC. 312pp.

BREWERTON, L.J. AND EDMUNDS, W.M. 1997. The Natural (Baseline) Quality of Groundwaters in England and Wales. Magnesian Limestone of Yorkshire and Northumbria. *Research and Development Project Record,* W6/i722/7. Environment Agency and Natural Environment Research Council.

CAIRNEY, T., AND HAMILL, L. 1977. Interconnection of surface and underground water resources in southeast Durham. *Journal of Hydrology*, 33, 73 – 86.

CULSHAW, M., TRAGHEIM, D., BATESON, L., DONNELLY, L. 2006. Measurement of ground movements in Stoke-on-Trent (UK) using radar interferometry. *Proceeding of the International Association of Engineering Geologists 10th International Congress: Engineering geology for tomorrow's cities.* Nottingham 1 6 – 10 September 2006.

CUSS, R.J. AND THOMPSON, G. 2003. Ground penetrating radar investigation of the fissuring of the A690 in Houghton-le-Spring. *British Geological Survey Commissioned Report*, CR/03/301R.

CUSS, R.J. AND BEAMISH, D. 2002. Ground penetrating radar and ground conductivity investigation of the fissuring of the A690 in Houghton-le-Spring. *British Geological Survey Internal Report*, IR/02/142.

ENVIRONMENT AGENCY. 2001. Guidance on Monitoring of Landfill Leachate, Groundwater and Surface Water. 158pp.

ENVIRONMENTAL SIMULATIONS INTERNATIONAL LIMITED (ESI). 2003. Houghton-le-Spring Landfill hydrogeological risk assessment. Report Reference 6373R1. June 2003. 87pp.

ENVIRONMENTAL SIMULATIONS INTERNATIONAL LIMITED (ESI). 2004. Protocol for Monitoring Environmental Surface and Groundwater at Houghton-le-Spring Landfill. Report Reference 6373D3, August 2004. 17pp.

ENVIROS CONSULTING LIMITED. 2003. Houghton-le-Spring Landfill Environmental Setting and Installation Design Report. 52pp.

LEESON, J., EDWARDS, A. (SLR CONSULTANTS); SMITH, J.W.N. AND POTTER, H.A.B. (2003). *Hydrogeological Risk Assessments for Landfills* and the Derivation of Groundwater Control and Trigger Levels.

RAMSEY, M.H. 1998. Sampling as a source of measurement uncertainty: techniques for quantification and comparison with analytical sources.

SMITH, D.B. 1994. Geology of the country around Sunderland. *Memoir of the British Geological Survey*, Sheet 21 (England and Wales.) ISBN 0 11 884498 9.

WISCONSIN DEPARTMENT OF TRANSPORTATION. 2004. *Anti-Caking Admixtures to Road Salt*. A Transportation Synthesis Report prepared for Bureau of Highway Operations by CTC and Associates LLC.

YOUNG, B. 2003. Renewed fissuring in the Magnesian Limestone beneath the A690 road at Houghton-le-Spring, City of Sunderland. *British Geological Survey Internal Report*, IR/03/111.

YOUNG, B AND CULSHAW, M.G. 2001. Fissuring and related ground movements in the Magnesian Limestone and Coal Measures of the Houghton-le-Spring area, City of Sunderland. *British Geological Survey Technical Report*, WA/01/04.

YOUNG, B AND LAWRENCE, D.J.D. 2002. Recent fissuring in the Magnesian Limestone at Houghton-le-Spring, City of Sunderland. *British Geological Survey Research Report*, RR/02/03.

Younger, P.L. 1994. Hydrogeology in the *Geology of North East England* (Second Edition). Special Publication of the Natural History Society of Northumbria.

Appendix 1 Monitoring Well Detail supplied by Biffa Waste Services Limited

Page 1

BH	North	East	Slotted Screens	Redrill/Replacement	Datum Level (BEDS)	Datum Level (ESI)	Datum Level (BHL)
BH1	550510.72	434324.45	51 - 60	Redrill	123.21	123	124.93
BH1 (redrill)	550501.22	434301.21	63.5-69.6		123.21	123	123
BH2	550610.57	434421.05	53-56 and 62-65	Redrill	122.68	122.5	122.76
BH2 (redrill)	550599.10	434414.00	61-67		122.68	122.5	122.45
BH9	550593.74	433940.48	52-58	Originally G1	107.66	107.3	107.36
BH10	550477.38	434163.82	55-61	GWG45	113.17	113	113.31
A1	550882.90	' 434473.10	47.4-53.4	New installation	103.49	103.4	103.6
A2	550880.10	434474.20	38-44	New installation	103.58	103.7	103.7
B1	550816.80	434497.10	56-62	New installation	104.3	104.5	104.45
F1	550948.81	434448.79	43-60	New Installation	97.96	97.6	97.63
F2	550953.72	434447.16	32-38	New Installation	97.64	97.2	97.22
G1	550596.85	434406.74	50-55.95	New Installation	123.44	123	123.04
G2	550592.03	434405.83	58.15-66.15	New Installation	123.58	123.3	123.29
GW8	550853.65	434007.05	29.20-35.20	Originally G9	87.53	87.2	87.45
H1	550906.37	434219.54	37-45	New Installation	95.55	95	95.03
H2	550905.87	434214.32	30-33	New Installation	95.54	95.1	95.09
I2	550567.99	434208.97	41.25-47.25	New Installation	120.92	120.4	120.43
J2	550676.43	433971.08	24-30	New Installtion	107.66	107.4	107.35
K1	550848.30	433998.20	42.5-45.50	New installation to pair GW8	87.94	88	N/A
L1	N/A	N/A	50-53	Replacement for GW7	93.5	94	N/A
L2	N/A	N/A	22.4-31.4	Replacement for GW7	93.55	94	N/A
M1(*)	550890.58	434330.45	36.50-39.50	Replacement for GW6	101.03	96	N/A
M2(*)	550890.03	434326.46	24-33	Replacment for GW6	100.94	96	N/A
N1	N/A	N/A	60.50 - 63.50	Replacement for GW3	112.03	112	N/A
N2	N/A	N/A	40-49	Replacement for GW3	112.27	112	N/A
RB2	N/A	N/A	32.8 - 41.80	Replacement for B2	104.53	100	N/A
RI1	N/A	N/A	51.3 - 60.3	Replacement of I1	121.24	120.1	N/A
RJ1	N/A	N/A	34-43.20	Replacement of J1	107.99	107.1	N/A

' Raised Jan 06

Pg.

Datum Level (Last Survey)	Total BH Depth (From Log)	BH Depth (ESI)	Log	Date	Carried out
	62.3	69.6	Yes	Unknown	W Armstrong
GL = 122.73 CL = 123.21	69.6	69.6	Yes	Unknown	W Armstrong
	65.5	67	Yes	Unknown	W Armstrong
GL = 122.43 CL = 122.68	71	67	Yes	Unknown	W Armstrong
GL = 107.21 CL = 107.66	61	58	Yes	Unknown	W Armstrong
GL = 113.11 CL = 113.17	60	43.9	Yes	Unknown	W Armstrong
GL = N/A CL = 103.49	56.4	53.4	Yes	15/04/1998	Weeks
GL = 103.54 CL = 103.58	48	44	Yes	16/04/1998	Weeks
GL = 104.29 CL = 104.30	62.8	35.01	Yes	03/04/1998	Weeks
GL = 97.44 CL = 97.96	61.98	30.47	Yes	26/10/1998	Weeks
GL = 97.16 CL = 97.64	41	30.25	Yes	09/11/1998	Weeks
GL = 122.84 CL = 123.44	70	56	Yes	17/11/1998	Weeks
GL = 123.06 CL = 123.58	70.4	66.2	Yes	03/12/1998	Weeks
GL = 87.21 CL = 87.53	35.2	35.2	Yes	Unknown	W Armstrong
GL = 94.90 CL = 95.55	46.4	45	Yes	11/11/1998	Weeks
GL = 94.98 CL = 95.55	36	33	Yes	18/11/1998	Weeks
GL = 120.92 CL = 120.38	49.27	47.3	Yes	27/11/1998	Weeks
GL = 107.27 CL = 107.67	30.5	30	Yes	07/12/1998	Weeks
GL = 87.40 CL = 87.94	53	43	Yes	17/02/2004	ESI
GL = 93.04 CL = 93.50	54	54	Yes	21/01/2004	ESI
GL = 93.12 GL = 93.55	31.4	31	Yes	27/01/2004	ESI
101.03*	41.8	48	Yes	13/01/2004	ESI
100.94*	33.5	40	Yes	15/01/2004	ESI
GL = 111.42 CL = 112.03	65.8	63	Yes	21/01/2004	ESI
GL = 112.27 CL = 111.68	50	48	Yes	26/01/2004	ESI
GL = 103.85 CL = 104.53	44.9	41	Yes	09/01/2004	ESI
GL = 120.69 CL = 121.24	63	59	Yes	30/01/2004	ESI
GL = 107.4 CL = 107.99	48	45	Yes	16/02/2004	ESI

Appendix 2 Biffa Waste Services Limited Amendments to the ESI (2004) Sampling Protocol

Biffa Waste Services Ltd
Amendments to ESI 'Protocol for Monitoring Environmental Surface Water and Groundwater at Houghton le Spring Landfill'
Date: 23rd May 2006

Location	Original	Amended
Pg 4, Tab 3.1	*Purge time column*	Purge time varies from those calculated on site
Pg 4, Tab 3.1	*H1 and H2 – Diameter reported as 110mm*	Actual diameter for H1 and H2 is 50mm
Pg 7, Sec 5, Para 2	*Before a sampling round begins, any meters for on-site measurements (including EC, pH, DO and temperature) must be calibrated according to manufacturers' instructions.*	EC, pH and DO are not recorded on site and are undertaken at accredited labs.
Pg7, Sec 5, Para 4	*Ground levels should be measured from a standard datum, which should be recorded with the measurement*	Standard datum measurements are determined once entered onto BEDS (Biffa Environmental Data System)
Pg 7, Sec 5, Para 5	*Any parameters, such as EC and DO, which are measured on site, should be recorded in*	EC and DO are not recorded on site and undertaken at accredited labs

	the water sampling notebook.	
Pg 8, Sec 6, Para 2	*If tubing needs to be withdrawn from a borehole (e.g. for maintenance purposes) and is to be reinstalled, it should be wound onto a reel that will keep it clear of the ground and any surrounding vegetation*	In order to ensure that tubing remains uncontaminated during maintenance, the discharge end of the pipe is fed into the borehole whilst the pipe is inverted.
Pg 9, Sec 7, Sub-Sec 7.1, Par 1	*If for any reason the pipe needs to withdrawn from the borehole it should be wound onto a reel…*	In order to ensure that tubing remains uncontaminated during maintenance, the discharge end of the pipe is fed into the borehole whilst the pipe is inverted.
Pg 9, Sec 7, Sub-sec 7.1, Sub-heading *Sampling Method*, Para 2	*Method 1 is the preferred method for sampling all the boreholes.*	Due to the positioning of many of the groundwater boreholes and the logistics required to mobilise all equipment required for Method 1, all boreholes are sampled using the environment agency guidance of 3 well volumes to provide a representative groundwater sample. This is considered the most efficient method.
Pg 10, Sub-sec 7.3	*Parameters to be measured on site are EC, pH*	EC, pH and DO are not recorded on site and

	and DO and temperature. The recommended method for measuring these parameter is using a flow-through cell	are undertaken at accredited labs therefore the flow-through cell method is not required.
Pg 11, Sub-sec 7.3, Para 2	*A duplicate, filtered sample may be submitted at the same time for comparative purposes*	Duplicate samples are not taken of turbid water.
Pg 12, Section 8, Para 11	*The analysing laboratory should be instructed to filter the sample for analysis for the major ions and meta, but to use unfiltered samples for analysing organic chemicals*	Unknown
Pg 16, Sec 10, Para 4	*If either a control or trigger level is exceeded, repeat samples should be taken immediately*	Unknown

Appendix 3 Summary of field observations

Borehole I.D.		Easting	Northing	Date	Rest Water Level m bgl	Casing diameter mm
RJ1	2128	33968	50671	12-Jun-06	38.58	110
GW9	2009	33938	50592	12-Jun-06	42.02	110
J2	2118			12-Jun-06	29.06	50
K1	2219	33995	50849	12-Jun-06	20.38	110
GW8	2112			12-Jun-06	19.82	110
PHASE 1 LEACHATE	3001	34456	50881	12-Jun-06	n/a	n/a
PHASE II LEACHATE	3002			12-Jun-06	n/a	n/a
F2	2109	34446	50950	13-Jun-06	30.41	50
F1	2108	34450	50949	13-Jun-06	30.60	50
H2	2114	34217	50906	13-Jun-06	27.76	50
H1	2113	34212	50905	13-Jun-06	27.77	50
RB2	2128	34489	50823	13-Jun-06	36.02	110
N2	2125	34494	50756	13-Jun-06	43.66	110
N2A	Duplicate of N2			13-Jun-06		
A1	2101	34472	50884	14-Jun-06	36.04	50
GRASWELL BURN	4001	30422	50975	14-Jun-06		
A2	2102	34472	50879	14-Jun-06	36.13	50
B1	2103	34496	50821	14-Jun-06	36.02	50
L1	2120	34140	50892	14-Jun-06	26.08	110
L1A	Duplicate of L1			14-Jun-06		
L2	2121	34136	50886	15-Jun-06	25.77	110
POND	4002	34086	50637	15-Jun-06		
M1	2122			15-Jun-06	33.12	110
M1A	Duplicate of M1			15-Jun-06		
PHASE IIB LEACHATE	3102			15-Jun-06	n/a	n/a
PHASE IIBa LEACHATE	3102A			15-Jun-06	n/a	n/a
BA (Blank)	1111			15-Jun-06		
N1	2124			16-Jun-06	n/d	n/d
Blank BB	1112			16-Jun-06	n/a	n/a
Stoneygate Pumping Station	1113	35449	51756	16-Jun-06	n/a	n/a
BH10	2101	34156	50475	16-Jun-06	42.82	110
BH1	2001			16-Jun-06		
BH2	2002			16-Jun-06		
G2	2111	34402	50593	16-Jun-06	54.13	50
G1	NO SAMPLE			16-Jun-06	53.76	50
I2	NO SAMPLE	34208	50567	16-Jun-06	47.13	110
RI1	NO SAMPLE	34213	50570	16-Jun-06	51.94	110

Borehole I.D.	Casing above GL m	Sampling Method	BH Depth m	Water column m
RJ1	0.58	Wattera	45	6
GW9	0.45	Wattera	58	16
J2	0.29	Bailer	30	1
K1	0.51	Wattera	43	23
GW8		Wattera	35	15
PHASE 1 LEACHATE	n/a	Tap	n/a	n/a
PHASE II LEACHATE	n/a	Tap	n/a	n/a
F2	0.45	Wattera	38	8
F1	0.47	Wattera	60	29
H2	0.62	Wattera	33	5
H1	0.26	Wattera	45	17
RB2	0.55	Wattera	41	5
N2	0.54	Wattera	48	4
N2A		Wattera		0
A1	0	Wattera	53	17
GRASWELL BURN		Wattera		0
A2	0.00	Wattera	44	8
B1	0.00	Wattera	62	26
L1	0.44	Wattera	56	30
L1A		Wattera		0
L2	0.42	Wattera	32	6
POND		Beaker		
M1	0.45	Wattera	49	15
M1A		Wattera		0
PHASE IIB LEACHATE	n/a	Tap	n/a	n/a
PHASE IIBa LEACHATE	n/a	Tap	n/a	n/a
BA (Blank)				0
N1	n/d	Wattera	n/d	n/d
Blank BB	n/a	Wattera	n/a	n/a
Stoneygate Pumping Station	n/a	Pump	n/a	n/a
BH10	0.00	Wattera	62	20
BH1		Wattera		0
BH2		Wattera		0
G2	0.50	Wattera	66	12
G1			56	2
I2	0.51		47	0
RI1	0.56		60	9

Borehole I.D.	pump start time	pump stop time	purge time	pump speed l/min	Purge Volume (Biffa Calc) l
RJ1	9:38	11:14	1:36	3	60
GW9	9:54	13:25	3:31	2	160
J2			0:00		2
K1	11:49	16:45	4:56	2	645
GW8	13:51	15:30	1:39	6	438
PHASE 1 LEACHATE	n/a	n/a	n/a	n/a	n/a
PHASE II LEACHATE	n/a	n/a	n/a	n/a	n/a
F2	8:43	10:40	1:57	2	45
F1	9:28	10:55	1:27	2	174
H2	11:49	12:00	0:11	5	31
H1	12:28	9:15 next day	1:10	4	101
RB2	15:27	16:17	0:50	3	142
N2	15:35	16:50	1:15	3	195
N2A			0:00		
A1	10:12	10:40	0:28	3	102
GRASWELL BURN			0:00		
A2	10:55	11:20	0:25	3	46
B1	11:48	12:45	0:57	3	153
L1	8:40	13:15	4:35	3	850
L1A			0:00		
L2	8:30	9:25	0:55	4	183
POND					
M1	10:18	12:33	2:15	4	440
M1A			0:00		
PHASE IIB LEACHATE	n/a	n/a	n/a	n/a	n/a
PHASE IIBa LEACHATE	n/a	n/a	n/a	n/a	n/a
BA (Blank)			0:00		
N1	n/d	n/d	n/d	n/d	n/d
Blank BB	n/a	n/a	n/a	n/a	n/a
Stoneygate Pumping Station	n/a	n/a	n/a	n/a	n/a
BH10	10:30	12:25	1:55	2	558
BH1			0:00		
BH2			0:00		
G2	14:20	14:50	0:30	1	70
G1			0:00		
I2	n/a	n/a	n/a	n/a	n/a
RI1					

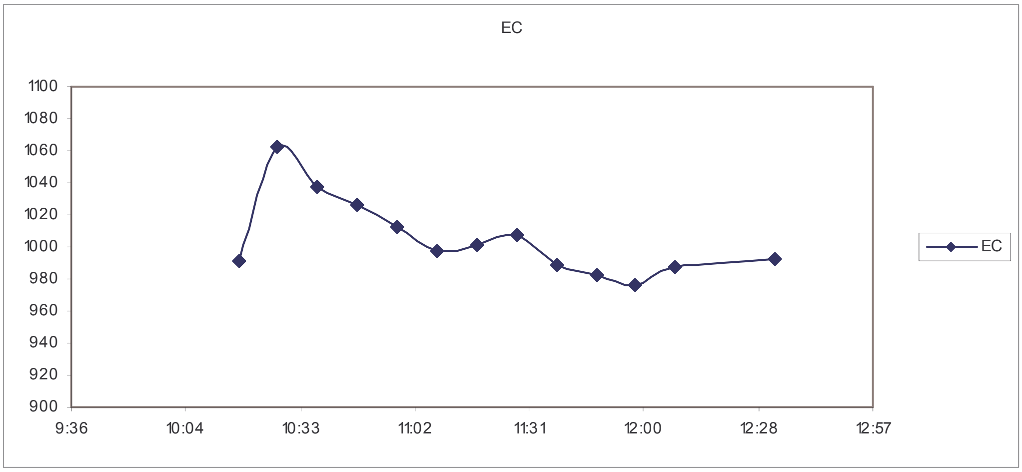
Borehole I.D.	Sample Description

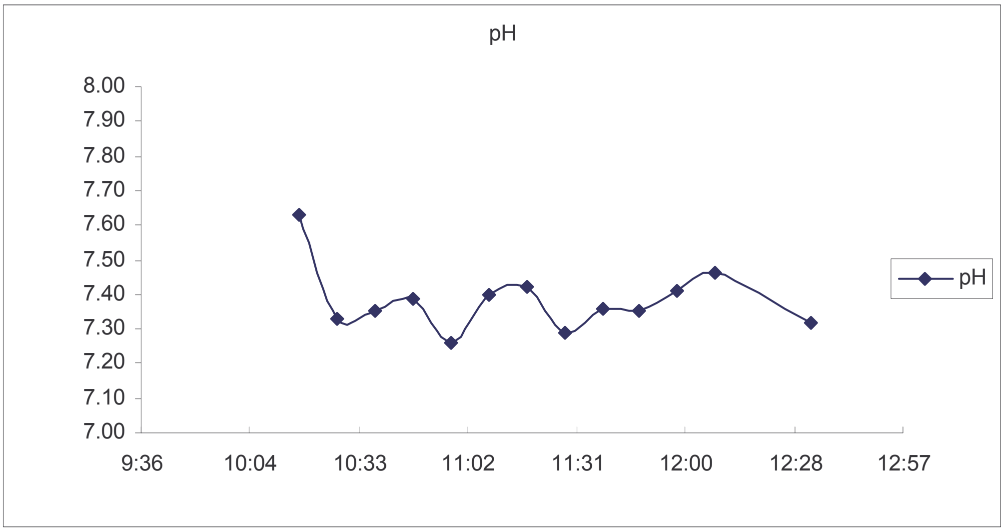
RJ1	Cloudy then cleared, no odour or product
GW9	Clear no product or odour
J2	Clear no product or odour - only 2 litres collected sample only sent to Scientifics
K1	Clear, no odour or product
GW8	Clear, no odour or product
PHASE 1 LEACHATE	Dark brown, methanogenic odour, degassing, no NAPL
PHASE II LEACHATE	Black, methanogenic odour, degassing, no NAPL
F2	Cloudy then cleared, no odour or product
F1	Clear, no odour or product
H2	Clear, no odour or product
H1	Cloudy then cleared, no odour or product
RB2	Clear, no odour or product
N2	Clear, no odour or product
N2A	Duplicate of N2
A1	Cloudy then cleared, no odour or product
GRASWELL BURN	Insufficient flow to collect sample
A2	Cloudy then cleared, no odour or product
B1	Clear, no odour or product
L1	Cloudy then cleared, no odour or product
L1A	Duplicate of L1
L2	Clear no product or odour
POND	Sampled directly from pond
M1	Clear no product or odour
M1A	Duplictae of M1
PHASE IIB LEACHATE	Dark brown, methanogenic odour, degassing, no NAPL
PHASE IIBa LEACHATE	
BA (Blank)	DI water poured directly into bottles
N1	pump breakdown started on 15th finished on 16th
Blank BB	Colleted through wattera tubing. Water supplied by VWR International to Biffa
Stoneygate Pumping Station	Colleted from tap at pumping station, tap constantly running
BH10	Clear no product or odour
BH1	
BH2	
G2	Clear no product or odour
G1	
I2	Insufficient sample
RI1	Not sampled , highly silted

Borehole I.D.	Field Temp °C	Field Eh uc mV	Field Eh mV	Field pH	HCO_3^- vol ml	HCO_3^- read
RJ1	15.1	275	484	7.37	25	148
GW9	15.5	266	475	7.09	25	136
J2	14.5	274	484	7.03	25	98
K1	17.4	144	351	7.57	25	48
GW8	16.3	102	310	7.77	25	41
PHASE 1 LEACHATE	24	55	254	7.55	25	1077
PHASE II LEACHATE	27.2	-42	155	7.12	25	2680
F2	14.5	245	455	7.49	25	50
F1	11.5	270	483	7.40	25	39
H2	11.6	239	451	7.53	25	42
H1	13.3	222	433	7.29	25	49
RB2	13.5	293	504	7.12	25	53
N2	13.5	281	492	7.16	25	52
N2A			224		25	
A1	12.1	208	420	7.62	25	29
GRASWELL BURN			224		25	
A2	15	248	457	7.33	25	29
B1	15	282	491	7.38	25	54
L1	13.2	254	465	7.42	25	43
L1A			224		25	
L2	12.8	276	487	7.19	25	34
POND	18.3	200	406	8.02	25	10
M1	14.2	250	460	7.32	25	43
M1A			224		25	
PHASE IIB LEACHATE	19.3	-106	99	6.98	25	950
PHASE IIBa LEACHATE			224		25	
BA (Blank)	14.1	171	381	9.10	25	4
N1	14.1	236	446	7.55	25	
Blank BB			224		25	
Stoneygate Pumping Station	10.1	199	412	6.74	25	28
BH10	13.3	261	472	7.25	25	28
BH1			224		25	
BH2			224		25	
G2	13.6	257	467	7.91	25	30
G1						
I2						
RI1						

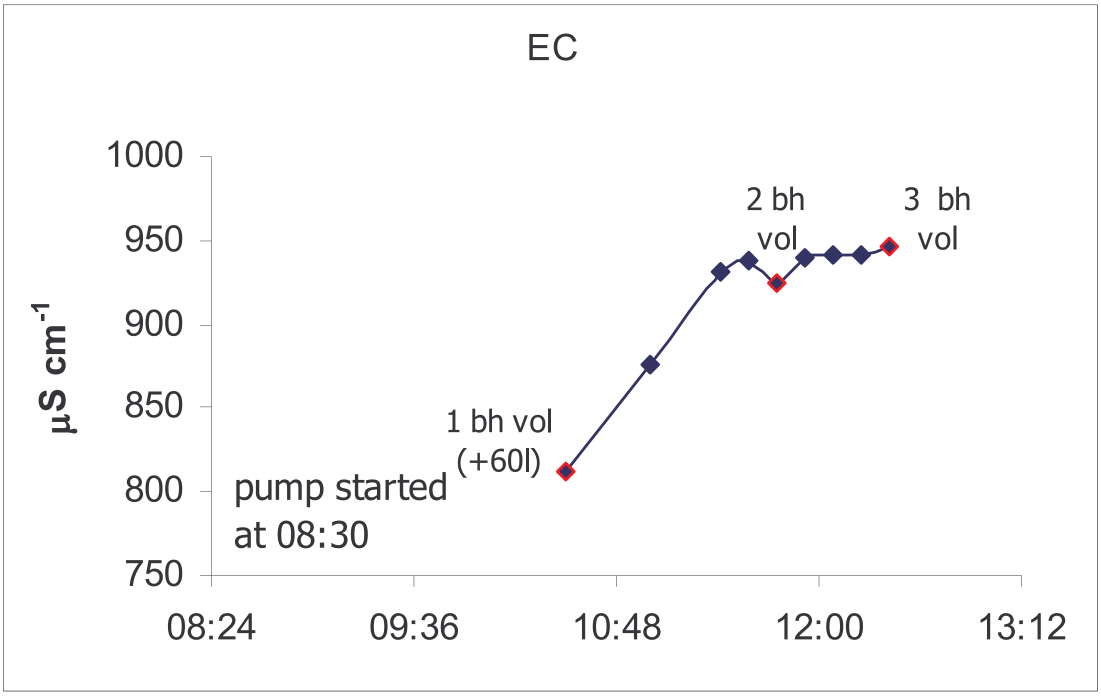
Borehole I.D.	Field HCO_3^- mg l^{-1}	Conductivity µS cm^{-1}	DO_2 mg l^{-1}
RJ1	722	1922	3.60
GW9	663	1982	5.02
J2	478	3080	4.60
K1	234	1084	3.73
GW8	200	1475	2.48
PHASE 1 LEACHATE	5252	16100	1.63
PHASE II LEACHATE	13070	15400	0.41
F2	244	808	7.82
F1	190	979	4.56
H2	205	825	7.20
H1	239	668	6.96
RB2	258	1089	3.40
N2	254	1134	7.27
N2A	0		
A1	141	930	5.63
GRASWELL BURN	0		
A2	141	900	3.40
B1	263	931	5.75
L1	210	888	3.85
L1A	0		
L2	166	751	5.82
POND	49	1010	6.24
M1	210	992	4.32
M1A	0		
PHASE IIB LEACHATE	4633	12100	0.09
PHASE IIBa LEACHATE	0		
BA (Blank)	20	29.1	4.79
N1	0	835	5.79
Blank BB	0		
Stoneygate Pumping Station	137	913	5.57
BH10	137	947	6.28
BH1	0		
BH2	0		
G2	146	1372	3.56
G1			
I2			
RI1			

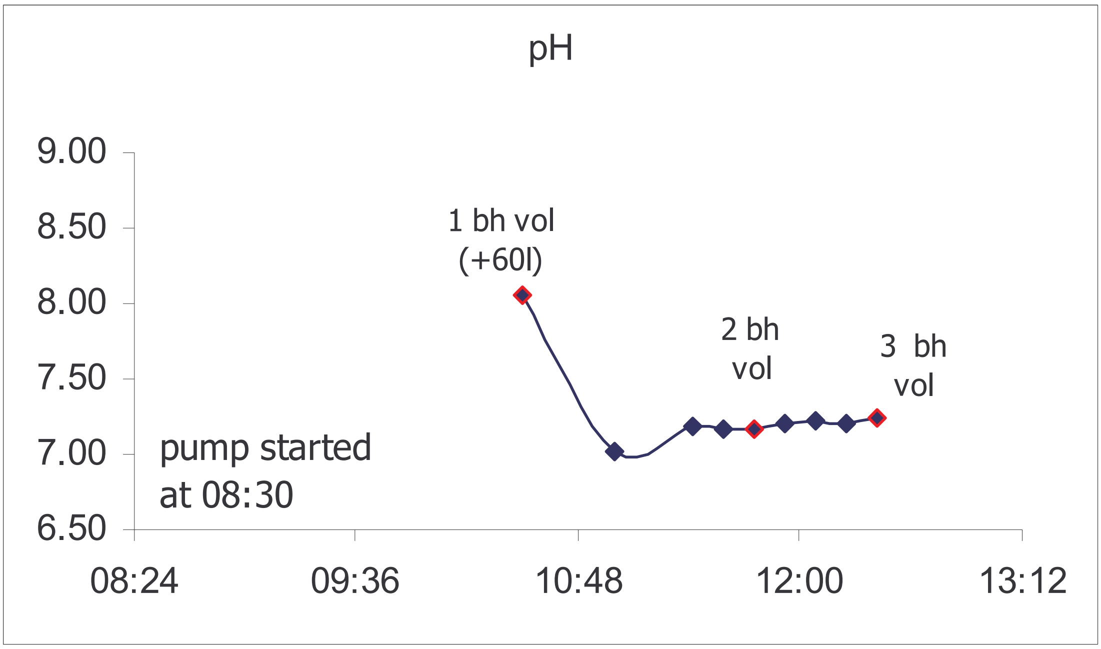
BOREHOLE M1: PURGE MONITORING RESULTS

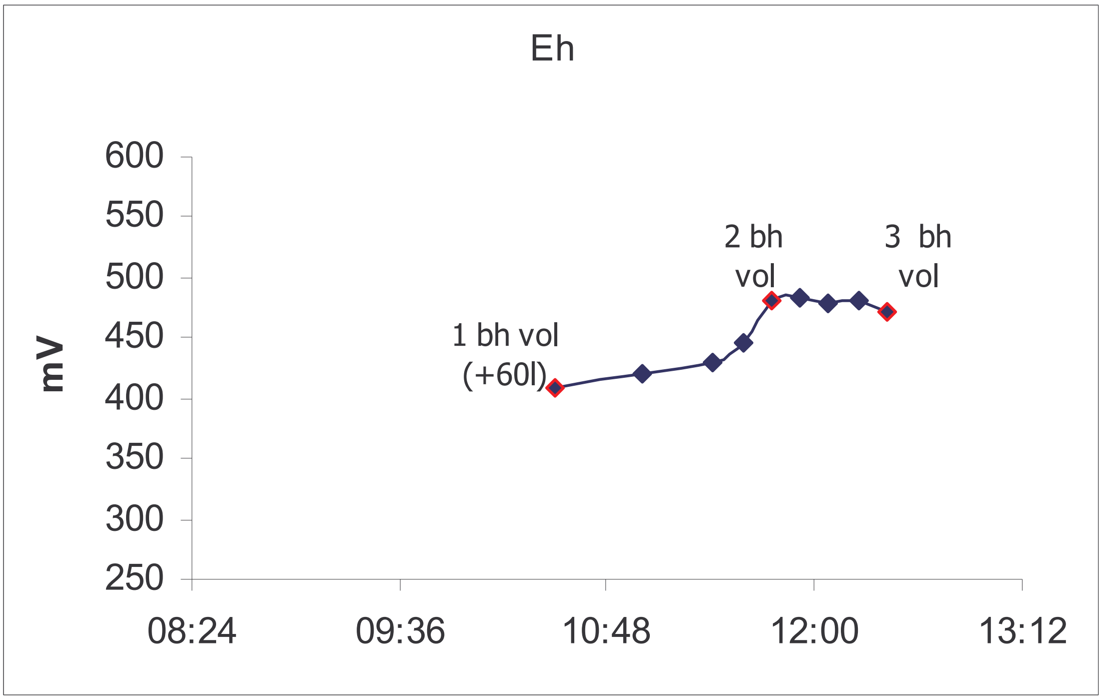


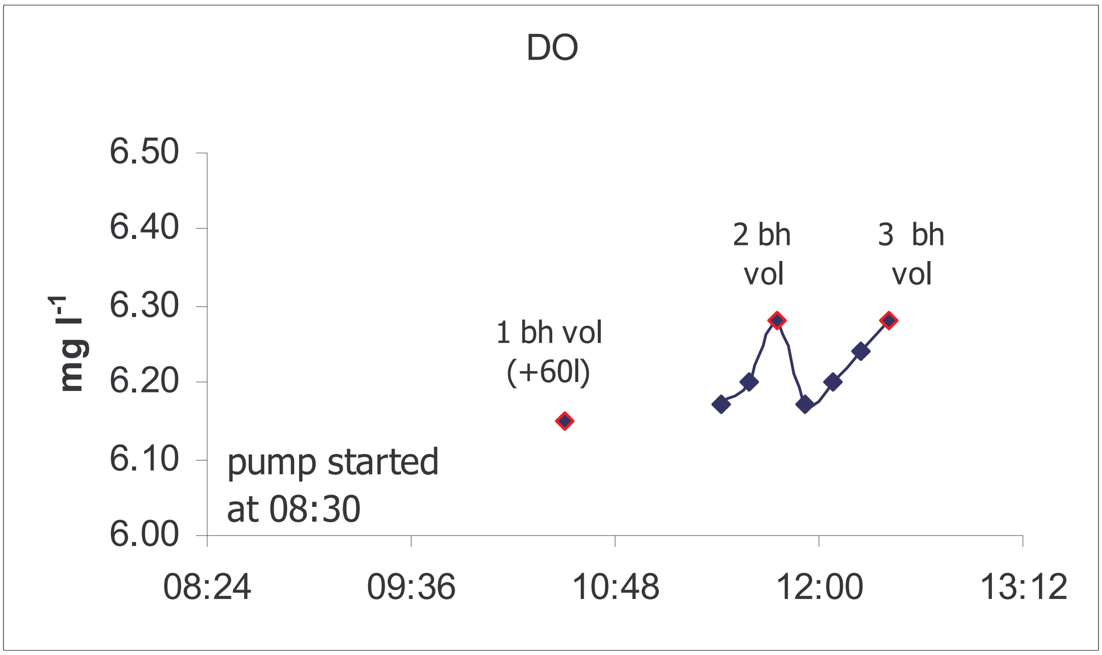


BOREHOLE 10: PURGE MONITORING RESULTS

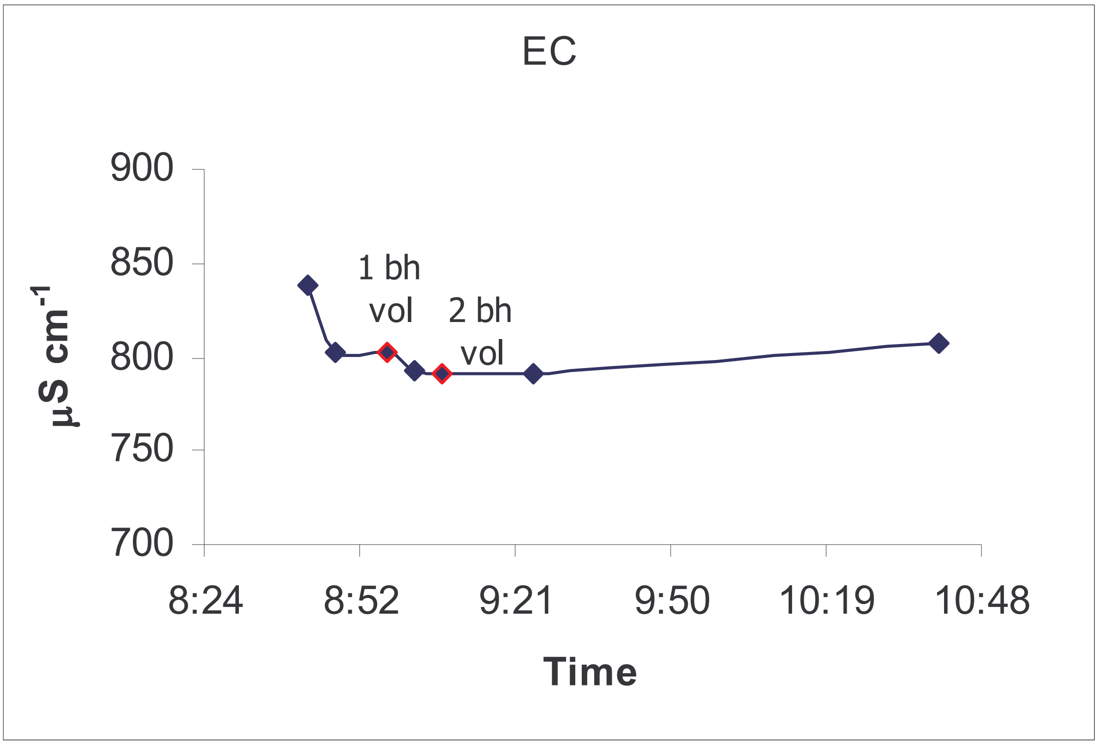


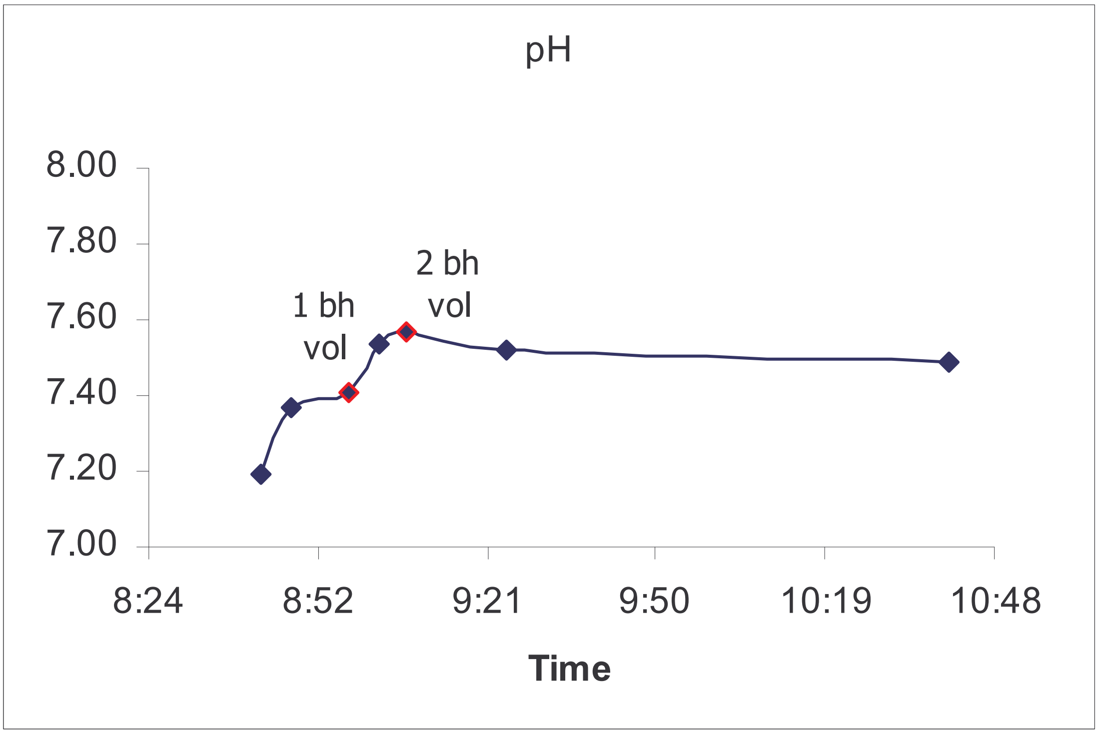


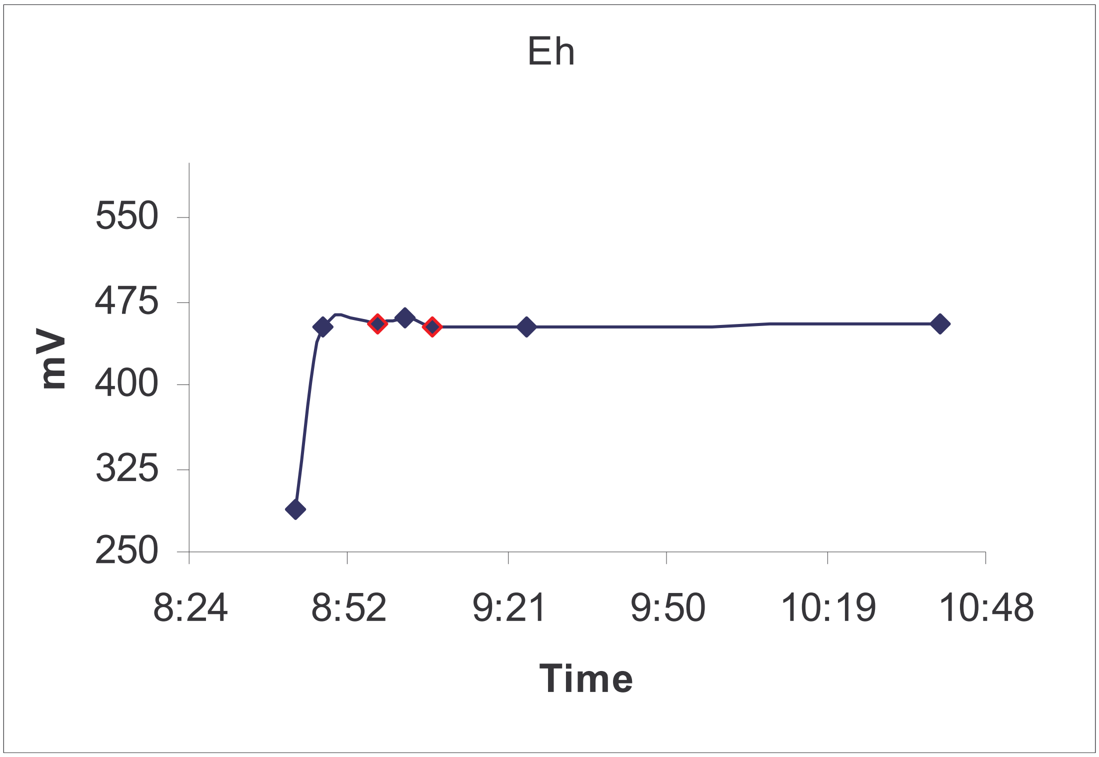

Eh
600
550
500
450
400
350
300
250
mV
1 bh vol
(+60l)
2 bh
vol
3 bh
vol
08:24
09:36
10:48
12:00
13:12

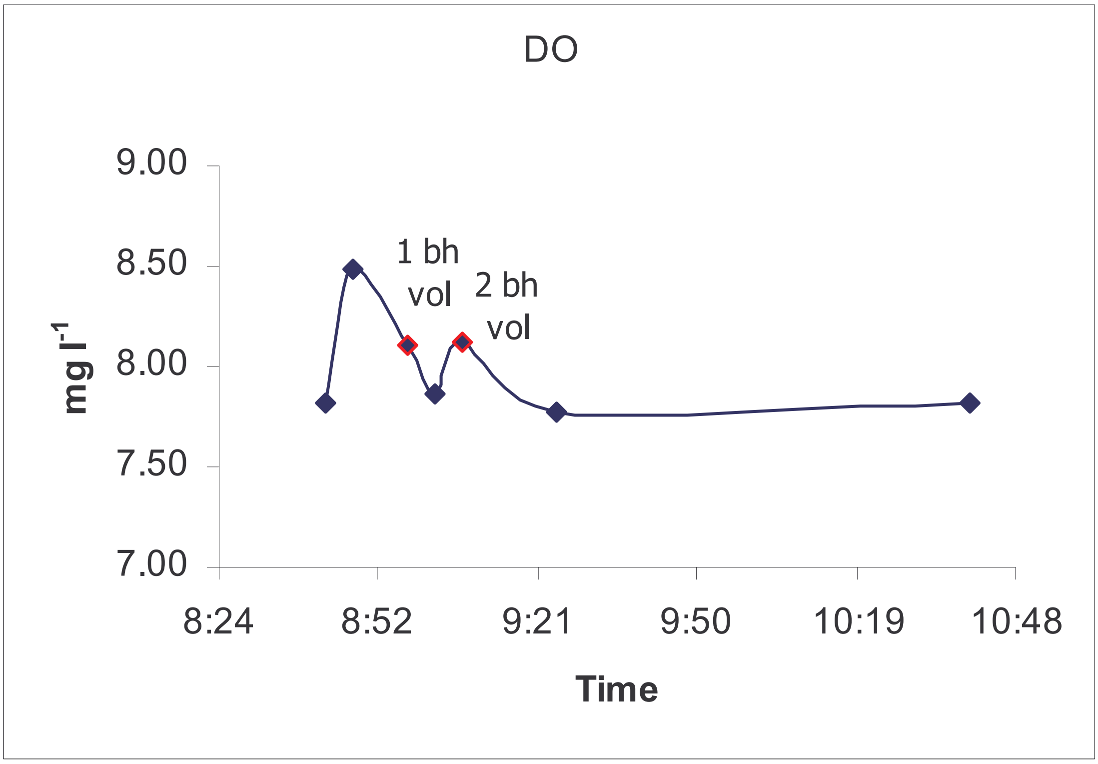

DO
6.50
6.40
6.30
6.20
6.10
6.00
mg l-1
1 bh vol
(+60l)
2 bh
vol
3 bh
vol
pump started
at 08:30
08:24
09:36
10:48
12:00
13:12

BOREHOLE F2: PURGE MONITORING RESULTS

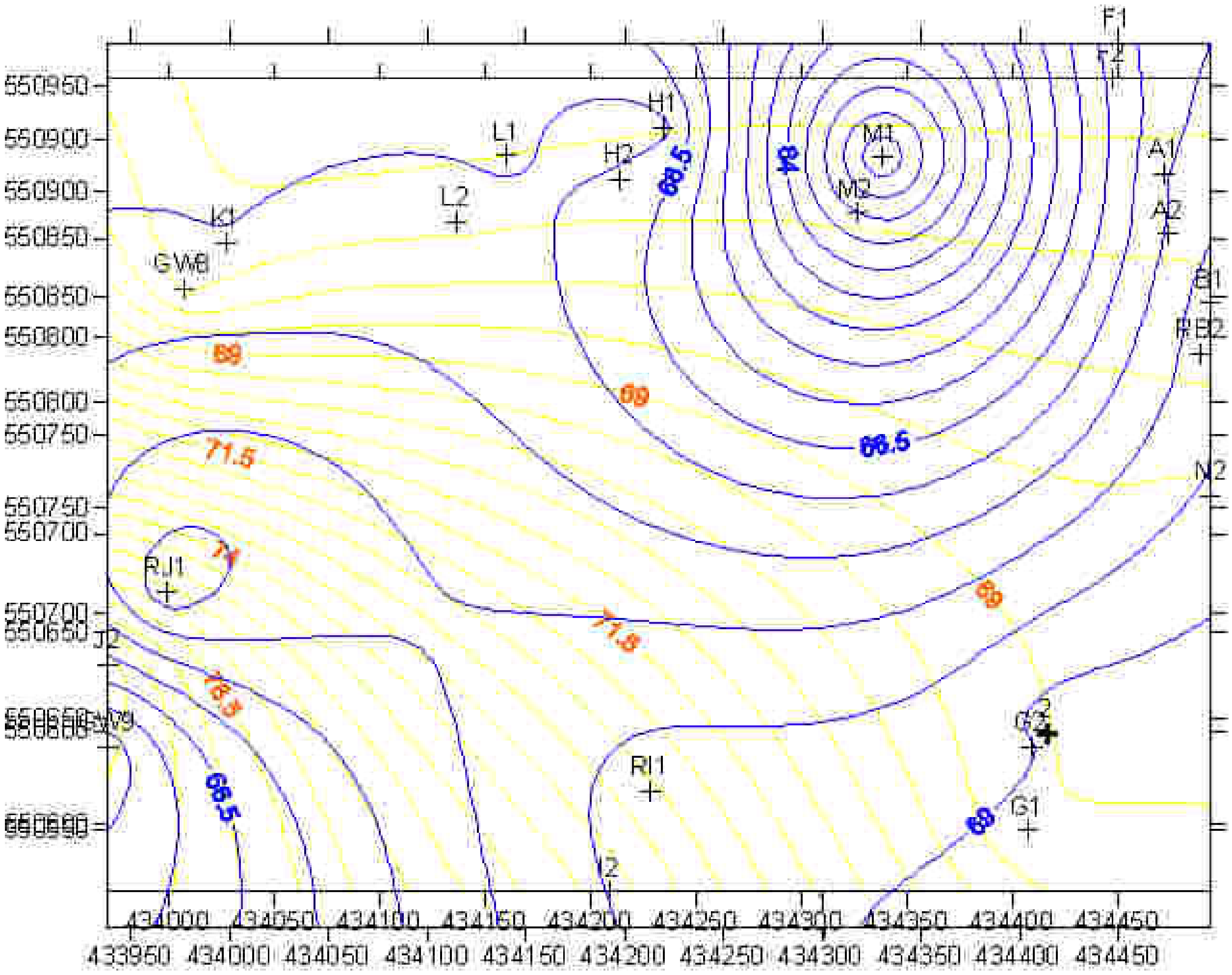




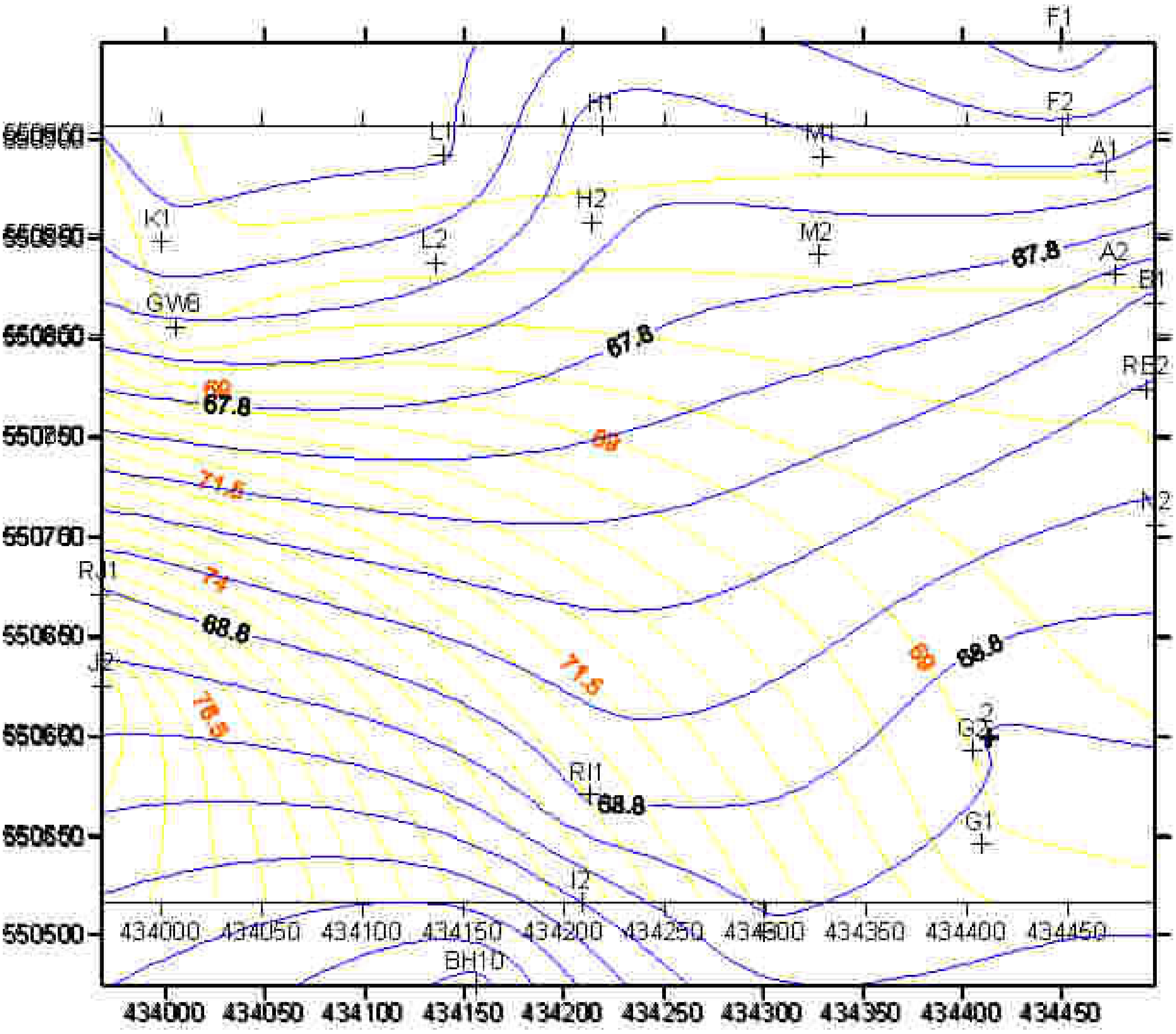

Eh
550
475
400
325
250
mV
8:24
8:52
9:21
9:50
10:19
10:48
Time


DO
9.00
8.50
8.00
7.50
7.00
mg l-1
1 bh vol
2 bh vol
8:24
8:52
9:21
9:50
10:19
10:48
Time

Appendix 4 Groundwater Contours derived from previous level surveys



Plot of groundwater contours (June 2006) determined from Biffa Waste Services Limited Latest Survey data (Appendix 1).



Plot of groundwater contours (June 2006) determined from Biffa Waste Services Limited BEDS data (Appendix 1).

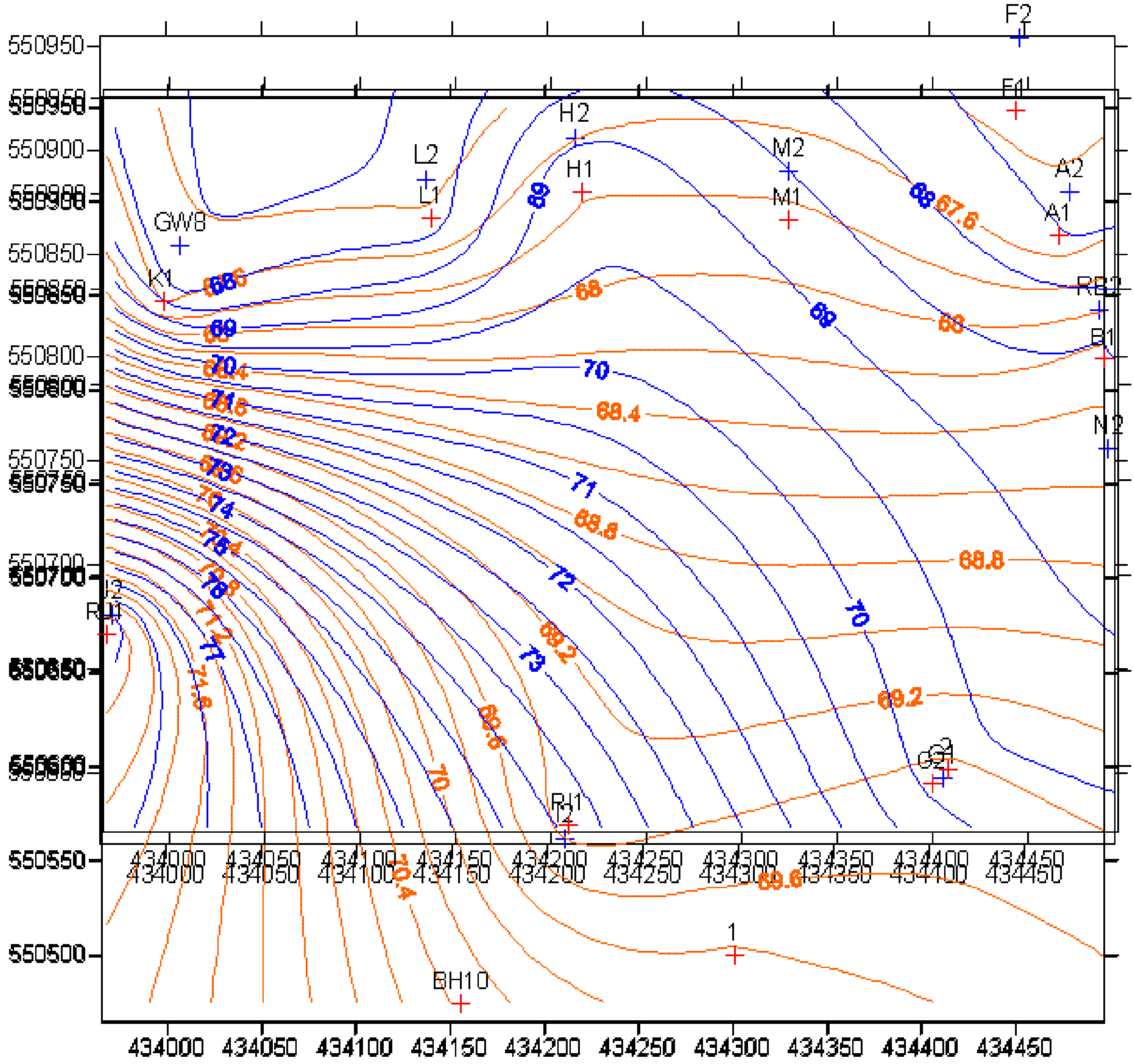
Appendix 5 Results of Levelling Survey carried out in September 2006, with revised plot of Groundwater Contours

Biffa Waste Services

Houghton le Spring Landfill Site

Groundwater Borehole levels October 2006.

Borehole	**Cap Level MAoD**	**Ground level MAoD**	**Depth to water (m)**	**Groundwater Level m AOD**
BH9	107.658	107.213	42.02	65.638
J1	107.989	107.404	35.58	72.409
J2	107.665	107.269	29.06	78.605
L1	93.5	93.039	26.08	67.42
L2	93.553	93.116	25.77	67.783
K1	87.944	87.4	20.38	67.564
BHGW8	87.53	87.21	19.82	67.71
N1	112.028	111.421	43.62	68.408
N2	112.266	111.681	43.66	68.606
B2	104.53	103.847	36.02	68.51
M1	100.969	100.488	33.12	67.849
M2	100.933	100.405		
H1	95.55	94.898	27.77	67.78
H2	95.545	94.977	27.76	67.785
F1	97.957	97.444	30.6	67.357
F2	97.636	97.155	30.41	67.226
A1	103.489	103.444	36.04	67.449
A2	103.576	103.538	36.13	67.446
B1	104.3	104.291	36.02	68.28
I1	121.244	120.692	47.04	74.204
I2	120.92	120.375	51.94	68.98
BH10	113.172	113.112	42.82	70.352
BH1	123.21	122.731	53.39	69.82
G1	123.442	122.84	53.76	69.682
G2	123.584	123.056	54.13	69.454
BH2	122.676	122.428	53.25	69.426


F2
F1
H2
H1
L2
L1
M2
M1
A2
A1
GW8
K1
RB2
B1
N2
I2
RH1
PH1
G2
G1
BH10
1
550950
550900
550850
550800
550750
550700
550650
550600
550550
550500
434000
434050
434100
434150
434200
434250
434300
434350
434400
434450
68
69
70
71
72
73
74
75
76
77
67.6
68.4
68.8
69.2
69.6
70
70.4
71.6

Appendix 6 Scope of laboratory testing scheduled by the Environment Agency

Groundwater Analytical Suites - Version 5.0 : Suites for use in 2006

Final

Last revised 8 December 2005

Next Review October 2006

Suite/Determinand	Det No	Method Code	Reporting limits	Units
			Scs=Starcross	
			Ntm=Nottingham	
I1 - Field (GWQMI1)				
DO (% saturation)	9901	26		% saturation
DO (mg/l)	9924	26 or 25		mg/l
pH (field/in situ)	3169	26		pH units
SEC (conductivity)	0062	26		μΣ/χμ
Temp	0076	26		deg C
I2 - Anions and Metals (GWQMI2)				
Ionic Balance	7044	25	calculated	%
Ammonia	0111	21	0.03	mg/l
Antimony		21	1	μγ/λ
Chloride	0172	21	1	mg/l
Nitrate	0117	25	calculated	mg/l
Nitrite	0118	21	0.004	mg/l
TON	0116	21	0.2	mg/l
Orthophosphate	0180	21	0.02	mg/l
Silica (dissolved)	0182	21	0.2	mg/l
Total Hardness	0158	25	calculated	mg/l
Alkalinity	0162	21	10	mg/l
pH (Lab)	0061	21	0.05	pH units
DOC	0301	21	0.2	mg/l
Aluminium	6057	21	10	μγ/λ
Barium	6062	21	10	μγ/λ
Beryllium	9696	21	1	μγ/λ
Boron	6059	21	100	μγ/λ
Bromate		27	0.0005	mg/l

Bromide	0171	21	0.05	mg/l
Cadmium	0108	21	0.1	μγ/λ
Calcium	0241	21	1	mg/l
Chromium	3164	21	0.5	μγ/λ
Cobalt	6054	21	1	μγ/λ
Copper	6452	21	1Scs/0.5Ntm	μγ/λ
Fluoride	0177	21	0.05	mg/l
Iron	6051	21	30	μγ/λ
Lithium	6064	21	5	μγ/λ
Lead	0050	21	2Scs/0.4 Ntm	μγ/λ
Magnesium	0237	21	0.3	mg/l
Manganese	6050	21	10	μγ/λ
Nickel	6462	21	5	μγ/λ
Potassium	0211	21	0.1	mg/l
Silver	6030	21	1	μγ/λ
Sodium	0207	21	2	mg/l
Strontium	6063	21	2	μγ/λ
Sulphate	0183	21	10	mg/l
Vanadium	6061	21	2	μγ/λ
Zinc	6455	21	5	μγ/λ
Tin	6040	21	2.5	μγ/λ
Uranium	6473	21	0.5	μγ/λ
Titanium	6060	21	1?	μγ/λ
Thalium	6373	21	0.5	μγ/λ
at regional discretion				
Sodium : Chloride Ratio	5883	25	calculated	n/a
Calcium : Magnesium Ratio	5884	25	calculated	n/a

I3 - Dissolved Metals (Filtered) (GWQMI3)

Iron	6460	21	30	μγ/λ
Manganese	6458	21	10	μγ/λ
Others at regional discretion				

I4 - Special inorganics (GWQMI4)

Arsenic		21	1	μγ/λ
Mercury	0105	21	0.01	μγ/λ
Selenium	6049	21	1	μγ/λ
Cyanide	0175	21	0.005	mg/l

I5 - Optional inorganics (GWQMI5)

individual dets at regional discretion - extra bottles

Sulphide	0167	21	0.015	mg/l
Iodide (Ntm currently, Scs from April06)	0179	21	0.1	mg/l

O1 - ONP pesticides (GWQMO1)

Atrazine		21		μγ/λ
Atrazine Desethyl *	8804	21		μγ/λ
Atrazine Desisopropyl*	8997	21		μγ/λ
Azinphos-Ethyl		21		μγ/λ
Azinphos-Methyl		21		μγ/λ
Bendiocarb	9338	21		μγ/λ
Bupirimate	3948	21	0.005	μγ/λ
Carbophenothion		21		μγ/λ
Chlorfenvinphos	0503	21		μγ/λ
Chlorpyriphos-ethyl	9978	21		μγ/λ
Chlorpyriphos-methyl	7181	21		μγ/λ
Coumaphos	9474	21		μγ/λ
Cyanazine	6628	21		μγ/λ
Desmetryn	6635	21		μγ/λ
Diazinon	0723	21		μγ/λ
Dichlorvos	0507	21		μγ/λ
Dimethoate	6447	21		μγ/λ
Ethion	9979	21		μγ/λ
Ethofumesate	7154	21		μγ/λ
Fenchlorphos	6640	21		μγ/λ
Fenitrothion	9716	21		μγ/λ
Fenpropimorph	6776	21		μγ/λ
Fenthion	1118	21	[redacted]	μγ/λ
Fonofos	7159	21		μγ/λ
Iodofenphos	9000	21		μγ/λ
Iprodione	6649	21		μγ/λ
Malathion	0535	21		μγ/λ
Metalaxyl	9860	21		μγ/λ
Metazochlor	9002	21		μγ/λ
Mevinphos	9479	21	[redacted]	μγ/λ
Naproamide	6976	21		μγ/λ
Parathion-methyl	1119	21		μγ/λ
Parathion-ethyl	0543	21		μγ/λ
Pirimicarb	9959	21		μγ/λ
Pirimiphos-methyl	9851	21		μγ/λ
Pirimphos-ethyl	8998	21		μγ/λ
Prochloraz	7071	21		μγ/λ
Promethryne	5563	21		μγ/λ
Propazine	9634	21		μγ/λ
Propetamphos	9586	21		μγ/λ
Propyzamide	6448	21		μγ/λ
Simazine	3001	21		μγ/λ
Terbutryn	3009	21		μγ/λ
Triazophos	6487	21		μγ/λ

Trietazine	9911	21	[redacted]	μγ/λ
O2 -OCP pesticides (GWQMO2)				
1,2,3 Trichlorobenzene		21		μγ/λ
1,2,4 Trichlorobenzene		21		μγ/λ
1,3,5 Trichlorobenzene		21		μγ/λ
2,3,5,6 Tetrachlorothioanisole	8995	21		μγ/λ
2,3,5,6 Tetrchloroanailine		21		μγ/λ
Aldrin	0483	21		μγ/λ
Chlordane cis	0577	21		μγ/λ
Chlordane trans	0578	21		μγ/λ
DDE OP	0581	21		μγ/λ
DDE PP	0551	21		μγ/λ
DDT OP	0539	21	0.003	μγ/λ
DDT PP	0555	21		μγ/λ
Dichlobenil	9477	21		μγ/λ
Dieldrin	0511	21		μγ/λ
Endosulphan I	0569	21		μγ/λ
Endosulphan Ii	0570	21		μγ/λ
Endrin	0562	21	0.0025	μγ/λ
HCH Alpha	0487	21		μγ/λ
HCH Beta	0491	21		μγ/λ
HCH Delta	0495	21		μγ/λ
HCH Gamma	0499	21		μγ/λ
Heptachlor	0527	21		μγ/λ
Heptachlor epoxide (Cis)	8864	21		μγ/λ
Heptachlor epoxide (Trans)	8865	21		μγ/λ
Hexachlorbenzene	0576	21		μγ/λ
Hexachlorobutadiene	6648	21	0.003	μγ/λ
Isodrin	9494	21		μγ/λ
Methoxychlor	0579	21		μγ/λ
PCB 101	9770	21		μγ/λ
PCB 105	9197	21		μγ/λ
PCB 118	9771	21		μγ/λ
PCB 138	9772	21		μγ/λ
PCB 153	9773	21		μγ/λ
PCB 156	9258	21		μγ/λ
PCB 180	9774	21		μγ/λ
PCB 28	9768	21		μγ/λ
PCB 52	9769	21		μγ/λ
Permethrin-cis	9341	21		μγ/λ
Permethrin-trans	9342	21		μγ/λ
Propachlor	3119	21		μγ/λ
TDE OP	0573	21		μγ/λ
TDE PP	0559	21		μγ/λ

Tecnazene	9990	21		μγ/λ
Trifluralin	9989	21		μγ/λ

O3 - Acid herbicides (GWQMO3)

2,3,6 TBA	7726	21	0.04	μγ/λ
2,4 D	3545	21	0.05	μγ/λ
2,4 DB	3791	21	0.04	μγ/λ
2,4,5 T	3546	21	0.04	μγ/λ
Benazolin	3792	21	0.04	μγ/λ
Bentazone	4065	21	0.04	μγ/λ
Bromoxynil	6449	21	0.04	μγ/λ
Chlopyralid	6620	21	0.04	μγ/λ
Dicamba	3550	21	0.04	μγ/λ
Dichlorprop	3551	21	0.04	μγ/λ
Fluoroxypyr	4064	21	0.05	μγ/λ
Ioxynil	9068	21	0.04	μγ/λ
MCPA	3548	21	0.04	μγ/λ
MCPB	3790	21	0.06	μγ/λ
Mecoprop	3549	21	0.04	μγ/λ
Trichlopyr	3555	21	0.04	μγ/λ
Fenoprop	3552	21	0.04	μγ/λ
Pichloram	9883	21	0.04	μγ/λ

O4 - Urons/urocarbs (GWQMO4)

Carbetamide	9073	21	0.04	μγ/λ
Chloridazon	6760	21	0.04	μγ/λ
Chloroxuron	3399	21	0.04	μγ/λ
Chlortoluron	9348	21	0.04	μγ/λ
Diuron	3811	21	0.04	μγ/λ
Isoproturon	3117	21	0.04	μγ/λ
Linuron	3118	21	0.04	μγ/λ
Methabenzthiazuron	7053	21	0.04	μγ/λ
Monolinuron	3925	21	0.04	μγ/λ
Monuron	3400	21	0.04	μγ/λ
Fenuron	9339	21	0.04	μγ/λ
Diflurobenzuron	9345	21	0.04	μγ/λ
Neburon	9756	21	0.05	μγ/λ
Metsulfuron - methyl	9861	21	0.04	μγ/λ

O5 - Phenols (GWQMO5)

4-Chloro-3-methylphenol	3342	21	0.02	μγ/λ
Chlorophenol-2	9814	21	0.02	μγ/λ
Chlorophenol-3	9703	21	0.02	μγ/λ
Chlorophenol-4	9815	21	0.02	μγ/λ

Cresol-m	5561	21	0.02	μγ/λ
Cresol-o	5562	21	0.02	μγ/λ
Cresol-p	5560	21	0.02	μγ/λ
Dichlorophenol- 2,4	9816	21	0.02	μγ/λ
Dichlorophenol-2,5	9091	21	0.02	μγ/λ
Dichlorophenol-2,6	9817	21	0.02	μγ/λ
Pentachlorophenol	1085	21	0.02	μγ/λ
Phenol	9522	21	0.02	μγ/λ
Trichlorophenol-2,4,5	9818	21	0.02	μγ/λ
Trichlorophenol-2,4,6	9819	21	0.02	μγ/λ
Xylenol-2,3	9451	21	0.02	μγ/λ
Xylenol-2,4	3343	21	0.02	μγ/λ
Xylenol-2,5	9094	21	0.02	μγ/λ
Xylenol-2,6	6569	21	0.02	μγ/λ
Xylenol-3,4	6577	21	0.02	μγ/λ
Xylenol-3,5	5558	21	0.02	μγ/λ

O6 - VOCs (GWQMO6)

Benzene	3781	21	0.1	μγ/λ
Bromodichloromethane	3282	21	0.1	μγ/λ
Bromoform	3283	21	0.1	μγ/λ
Carbon tetrachloride	1049	21	0.1	μγ/λ
Chloroform	3373	21	0.1	μγ/λ
Dibromochloromethane	3292	21	0.1	μγ/λ
Dichloroethane-1,2	3272	21	1	μγ/λ
Ethyl benzene	4117	21	0.1	μγ/λ
MTBE	6656	21	0.5	μγ/λ
Naphthalene	9669	21	0.01	μγ/λ
Styrene	9888	21	1	μγ/λ
Tetrachloroethene	3328	21	0.1	μγ/λ
Toluene	3784	21	0.1	μγ/λ
Trichloroethane-1,1,1	3268	21	0.1	μγ/λ
Trichloroethane-1,1,2	9811	21	0.1	μγ/λ
Trichloroethene	3334	21	0.1	μγ/λ
Xylene-o	9845	21	0.1	μγ/λ
Xylene-p and Xylene-m	6716	21	0.2	μγ/λ
1,1,1,2 -Tetrachloroethane	6534	21	0.1	μγ/λ
1,1,2,2 Tetrachloroethane	7531	21	0.1	μγ/λ
1,1-Dichloroethane	3269	21	0.1	μγ/λ
1,1-Dichloroethene	9836	21	0.1	μγ/λ
1,2 -Dichloroethene (CIS)	6538	21	0.1	μγ/λ
1,2 -Dichloroethene (TRANS)	6539	21	0.1	μγ/λ
Tertiary Amyl Methyl Ether (TAME)	9839	21	0.1	μγ/λ
Ethyl Tertiary Butyl Ether (ETBE)	9844	21	0.1	μγ/λ

O7 - PAHs (GWQMO7)				
Benzo(a)pyrene		21	0.01	μγ/λ
Benzo(b)fluoranthene	0731	21	0.01	μγ/λ
Benzo(ghi)perylene	0714	21	0.01	μγ/λ
Benzo(k)fluoranthene	0733	21	0.01	μγ/λ
Fluoranthene	0736	21	0.01	μγ/λ
Indeno(123-cd)pyrene	0746	21	0.02	μγ/λ
Chrysene	8310	21	0.01	μγ/λ
Pyrene	7325	21	0.01	μγ/λ
Acenaphthylene	8311	21	0.01	μγ/λ
Acenaphthene	7395	21	0.01	μγ/λ
Fluorene	7864	21	0.01	μγ/λ
Phenanthrene	9671	21	0.01	μγ/λ
Anthracene	6753	21	0.01	μγ/λ
Benzo(a)anthracene	0772	21	0.01	μγ/λ
Dibenzo(ah)perylene	8360	21	0.01	μγ/λ
Total PAHs	6982	25	calculated	μγ/λ
O8 - Pyrethroids (GWQMO8)				
Cypermethrin	0073	21	0.001	μγ/λ
Flumethrin	9862	21	0.001	μγ/λ
O9 - Special organics (GWQMO9)				
individual dets at regional discretion				
Carbendazim	3475	21	0.04	μγ/λ
Chlorothalonil	6615	21	0.04	μγ/λ
Chlormequat	9952	21		μγ/λ
Flutriafol	6644	22	0.013	μγ/λ
Asulam (Asulox)			0.013	ug/l
O10 - Scans (GWQMO10)				
Volatile Organics	4084	21	presence	approx
Semi Volatile Organics	9247	21	presence	approx
G1 - Dissolved gases (GWQMG1)				
Methane	0915	21		
Carbon dioxide	159	21	calculated	
M1 - Total coliforms (GWQMM1)				
Faecal coliform	3461	21	1	No/100ml
Faecal Streptococci	6423	21	1	No/100ml

Appendix 7 Comparative Statistics: Duplicates

Sample:	Leachate Phase 2b	Leachate Phase 2b-duplicate	Difference	Mean	Difference as a percentage of the mean
Determinand:					
Ammonia as N	870	870	0.00	870.00	0.00
Bromate	<1	<1			
Bromide	11	11	0.00	11.00	0.00
Chloride	1570	1560	10.00	1565.00	0.64
Fluoride	0.39	0.38	0.01	0.39	2.60
Nitrate	0.62	0.67	-0.05	0.65	-7.75
Nitrite	4.2	3.8	0.40	4.00	10.00
Orthophosphate	<0.5	<0.5			
Sulphate	3.2	<0.2			
TON	4.8	4.5	0.30	4.65	6.45
Silica (dissolved)	22	22	0.00	22.00	0.00
Total Hardness	1430	1460	-30.00	1445.00	-2.08
Alkalinity	4450	4450	0.00	4450.00	0.00
pH	7.4	7.4	0.00	7.40	0.00
DOC	670	660	10.00	665.00	1.50
Aluminium	<0.04	<0.04			
Antimony	5.2	5.4	-0.20	5.30	-3.77
Barium	2	2.1	-0.10	2.05	-4.88
Beryllium	0.0002	0.0001	0.00	0.00	66.67
Boron	3.5	3.4	0.10	3.45	2.90
Cadmium	0.4	0.3	0.10	0.35	28.57
Calcium	220	230	-10.00	225.00	-4.44
Chromium	0.063	0.062	0.00	0.06	1.60
Cobalt	21	22	-1.00	21.50	-4.65
Copper	<0.003	<0.003			
Iron	18	18	0.00	18.00	0.00
Lithium	<0.09	<0.09			
Lead	15	14	1.00	14.50	6.90
Magnesium	220	220	0.00	220.00	0.00
Manganese	0.56	0.54	0.02	0.55	3.64
Molybdenum	3	3	0.00	3.00	0.00
Nickel	170	180	-10.00	175.00	-5.71
Potassium	470	470	0.00	470.00	0.00
Silver	<4	<4			

Sample:	Leachate Phase 2b	Leachate Phase 2b-duplicate	Difference	Mean	Difference as a percentage of the mean
Sodium	1200	1200	0.00	1200.00	0.00
Strontium	1.7	1.6	0.10	1.65	6.06
Vanadium	0.036	0.038	0.00	0.04	-5.41
Zinc	0.18	0.2	-0.02	0.19	-10.53
Tin	6.2	5.8	0.40	6.00	6.67
Uranium	<0.07	<0.07			
Titanium	0.04	0.04	0.00	0.04	0.00
Thallium	1	0.6	0.40	0.80	50.00
Sodium:Chloride Ratio	0.76	0.77	-0.01	0.77	-1.31
Calcium:Magnesium Ratio	1	1.05	-0.05	1.03	-4.88
Iron (total)	24	25	-1.00	24.50	-4.08
Manganese (total)	0.79	0.79	0.00	0.79	0.00
Arsenic	15	17	-2.00	16.00	-12.50
Mercury	<4	<4			
Selenium	5	8	-3.00	6.50	-46.15
Total Cyanide	<0.01	<0.01			
Sulphide	<0.1	<0.1			
Iodide	2800	2600	200.00	2700.00	7.41
Faecal Coliform	256	404	-148.00	330.00	-44.85
Faecal Streptococci	864	928	-64.00	896.00	-7.14
COD	2140	2120	20.00	2130.00	0.94

RED VALUES < VALUE SHOWN

Sample:	Borehole L1	Borehole L1A	Difference	Mean	Difference as a percentage of the mean
Determinand:					
Ammonia as N	<0.1	<0.1			
Bromate	<0.001	<0.001			
Bromide	<0.3	<0.3			
Chloride	30	30	0.00	30.00	0.00
Fluoride	0.2	0.19	0.01	0.20	5.13
Nitrate	33	32	1.00	32.50	3.08
Nitrite	<0.3	<0.3			
Orthophosphate	<0.5	<0.5			
Sulphate	120	110			
TON	33	32	1.00	32.50	3.08
Silica (dissolved)	3.2	3.2	0.00	3.20	0.00
Total Hardness	440	440	0.00	440.00	0.00
Alkalinity	260	260	0.00	260.00	0.00
pH	7.8	8	-0.20	7.90	-2.53
DOC	0.3	0.3	0.00	0.30	0.00

Sample:	Borehole L1	Borehole L1A	Difference	Mean	Difference as a percentage of the mean
Aluminium	<0.04	<0.04			
Antimony	<0.1	<0.1			
Barium	0.03	0.03	0.00	0.03	0.00
Beryllium	0.0001	0.0001	0.00	0.00	0.00
Boron	<0.07	<0.07			
Cadmium	<0.2	<0.2			
Calcium	87	88	-1.00	87.50	-1.14
Chromium	<0.002	<0.002			
Cobalt	<0.4	<0.4			
Copper	<0.003	<0.003			
Iron	<0.002	<0.002			
Lithium	<0.09	<0.09			
Lead	0.3	0.3	0.00	0.30	0.00
Magnesium	56	56	0.00	56.00	0.00
Manganese	<0.0007	<0.0007			
Molybdenum	<0.4	<0.4			
Nickel	<0.7	<0.7			
Potassium	0.82	0.8	0.02	0.81	2.47
Silver	<4	<4			
Sodium	16	16	0.00	16.00	0.00
Strontium	<0.08	<0.08			
Vanadium	<0.002	<0.002			
Zinc	<0.003	<0.003			
Tin	<0.2	<0.2			
Uranium	1.3	1.2			
Titanium	<0.01	<0.01			
Thallium	0.9	0.8	0.10	0.85	11.76
Sodium:Chloride Ratio	0.53	0.53	0.00	0.53	0.00
Calcium:Magnesium Ratio	1.55	1.57	-0.02	1.56	-1.28
Iron (total)	0.32	0.26	0.06	0.29	20.69
Manganese (total)	0.005	0.007	0.00	0.01	-33.33
Arsenic	<0.6	<0.6			
Mercury	<4	<4			
Selenium	3	2	1.00	2.50	40.00
Total Cyanide	<0.01	<0.01			
Sulphide	<0.1	<0.1			
Iodide	<30	<30			
Faecal Coliform	0	0	0.00	0.00	
Faecal Streptococci	0	0	0.00	0.00	
COD	<5	<5			

Sample: Determinand:	Borehole M1	Borehole M1A	Difference	Mean	Difference as a percentage of the mean
Ammonia as N	<0.1	<0.1			
Bromate	<0.001	<0.001			
Bromide	<0.3	<0.3			
Chloride	45	44	1.00	44.50	2.25
Fluoride	0.2	0.19	0.01	0.20	5.13
Nitrate	40	41	-1.00	40.50	-2.47
Nitrite	<0.3	<0.3			
Orthophosphate	<0.5	<0.5			
Sulphate	170	170			
TON	40	41	-1.00	40.50	-2.47
Silica (dissolved)	2.9	2.9	0.00	2.90	0.00
Total Hardness	520	490	30.00	505.00	5.94
Alkalinity	230	230	0.00	230.00	0.00
pH	8	8	0.00	8.00	0.00
DOC	4	1	3.00	2.50	120.00
Aluminium	<0.04	<0.04			
Antimony	<0.1	<0.1			
Barium	0.06	0.02	0.04	0.04	100.00
Beryllium	0.0003	0.0002	0.00	0.00	40.00
Boron	<0.07	<0.07			
Cadmium	<0.2	<0.2			
Calcium	110	100	10.00	105.00	9.52
Chromium	0.003	0.002	0.00	0.00	40.00
Cobalt	<0.4	<0.4			
Copper	<0.003	<0.003			
Iron	0.087	0.002	0.09	0.04	191.01
Lithium	<0.09	<0.09			
Lead	0.7	0.6	0.10	0.65	15.38
Magnesium	60	60	0.00	60.00	0.00
Manganese	<0.0007	<0.0007			
Molybdenum	<0.4	<0.4			
Nickel	1	0.7	0.30	0.85	35.29
Potassium	2.2	1.5	0.70	1.85	37.84
Silver	<4	<4			
Sodium	27	25	2.00	26.00	7.69
Strontium	<0.08	<0.08			

Sample:	Borehole M1	Borehole M1A	Difference	Mean	Difference as a percentage of the mean
Vanadium	<0.002	<0.002			
Zinc	<0.003	<0.003			
Tin	<0.2	<0.2			
Uranium	1.1	1			
Titanium	<0.01	<0.01			
Thallium	0.5	0.9	-0.40	0.70	-57.14
Sodium:Chloride Ratio	0.6	0.57	0.03	0.59	5.13
Calcium:Magnesium Ratio	1.83	1.67	0.16	1.75	9.14
Iron (total)	0.069	0.087	-0.02	0.08	-23.08
Manganese (total)	0.0007	0.001	0.00	0.00	-35.29
Arsenic	<0.6	<0.6			
Mercury	<4	<4			
Selenium	7	9	-2.00	8.00	-25.00
Total Cyanide	<0.01	<0.01			
Sulphide	<0.1	<0.1			
Iodide	30	<30			
Faecal Coliform	0	0	0.00	0.00	
Faecal Streptococci	0	0	0.00	0.00	
COD	<5	<5			

Sample:	Borehole N2	Borehole N2A	Difference	Mean	Difference as a percentage of the mean
Determinand:					
Ammonia as N	<0.1	<0.1			
Bromate	<0.1	<0.1			
Bromide	<0.3	<0.3			
Chloride	120	120	0.00	120.00	0.00
Fluoride	0.22	0.23	-0.01	0.23	-4.44
Nitrate	49	49	0.00	49.00	0.00
Nitrite	<0.3	<0.3			
Orthophosphate	<0.5	<0.5			
Sulphate	98	100			
TON	49	49	0.00	49.00	0.00
Silica (dissolved)	2.3	2.3	0.00	2.30	0.00
Total Hardness	440	440	0.00	440.00	0.00
Alkalinity	250	230	20.00	240.00	8.33
pH	7.8	7.9	-0.10	7.85	-1.27
DOC	0.4	0.4	0.00	0.40	0.00
Aluminium	<0.04	<0.04			
Antimony	0.3	4.7	-4.40	2.50	-176.00
Barium	0.04	0.04	0.00	0.04	0.00
Beryllium	0.0001	0.0001	0.00	0.00	0.00
Boron	<0.07	<0.07			
Cadmium	<0.2	<0.2			
Calcium	100	100	0.00	100.00	0.00
Chromium	<0.002	<0.002			
Cobalt	<2	<2			
Copper	<0.003	<0.003			
Iron	<0.002	<0.002			
Lithium	<0.09	<0.09			
Lead	3.3	0.8	2.50	2.05	121.95
Magnesium	48	48	0.00	48.00	0.00
Manganese	<0.0007	<0.0007			
Molybdenum	<0.2	<0.2			
Nickel	<0.7	<0.7			
Potassium	0.78	0.95	-0.17	0.87	-19.65
Silver	<0.1	<0.1			
Sodium	66	64	2.00	65.00	3.08
Strontium	<0.08	<0.08			
Vanadium	<0.002	<0.002			

Sample:	Borehole N2	Borehole N2A	Difference	Mean	Difference as a percentage of the mean
Zinc	<0.003	<0.003			
Tin	0.2	2	-1.80	1.10	-163.64
Uranium	0.83	0.88			
Titanium	<0.01	<0.01			
Thallium	1	1	0.00	1.00	0.00
Sodium:Chloride Ratio	0.55	0.53	0.02	0.54	3.70
Calcium:Magnesium Ratio	2.08	2.08	0.00	2.08	0.00
Iron (total)	0.035	0.02	0.02	0.03	54.55
Manganese (total)	0.003	0.002	0.00	0.00	40.00
Arsenic	<1	<1			
Mercury	<2	<2			
Selenium	<6	<6			
Total Cyanide	<0.01	<0.01			
Sulphide	<0.1	<0.1			
Iodide	20	20	0.00	20.00	0.00
Faecal Coliform	0	0	0.00	0.00	
Faecal Streptococci	0	0	0.00	0.00	
COD	<5	<5			

Appendix 8 Comparative results.

Sample:	Leachate Phase 2b	Leachate Phase 2b-duplicate	Severn Trent Result	Borehole L1	Borehole L1A-duplicate	Severn Trent Result
Determinand:						
Ammonia as N	870	870	622	<0.1	<0.1	<0.04
Bromate	<1	<1		<0.001	<0.001	
Bromide	11	11		<0.3	<0.3	
Chloride	1570	1560	1870	30	30	28
Fluoride	0.39	0.38	0.7	0.2	0.19	0.17
Nitrate	0.62	0.67	0.5	33	32	7.6
Nitrite	4.2	3.8		<0.3	<0.3	
Orthophosphate	<0.5	<0.5		<0.5	<0.5	
Sulphate	3.2	<0.2	<5	120	110	148
TON	4.8	4.5	0.5	33	32	7.6
Silica (dissolved)	22	22		3.2	3.2	
Total Hardness	1430	1460		440	440	
Alkalinity	4450	4450	4610	260	260	262
pH	7.4	7.4	7.8	7.8	8	7.8
DOC	670	660		0.3	0.3	
Aluminium	<0.04	<0.04		<0.04	<0.04	
Antimony	5.2	5.4	<0.001	<0.1	<0.1	<0.001
Barium	2	2.1	2.9	0.03	0.03	0.044
Beryllium	0.0002	0.0001	<0.005	0.0001	0.0001	<0.005
Boron	3.5	3.4	4.7	<0.07	<0.07	<0.3
Cadmium	0.4	0.3	<0.0005	<0.2	<0.2	<0.0005
Calcium	220	230	210	87	88	95
Chromium	0.063	0.062	0.065	<0.002	<0.002	<0.005
Cobalt	21	22	0.016	<0.4	<0.4	<0.005
Copper	<0.003	<0.003	0.015	<0.003	<0.003	<0.005
Iron	18	18		<0.002	<0.002	
Lithium	<0.09	<0.09		<0.09	<0.09	
Lead	15	14	0.026	0.3	0.3	0.01
Magnesium	220	220	220	56	56	58
Manganese	0.56	0.54		<0.0007	<0.0007	
Molybdenum	3	3	<0.005	<0.4	<0.4	<0.005
Nickel	170	180	0.18	<0.7	<0.7	<0.005
Potassium	470	470	454	0.82	0.8	0.8

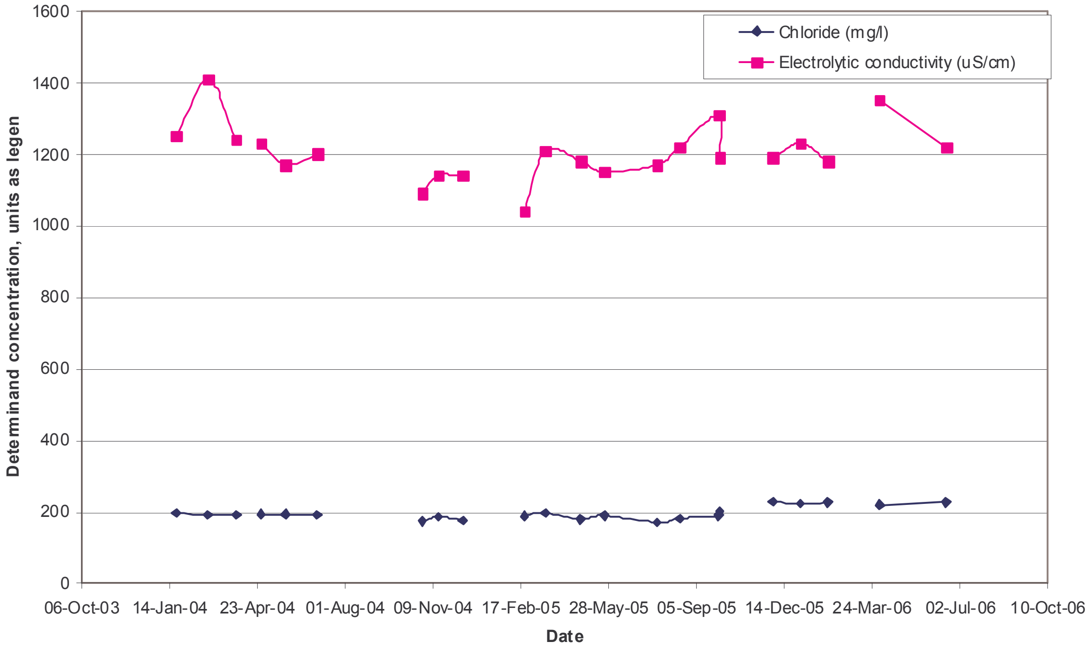
Sample:	Leachate Phase 2b	Leachate Phase 2b-duplicate	Severn Trent Result	Borehole L1	Borehole L1A-duplicate	Severn Trent Result
Silver	<4	<4	<0.015	<4	<4	<0.015
Sodium	1200	1200	1300	16	16	16
Strontium	1.7	1.6		<0.08	<0.08	
Vanadium	0.036	0.038	0.041	<0.002	<0.002	<0.005
Zinc	0.18	0.2	0.37	<0.003	<0.003	0.017
Tin	6.2	5.8	<0.1	<0.2	<0.2	<0.10
Uranium	<0.07	<0.07	0.3	1.3	1.2	2.3
Titanium	0.04	0.04	<0.005	<0.01	<0.01	<0.005
Thallium	1	0.6	<0.1	0.9	0.8	<0.1
Iron (total)	24	25	27.65	0.32	0.26	0.19
Manganese (total)	0.79	0.79	0.87	0.005	0.007	0.043
Arsenic	15	17	<0.001	<0.6	<0.6	
Mercury	<4	<4	<0.0001	<4	<4	<0.0001
Selenium	5	8	<0.001	3	2	<0.001
Total Cyanide	<0.01	<0.01	<0.1	<0.01	<0.01	<0.1
Sulphide	<0.1	<0.1		<0.1	<0.1	
Iodide	2800	2600		<30	<30	
COD	2140	2120	2320	<5	<5	<20

Sample:	Borehole M1	Borehole M1A	Severn Trent Result	Borehole N2	Borehole N2A	Severn Trent Result
Determinand:						
Ammonia as N	<0.1	<0.1	<0.04	<0.1	<0.1	<0.04
Bromate	<0.001	<0.001		<0.1	<0.1	
Bromide	<0.3	<0.3		<0.3	<0.3	
Chloride	45	44	43	120	120	122
Fluoride	0.2	0.19	0.18	0.22	0.23	0.27
Nitrate	40	41	9.3	49	49	11.7
Nitrite	<0.3	<0.3		<0.3	<0.3	
Orthophosphate	<0.5	<0.5		<0.5	<0.5	
Sulphate	170	170	210	98	100	133
TON	40	41	9.3	49	49	11.7
Silica (dissolved)	2.9	2.9		2.3	2.3	
Total Hardness	520	490		440	440	
Alkalinity	230	230	227	250	230	243
pH	8	8	7.9	7.8	7.9	7.5
DOC	4	1		0.4	0.4	
Aluminium	<0.04	<0.04		<0.04	<0.04	
Antimony	<0.1	<0.1	<0.001	0.3	4.7	<0.001
Barium	0.06	0.02	0.032	0.04	0.04	0.19
Beryllium	0.0003	0.0002	<0.005	0.0001	0.0001	<0.005
Boron	<0.07	<0.07	<0.3	<0.07	<0.07	<0.3
Cadmium	<0.2	<0.2	<0.0005	<0.2	<0.2	<0.0005

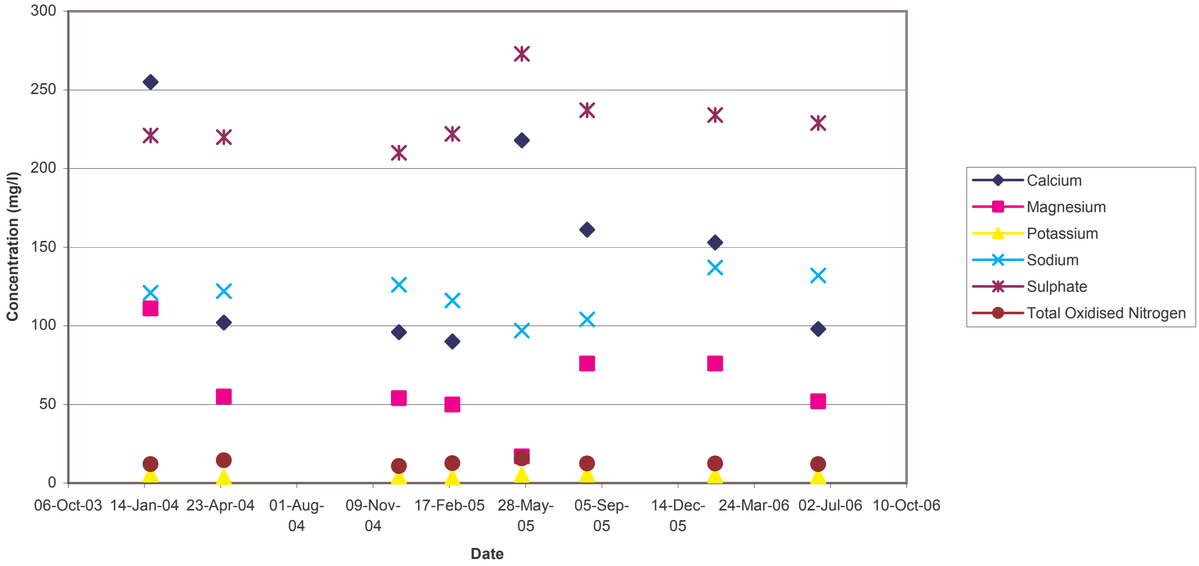
Sample:	Borehole M1	Borehole M1A	Severn Trent Result	Borehole N2	Borehole N2A	Severn Trent Result
Calcium	110	100	103	100	100	128
Chromium	0.003	0.002	<0.005	<0.002	<0.002	<0.005
Cobalt	<0.4	<0.4	<0.005	<2	<2	<0.005
Copper	<0.003	<0.003	<0.005	<0.003	<0.003	<0.005
Iron	0.087	0.002		<0.002	<0.002	
Lithium	<0.09	<0.09		<0.09	<0.09	
Lead	0.7	0.6	0.007	3.3	0.8	0.015
Magnesium	60	60	61	48	48	60
Manganese	<0.0007	<0.0007		<0.0007	<0.0007	
Molybdenum	<0.4	<0.4	<0.005	<0.2	<0.2	<0.005
Nickel	1	0.7	0.005	<0.7	<0.7	<0.005
Potassium	2.2	1.5	1.4	0.78	0.95	0.8
Silver	<4	<4	<0.015	<0.1	<0.1	<0.015
Sodium	27	25	24	66	64	65
Strontium	<0.08	<0.08		<0.08	<0.08	
Vanadium	<0.002	<0.002	<0.005	<0.002	<0.002	0.007
Zinc	<0.003	<0.003	0.014	<0.003	<0.003	0.015
Tin	<0.2	<0.2	<0.10	0.2	2	<0.10
Uranium	1.1	1	1.4	0.83	0.88	1.2
Titanium	<0.01	<0.01	<0.005	<0.01	<0.01	0.022
Thallium	0.5	0.9	<0.1	1	1	<0.1
Iron (total)	0.069	0.087	0.07	0.035	0.02	1.44
Manganese (total)	0.0007	0.001	0.038	0.003	0.002	0.32
Arsenic	<0.6	<0.6		<1	<1	0.002
Mercury	<4	<4	<0.0001	<2	<2	<0.0001
Selenium	7	9	0.007	<6	<6	0.006
Total Cyanide	<0.01	<0.01	<0.1	<0.01	<0.01	<0.1
Sulphide	<0.1	<0.1		<0.1	<0.1	
Iodide	30	<30		20	20	
COD	<5	<5	<20	<5	<5	<20

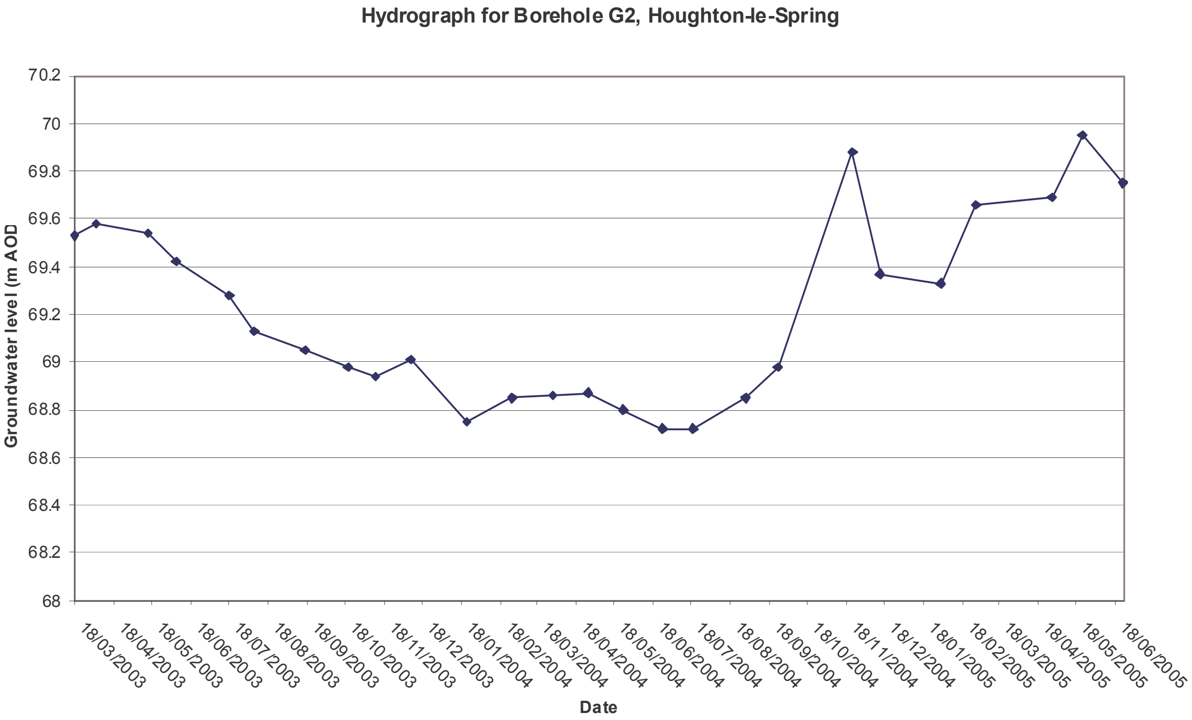
Appendix 9 Selected results from the temporal monitoring carried out by Biffa Waste Services Limited

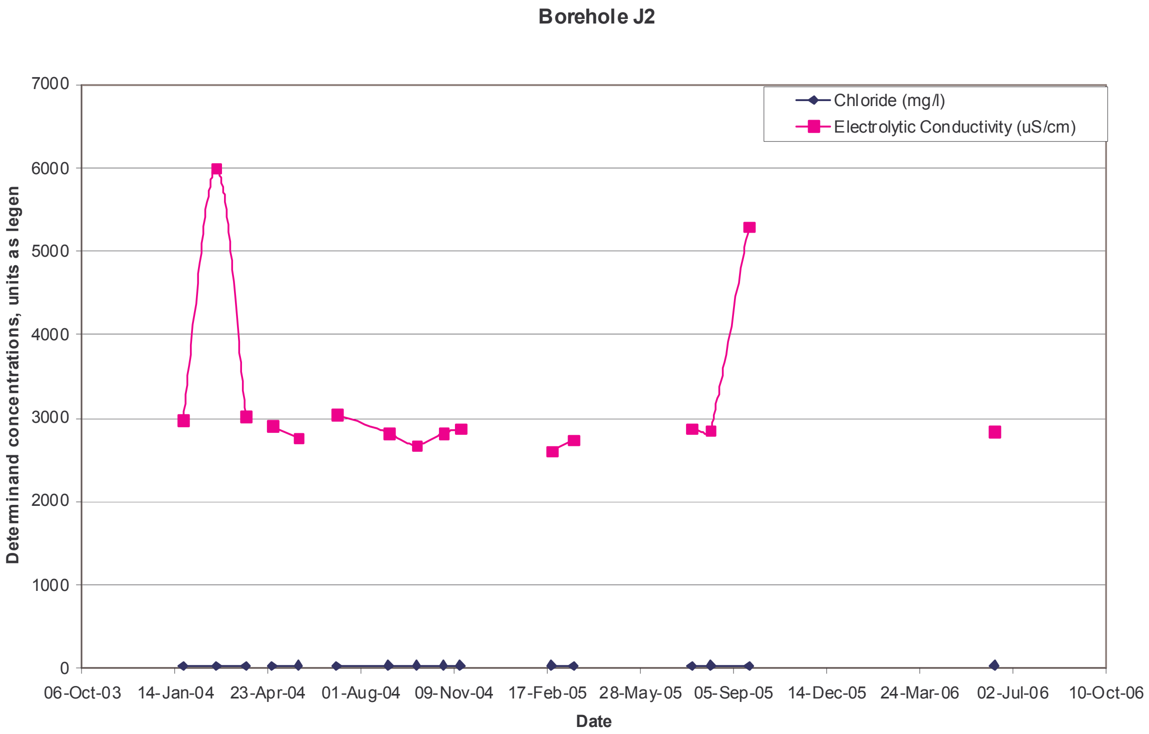
Borehole G2

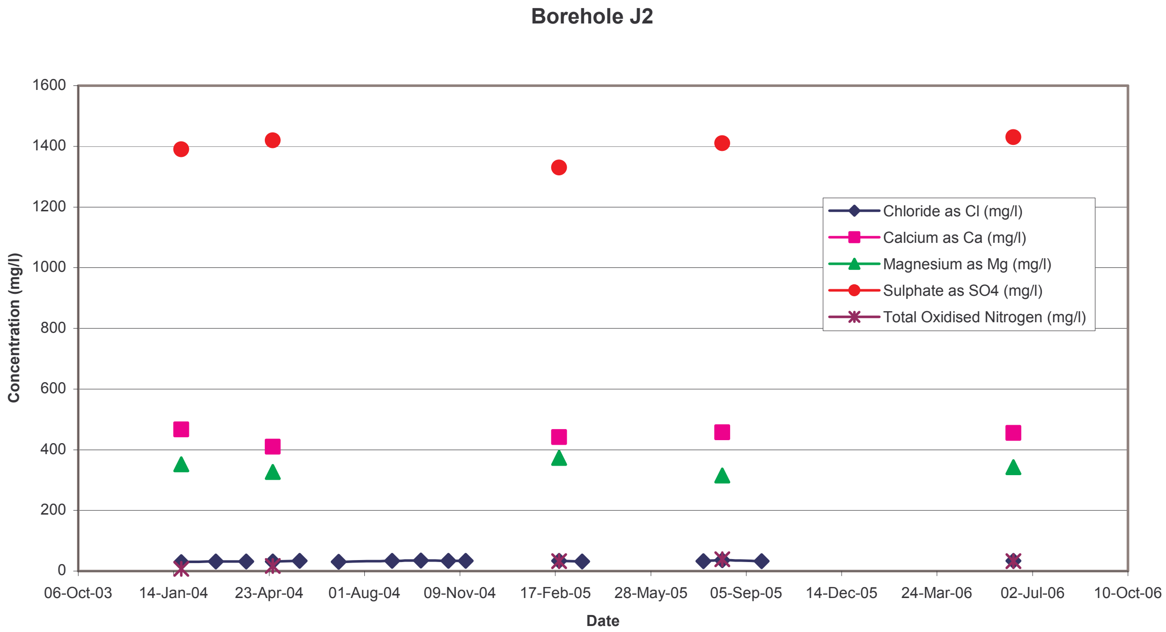


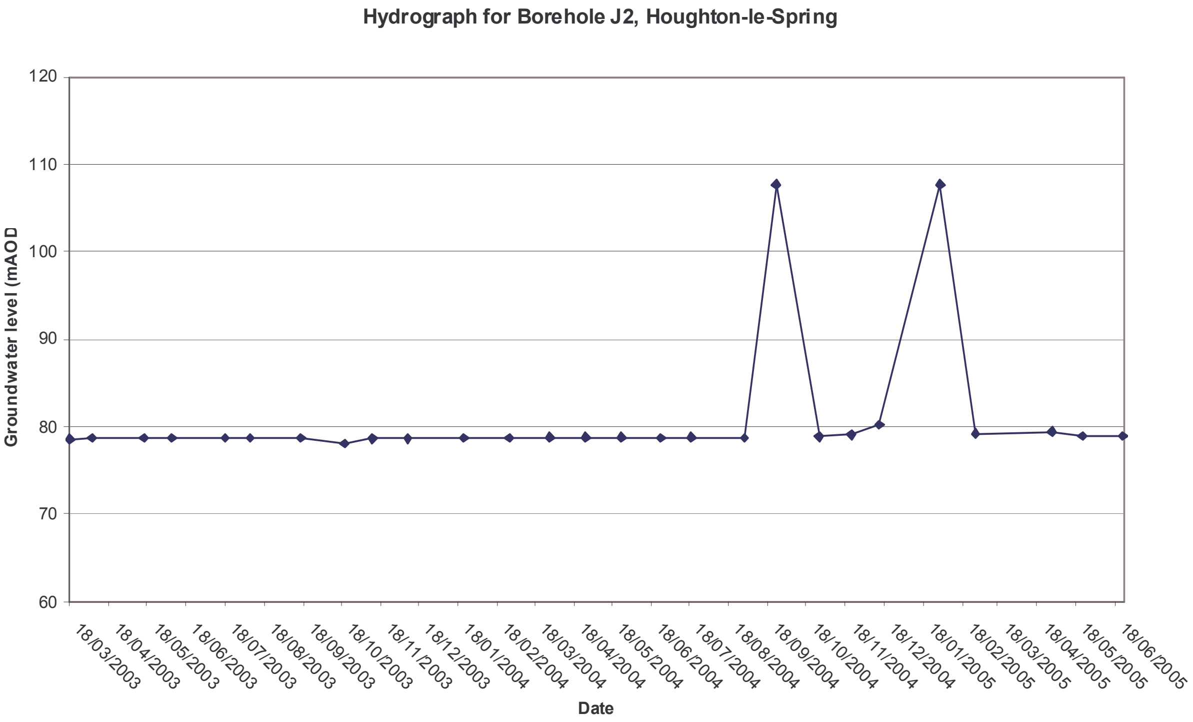
Borehole G2 Groundwater chemistry

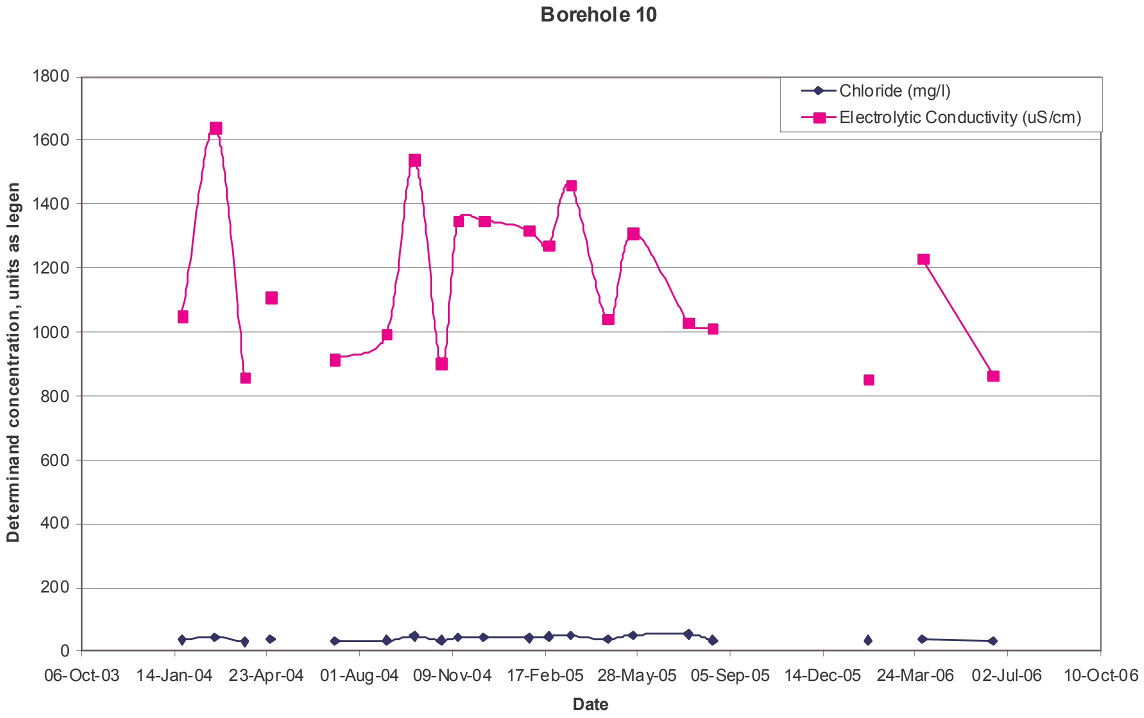


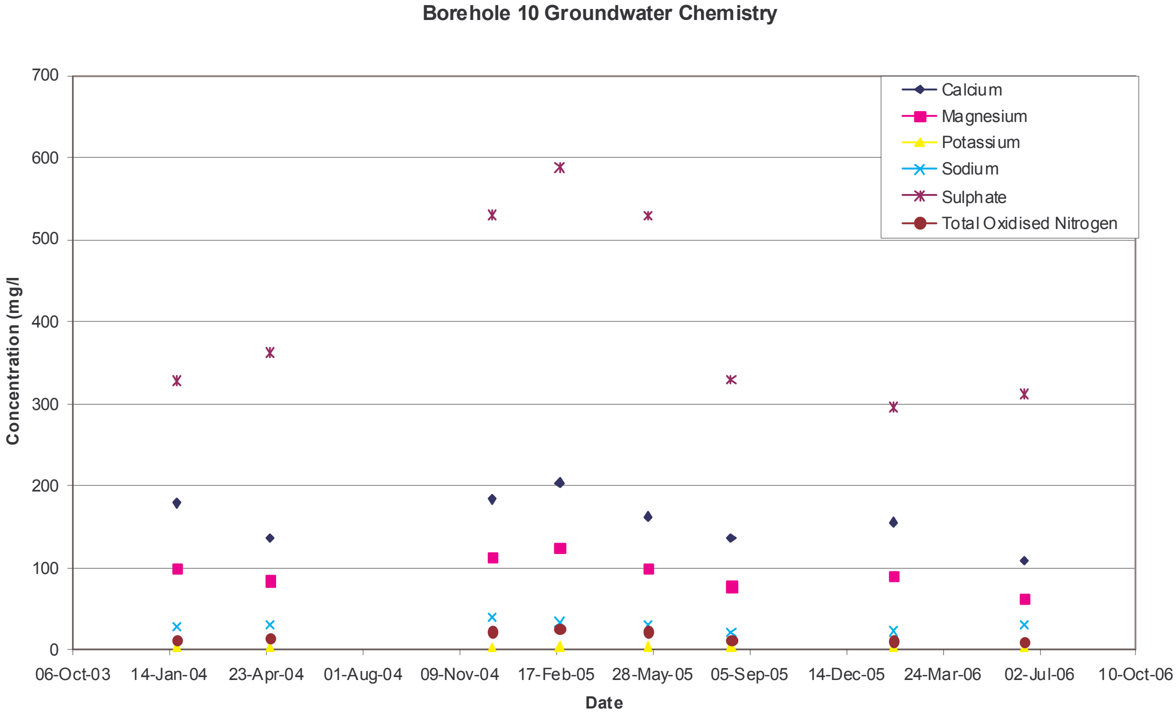

Hydrograph for Borehole G2, Houghton-le-Spring
Groundwater level (m AOD
70.2
70
69.8
69.6
69.4
69.2
69
68.8
68.6
68.4
68.2
68
18/03/2003
18/04/2003
18/05/2003
18/06/2003
18/07/2003
18/08/2003
18/09/2003
18/10/2003
18/11/2003
18/12/2003
18/01/2004
18/02/2004
18/03/2004
18/04/2004
18/05/2004
18/06/2004
18/07/2004
18/08/2004
18/09/2004
18/10/2004
18/11/2004
18/12/2004
18/01/2005
18/02/2005
18/03/2005
18/04/2005
18/05/2005
18/06/2005
Date

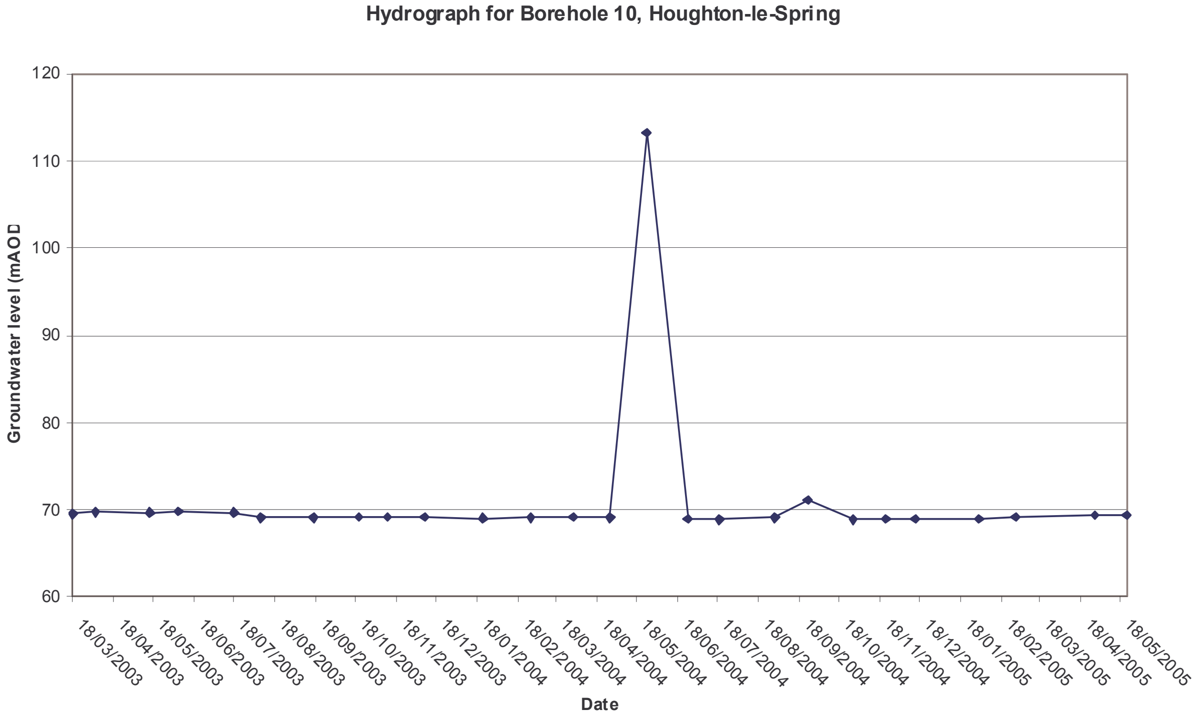

Borehole J2
7000
6000
5000
4000
3000
2000
1000
0
Determinand concentrations, units as legen
Chloride (mg/l)
Electrolytic Conductivity (uS/cm)
06-Oct-03
14-Jan-04
23-Apr-04
01-Aug-04
09-Nov-04
17-Feb-05
28-May-05
05-Sep-05
14-Dec-05
24-Mar-06
02-Jul-06
10-Oct-06
Date


Borehole J2
1600
1400
1200
1000
800
600
400
200
0
Concentration (mg/l)
Chloride as Cl (mg/l)
Calcium as Ca (mg/l)
Magnesium as Mg (mg/l)
Sulphate as SO4 (mg/l)
Total Oxidised Nitrogen (mg/l)
06-Oct-03
14-Jan-04
23-Apr-04
01-Aug-04
09-Nov-04
17-Feb-05
28-May-05
05-Sep-05
14-Dec-05
24-Mar-06
02-Jul-06
10-Oct-06
Date


Hydrograph for Borehole J2, Houghton-le-Spring
Groundwater level (mAOD
120
110
100
90
80
70
60
18/03/2003
18/04/2003
18/05/2003
18/06/2003
18/07/2003
18/08/2003
18/09/2003
18/10/2003
18/11/2003
18/12/2003
18/01/2004
18/02/2004
18/03/2004
18/04/2004
18/05/2004
18/06/2004
18/07/2004
18/08/2004
18/09/2004
18/10/2004
18/11/2004
18/12/2004
18/01/2005
18/02/2005
18/03/2005
18/04/2005
18/05/2005
18/06/2005
Date

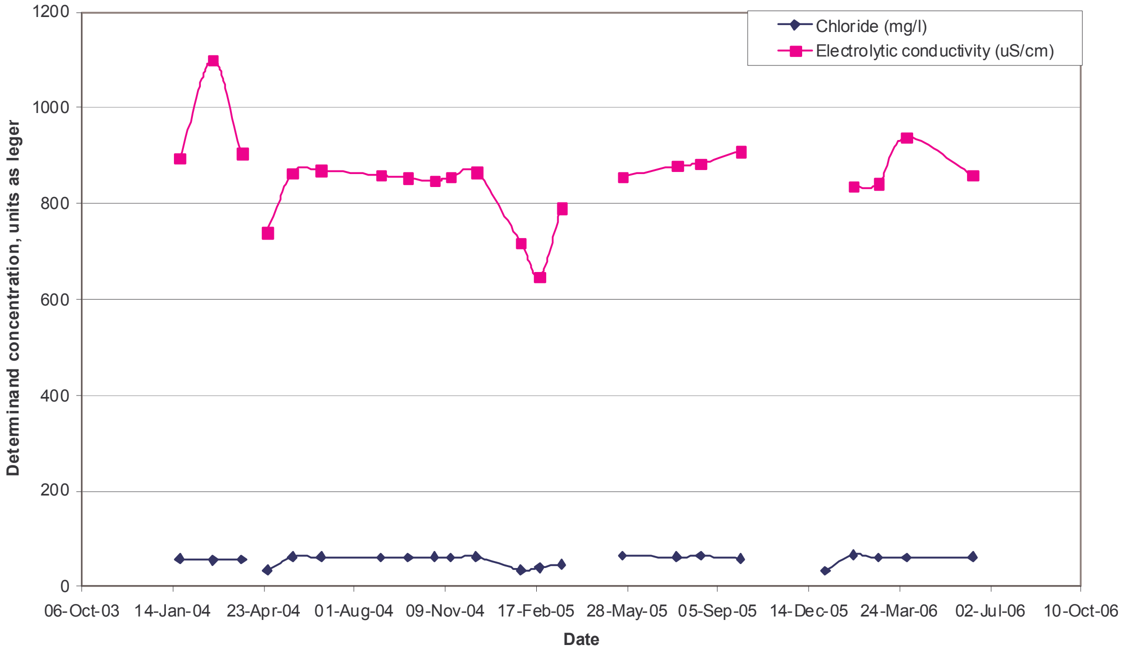

Borehole 10
Chloride (mg/l)
Electrolytic Conductivity (uS/cm)
Determinand concentration, units as legen
1800
1600
1400
1200
1000
800
600
400
200
0
06-Oct-03
14-Jan-04
23-Apr-04
01-Aug-04
09-Nov-04
17-Feb-05
28-May-05
05-Sep-05
14-Dec-05
24-Mar-06
02-Jul-06
10-Oct-06
Date


Borehole 10 Groundwater Chemistry
Calcium
Magnesium
Potassium
Sodium
Sulphate
Total Oxidised Nitrogen
Concentration (mg/l
700
600
500
400
300
200
100
0
06-Oct-03
14-Jan-04
23-Apr-04
01-Aug-04
09-Nov-04
17-Feb-05
28-May-05
05-Sep-05
14-Dec-05
24-Mar-06
02-Jul-06
10-Oct-06
Date

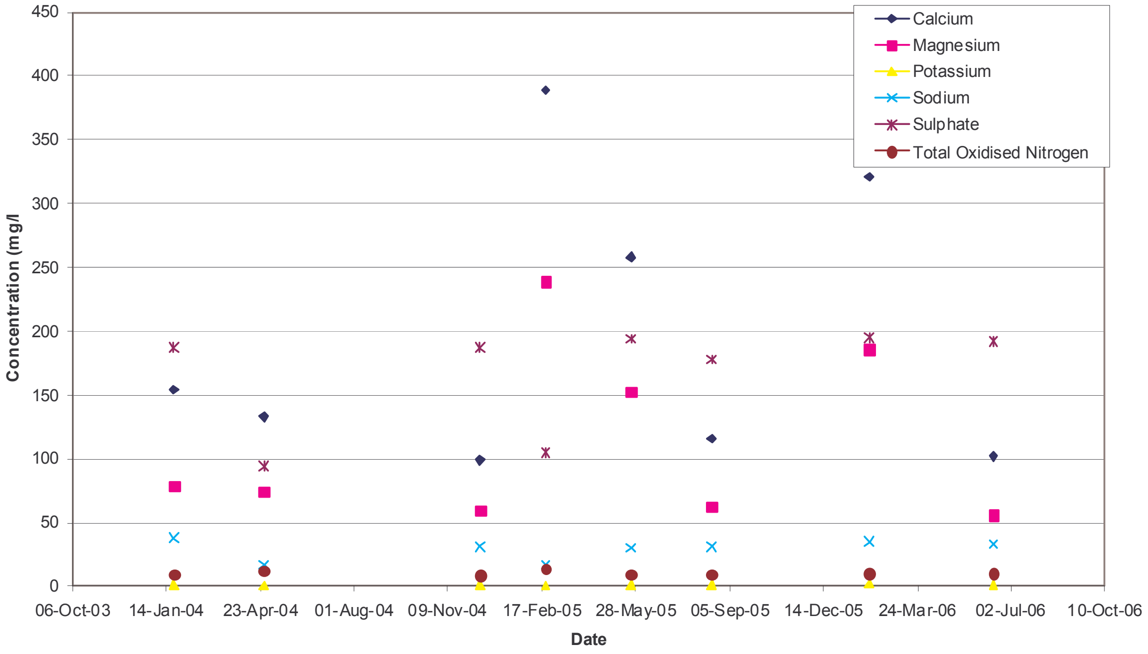


Hydrograph for Borehole 10, Houghton-le-Spring

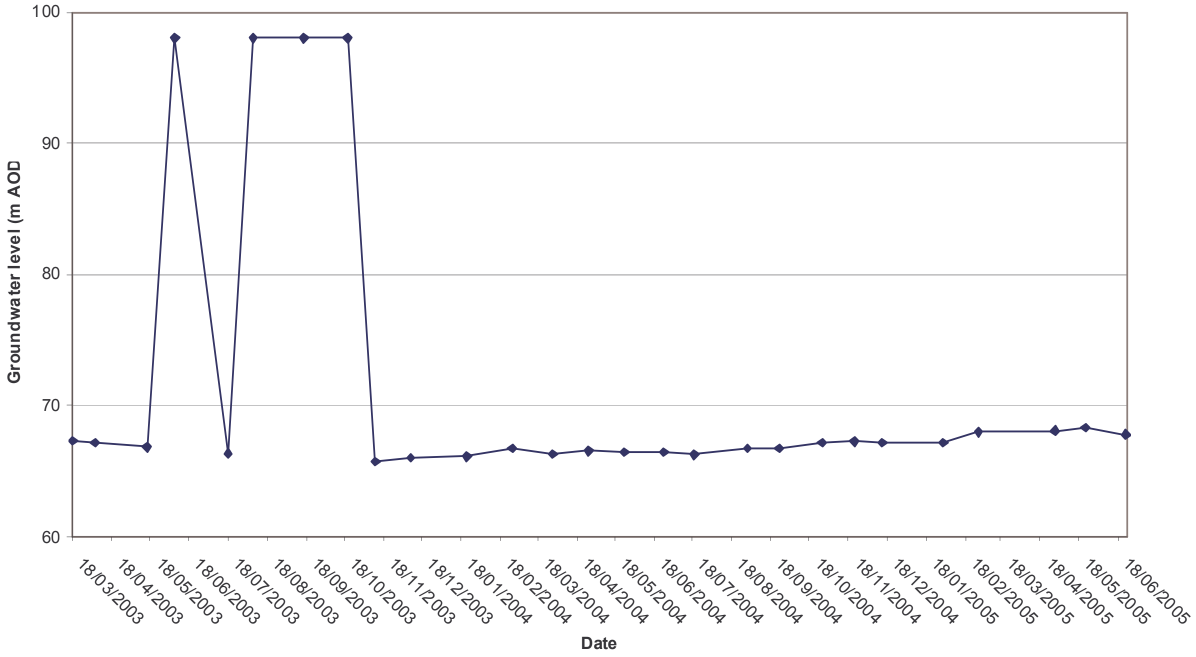
Borehole F1

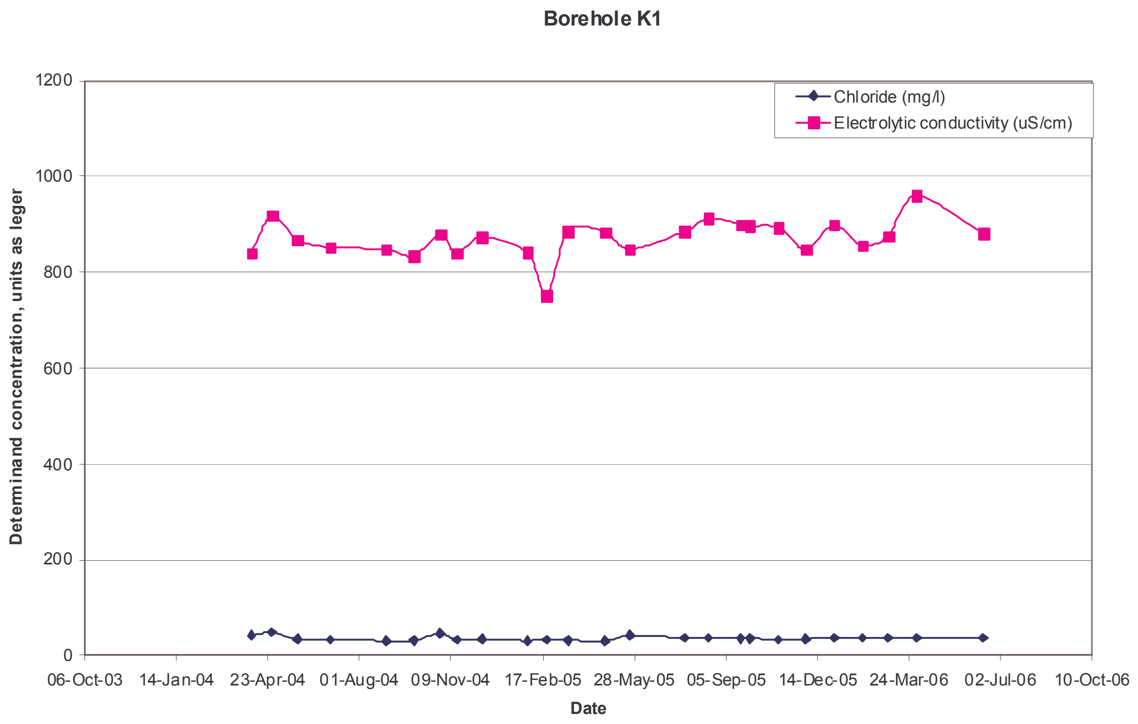


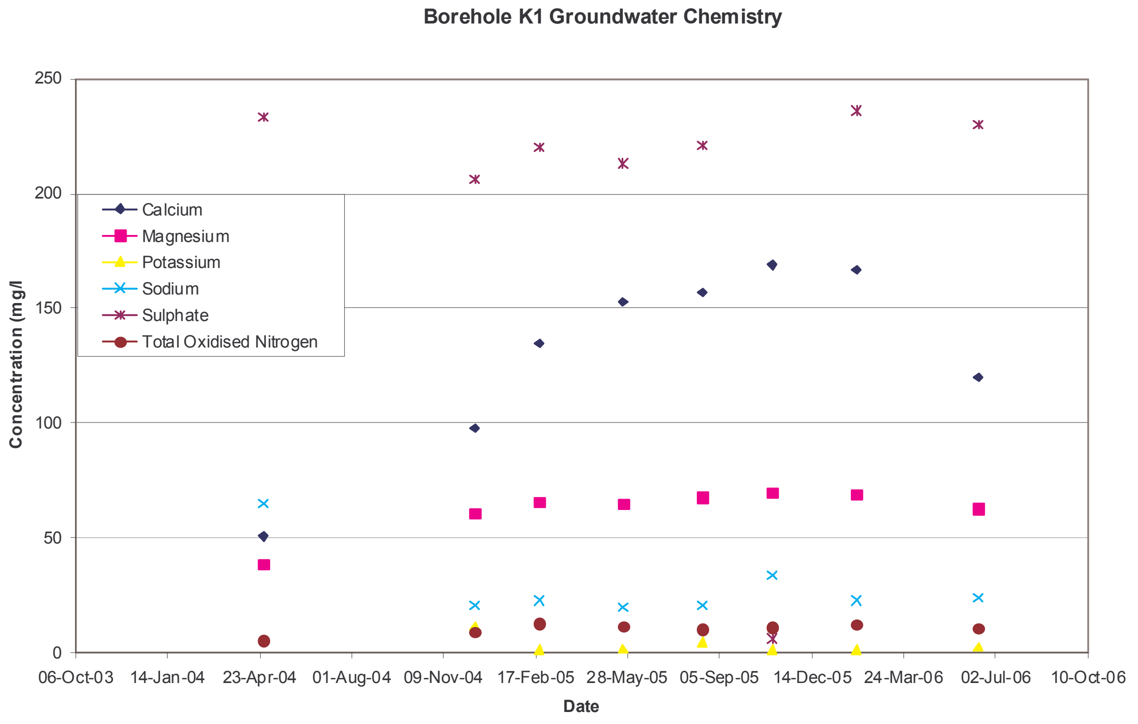
Borehole F1 Groundwater Chemistry

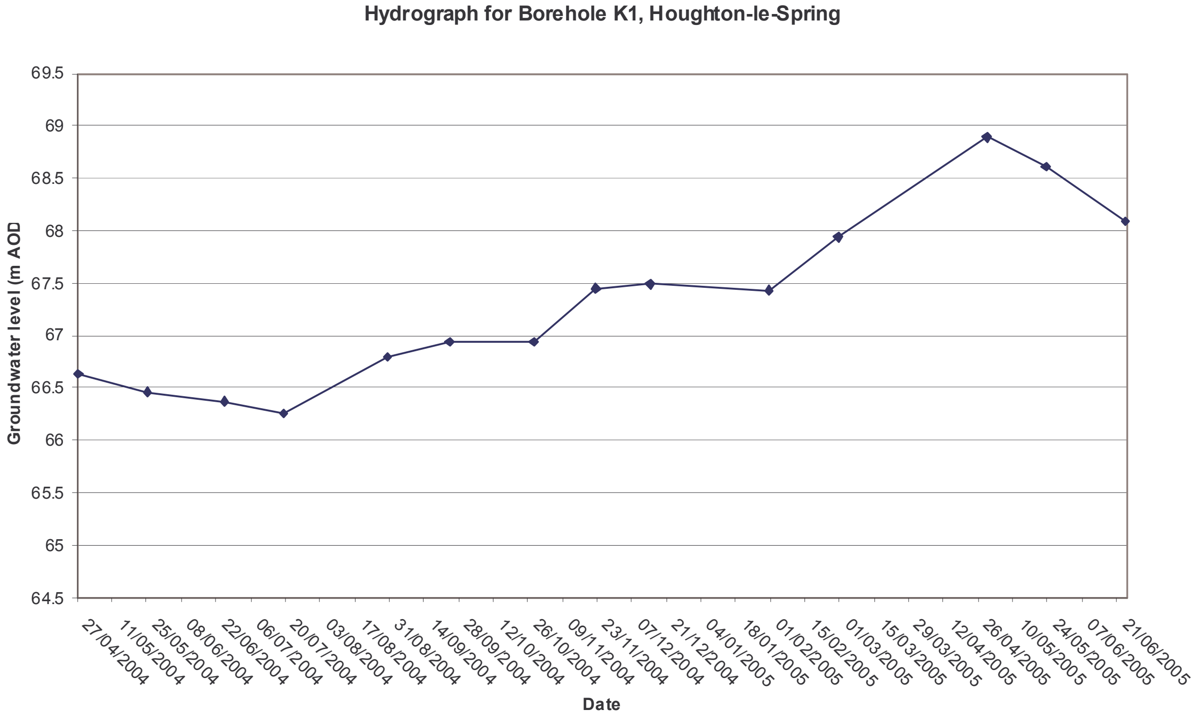


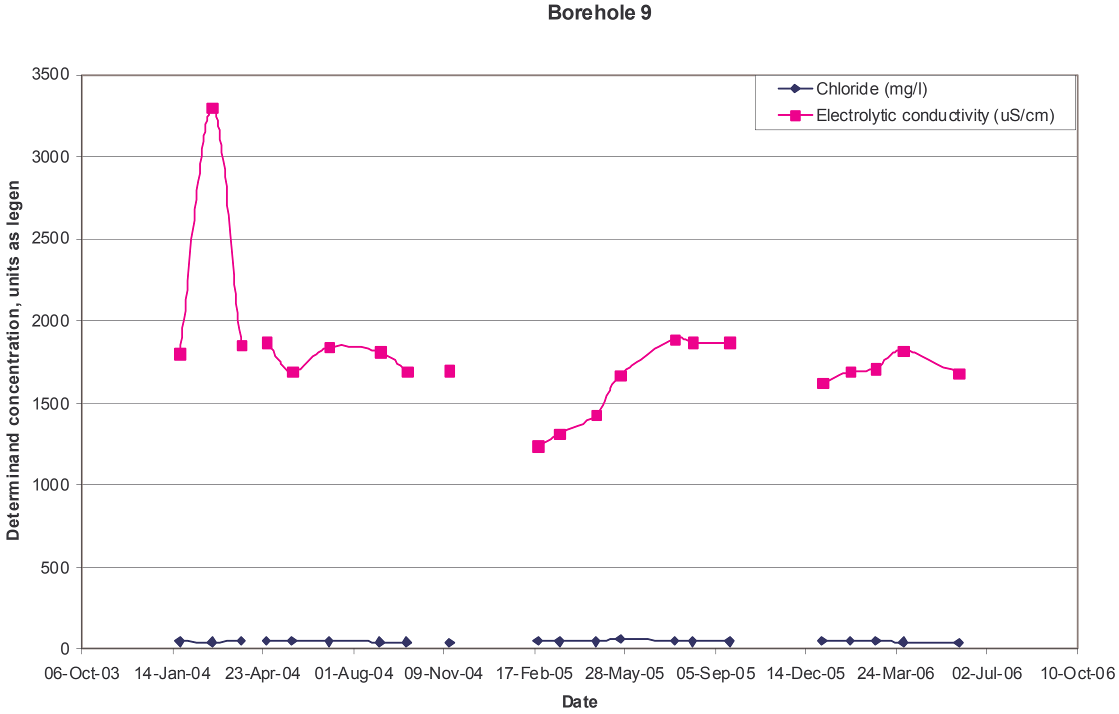
Hydrograph for Borehole F1, Houghton-le-Spring

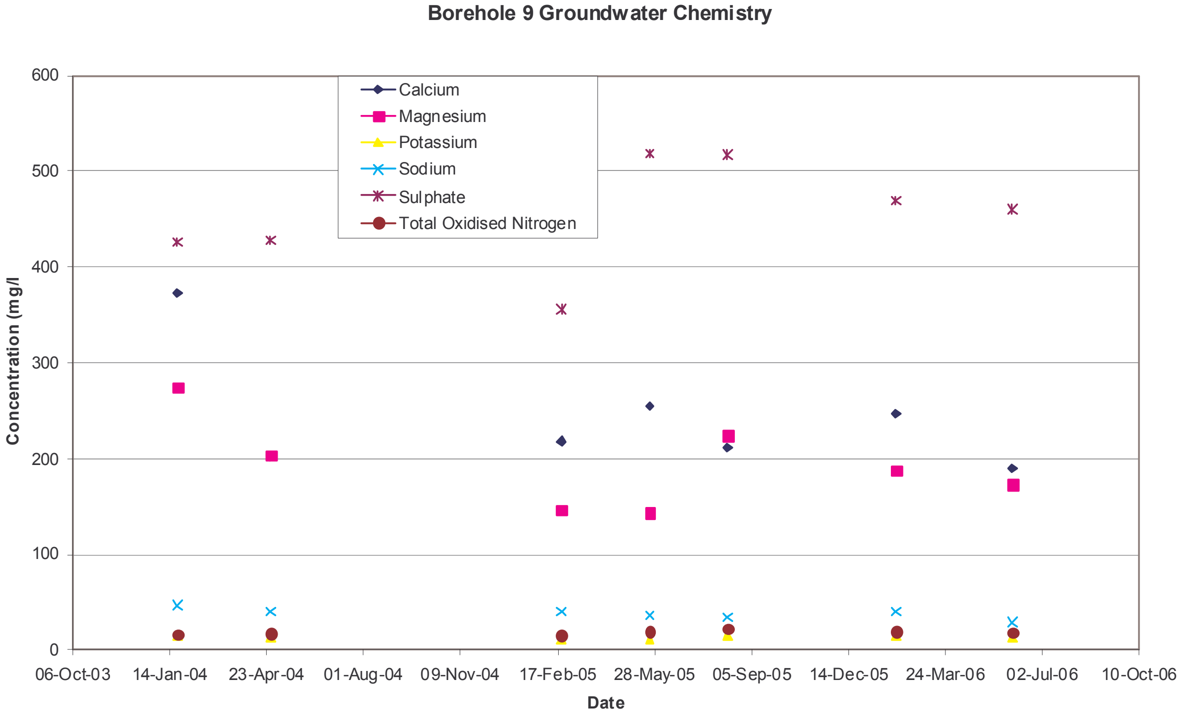


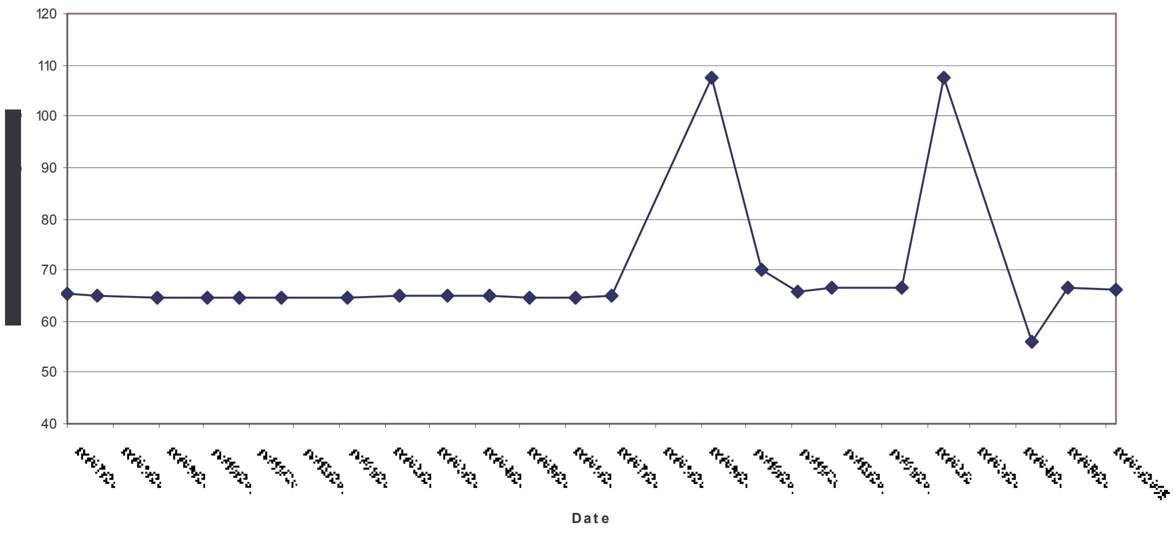

Borehole K1


Borehole K1 Groundwater Chemistry


Hydrograph for Borehole K1, Houghton-le-Spring
Groundwater level (m AOD
69.5
69
68.5
68
67.5
67
66.5
66
65.5
65
64.5
27/04/2004
11/05/2004
25/05/2004
08/06/2004
22/06/2004
06/07/2004
20/07/2004
03/08/2004
17/08/2004
31/08/2004
14/09/2004
28/09/2004
12/10/2004
26/10/2004
09/11/2004
23/11/2004
07/12/2004
21/12/2004
04/01/2005
18/01/2005
01/02/2005
15/02/2005
01/03/2005
15/03/2005
29/03/2005
12/04/2005
26/04/2005
10/05/2005
24/05/2005
07/06/2005
21/06/2005
Date


Borehole 9
Determinand concentration, units as legen
3500
3000
2500
2000
1500
1000
500
0
06-Oct-03
14-Jan-04
23-Apr-04
01-Aug-04
09-Nov-04
17-Feb-05
28-May-05
05-Sep-05
14-Dec-05
24-Mar-06
02-Jul-06
10-Oct-06
Date
Chloride (mg/l)
Electrolytic conductivity (uS/cm)

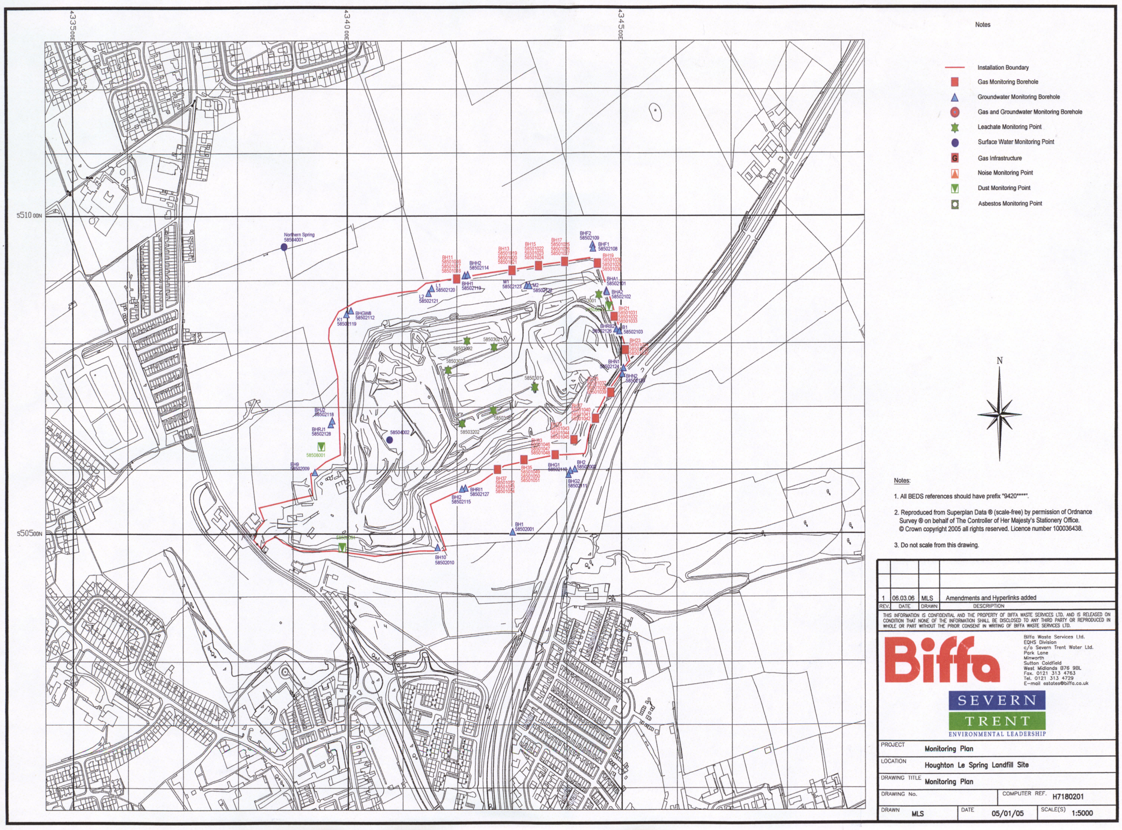

Borehole 9 Groundwater Chemistry
Concentration (mg/l)
600
500
400
300
200
100
0
06-Oct-03
14-Jan-04
23-Apr-04
01-Aug-04
09-Nov-04
17-Feb-05
28-May-05
05-Sep-05
14-Dec-05
24-Mar-06
02-Jul-06
10-Oct-06
Date
Calcium
Magnesium
Potassium
Sodium
Sulphate
Total Oxidised Nitrogen



Hydrograph for Borehole 9, Houghton-le-Spring

Appendix 10 : Borehole Location Plan

(reproduced with permission from Biffa Waste Services Limited)



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1	06.03.06	MLS	Amendments and Hyperlinks added

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SEVERN
TRENT
ENVIRONMENTAL LEADERSHIP

PROJECT Monitoring Plan
LOCATION Houghton Le Spring Landfill Site
DRAWING TITLE Monitoring Plan
DRAWING No. COMPUTER REF. H7180201
DRAWN MLS DATE 05/01/05 SCALE(S) 1:5000