Leachate Monitoring for the Brogborough Test Cell Project

Technical Report
CWM 169/98

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Leachate Monitoring for the Brogborough Test Cell Project: Final Report

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This report provides technical interpretation of leachate monitoring data, derived from the landfill test cell project, and suggests improvements and amendments to leachate monitoring protocols, used to assess the progression of waste stabilisation in landfills.

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FOREWORD

The Brogborough test cell project began in 1986 with the intention of determining how landfill gas production could be influenced by waste composition as well as landfill practices. The study has therefore involved the monitoring of leachate and gas production and quality, and of the conditions inside the cells. Over the years the project has received support from the Department of Trade and Industry (through ETSU), Department of the Environment and latterly the Environment Agency.

The main project has been managed by AEA Technology plc (the National Environmental Technology Centre, formerly the Environmental Safety Centre) and WRc has had an involvement throughout the project, both at Steering Group level and with leachate quality monitoring. This report describes the leachate monitoring programme carried out by WRc, between October 1994 and December 1997, under contract to the Wastes Technical Division of the Department of the Environment, now part of the Environment Agency (EA).

The authors acknowledge the support and assistance of Dr Martin Meadows, and latterly Dr Louise de Rome, for discussion and advice in their role as Project Manager for this contract. The opinions expressed in this report are those of the authors and do not necessarily represent those of the Environment Agency.

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PROJECT OBJECTIVES

This project was commissioned by the Department of the Environment, now the Environment Agency, in order to:

- support the Brogborough test cells project by carrying out regular sampling and analysis of the leachate pumped from the experimental cells and to provide technical advice and interpretation of the leachate chemistry to the Steering Group;
- provide the Waste Technical Division of the Department of the Environment, now part of the Environment Agency (EA), with feedback on the use of leachate monitoring protocols provided in a previous study and to suggest improvements or amendments as they were identified.

TECHNICAL BACKGROUND TO THE PROJECT

Six experimental test cells, at Shanks and McEwan's Brogborough landfill site, near Bedford, have been used to study landfill gas production and its enhancement under different operational and waste management procedures over the past ten years. The project has been managed by AEA Technology plc (the National Environmental Technology Centre, formerly the Environmental Safety Centre) and WRc has had an involvement throughout the project, both at Steering Group level and with leachate quality monitoring.

As the trials have progressed, leachate monitoring data have been interpreted and presented to the Steering Group at regular intervals, in order to provide additional supporting information to the project as a whole.

The report which follows describes the leachate monitoring programme carried out between October 1994 and December 1997 under contract to the Wastes Technical Division of the Department of the Environment, now part of the Environment Agency (EA).

OVERVIEW OF THE WORKING PROGRAMME

Leachate monitoring exercises were conducted more or less quarterly during the course of the contract. Prior to each planned exercise, leachate access wells were purged using on-site submersible pumps. The monitoring exercises were undertaken on the following day, entailing the collection of leachate samples and the conduct of on-site determinations. A sampling plan, with associated record sheets, was devised and utilised by monitoring staff. On-site determinations included leachate pH, temperature and electrical conductivity. Laboratory analyses included chloride, sulphate, ammoniacal nitrogen, total alkalinity (as $CaCO_3$), nitrite-nitrogen, nitrate-nitrogen, phosphate, sodium, potassium, calcium, magnesium, iron, manganese, cadmium, copper, nickel, zinc, BOD, COD, TOC, and volatile fatty acids.

A variety of sample handling options have been tested during the contract period, including the use of in-line filters as opposed to separate filtration apparatus. Other laboratory pre-treatment options prior to analysis have also been investigated.

SUMMARY OF THE MAIN FINDINGS

Field protocols and sample handling

Results presented in the report reinforce the conclusion that it is more important to use appropriate filtration techniques on-site than to put undue emphasis on sample pre-treatment in the laboratory. Significant improvements in sample integrity, and the resulting quality of the data (particularly for heavy metal determinations), can be achieved by employing on-site filtration during landfill monitoring exercises.

In-line disposable filters were much easier to use in the field compared with the alternative separate filtration apparatus. Although the cost of a disposable filter is in the region of £12 per sample (1997), we argue that this is adequately compensated for by efficiency of use when compared with the alternative cheaper, but more time consuming, approaches. In addition, the consistency and quality of the data generated and the level of confidence in its use can be much improved. The use of ion balance calculations in the quality assurance/quality control aspects of the exercise can assist in achieving these improvements.

We recommend using 0.45 μm filters to prepare leachate samples for dissolved metal determinations (both major cations and heavy metals) rather than 1.2 μm. Large capacity 0.45 μm are as easy to use in the field as 1.2 μm filters, consistency with groundwater filtration is achieved and there are additional cost advantages.

Alkalinity determinations to an endpoint of pH 4.5, as opposed to pH 3, generally returned better ion balances for landfill leachates. The complex chemical characteristics of leachate, and in particular the influence of volatile fatty acids and ammoniacal nitrogen on alkalinity determinations, adversely affect ion balances.

Trends in leachate depth and chemistry

Leachate levels in all the cells are unique although the underlying trends in Cells 1, 2, 4 and 6 have been similar. Since January 1994, these levels have continued to rise approximately 1-2 m yr^{-1}. Although the leachate level in Cell 5 (containing sewage sludge) was much higher than in the other cells at the start of the reported monitoring programme, the rise of 0.5 m in 1994 has declined further. Leachate level behaviour in Cell 3 is less easily explained. Preferential flow paths around the well casing, exacerbated by localised ponding of rain water, and the effects of liquid injection to the cell in February 1994, complicate the picture.

The organic strength of the leachate in Cell 1 has continued to decline along with the establishment of more neutral pH conditions. Generally, a shift from acetogenic conditions to a more optimised methanogenic state within the saturated regions of Cells 1 to 4 is assumed. General trends for other determinands have tended to become more consistent between cells since the initiation of the well purging strategy back in January 1994, although heavy metal leaching has been found to be influenced by pH conditions as well as by the presence of organic ligands.

Leachate temperature, although influenced by the underlying seasonal trend, has continued to rise during the monitoring period and currently lies between 30 and 35 °C in all the cells.

Chloride and ammoniacal nitrogen concentrations are lower in Cell 6 compared with the average value found in Cells 1 and 2. This is believed to be due to the diluting influence of the inert trade waste contained in this cell. In general, there has been a much more rapid assimilation of readily degradable organics in Cells 5 and 6, in comparison with the collective control data.

Our general conclusion is that the addition of digested sewage sludge has assisted in 'switching' on the waste stabilisation processes within the waste mass at an early stage following waste emplacement. There appears to be few disincentives from a waste stabilisation point of view and, although the total nitrogen and heavy metal content of the cell was higher than in the control cells at emplacement, this has not given rise to exceptional concentrations in the leachate over time.

Like the sludge co-disposal trial, there is some evidence that the addition of commercial and non-hazardous (more inert) waste to Cell 6 had a beneficial effect in accelerating the onset of methanogenic conditions.

RECOMMENDATIONS

Field protocols and sample handling

The use of in-line disposable filters are recommended in preference to either on-site filtration apparatus or filtration on return to the laboratory. Filtration is most important for heavy metal determinations whereas other general determinands, and in particular BOD, COD, TOC and other organic parameters such as pesticides and hydrocarbons, should still be carried out on unfiltered samples containing appropriate preservative where deemed necessary.

WRc recommend that 0.45 µm large capacity, pleated, in-line filters should be used for field based filtration of landfill leachates.

Alkalinity determinations should be carried out using the pH 4.5, rather than the pH 3, endpoint since the latter returns ion balances with unacceptable cation deficiencies. In general balances in error by more than 15% should be investigated further, in discussion with the analyst.

Routine ion balance checks should be incorporated into the sampling plan of a monitoring exercise. The results of these check samples should be reviewed by the responsible officer and then discussed with the field monitoring staff.

Design considerations for efficient bio-reactive landfills

The distribution and development of saturated moisture conditions within wastes is regarded as essential for the optimisation of conditions conducive to rapid anaerobic digestion under landfill conditions. The Brogborough test cells have provided further evidence to back up these claims and have provided some important indicators as to how a more optimised, bioreactor approach could be developed through further research and development work. Valuable data, which could be used in the study of the mixing and hydrodynamics of water flow in landfills, has been generated by the study, although this could be improved by surveying each of the leachate monitoring wells to a common datum.

Leachate monitoring at the cells has indicated that acetogenic and methanogenic conditions co-exist without detriment to gas production. However, methanogenic conditions were generally found to be associated with the saturated basal layers of waste in each cell. This contrasts with acetogenic conditions, which tend to be associated with the drier, unsaturated upper layers of waste.

It follows that controlled irrigation or recirculation of methanogenic leachate to capped waste should be one way of bringing about a more rapid stabilisation of landfilled waste in a sustainable landfill development. In recognition that the saturated basal layers of landfills could be encouraged to become more efficient in methane production, and irrigation or recirculation of leachate is one way that this could be brought about, studies should concentrate on the engineering requirements that would enable this to be achieved in a controlled and predictable way. In addition, process control 'tools' need to be developed which will allow a degree of feedback control on the process. The use of *in situ* hydrogen measurements within the unsaturated and saturated zones of waste may provide some means of achieving this objective.

Field sampling strategies designed to monitor the development and progress of bio-reactive conditions within a modern landfill should incorporate a leachate purging requirement prior to any sampling activity. Over-reliance on baling techniques during earlier phases of the Brogborough trials emphasised the ease with which erroneous conclusions were reached concerning the status of conditions within the wastes. If this is not appreciated, use of data of this kind can mislead site management, or those with regulatory responsibilities, and incur significant wastage of time and resources. The study has also indicated that an important release controlling parameter for metals is pH. Examination of this data set alongside that from other landfills, in ways that expose these controls, could demonstrate consistency in the way materials leach in the long term in landfills. Such information could be used to develop acceptance criteria and waste pre-treatment requirements for landfill disposal.

KEY WORDS

Landfill monitoring, landfill leachate, sample pre-treatment, sampling protocols, bioreactor landfill, waste stabilisation.

1. INTRODUCTION

1.1 Study Background

Over the past ten years, six experimental test cells at Shanks and McEwan's Brogborough landfill site, near Bedford, have been used to study landfill gas production and its enhancement using different waste mixes and emplacement techniques. The project has been managed by AEA Technology plc (the National Environmental Technology Centre, formerly the Environmental Safety Centre) and WRc has been involved throughout the project, both at Steering Group level and carrying out leachate quality monitoring. As the trials have progressed, leachate monitoring data have been interpreted and presented to the Steering Group at regular intervals, in order to provide additional supporting information to the project as a whole.

Following recommendations by WRc that the leachate sampling protocol should be adjusted to allow the purging of the access wells and the removal of more representative liquors, *in situ* inertial pumps were installed in 1992. These allowed the removal of stagnant leachate, ensuring that more mobile leachate could be sampled and analysed, thus improving the data which was being used to assess the progression of waste stabilisation.

Experience from this modified monitoring programme led to adjustments of the recommended sampling technique for landfill leachate, especially where sampling is carried out to monitor the progression of waste stabilisation. At the same time it became clear that a short study was appropriate to:

- investigate different aspects of a revised approach to landfill leachate monitoring so that recommendations could be made to the Environment Agency on the most appropriate approach for monitoring waste stabilisation in landfills; and
- to provide further advice and interpretation of the leachate chemistry for the benefit of the Steering Group.

This report describes the work programme, conducted between early 1994 and December 1997, which was designed to address the above issues.

1.2 Study aims and objectives

This project was originally commissioned by the Department of the Environment, although in its latter stages has been managed by the Environment Agency, with the following objectives:

- to support the Brogborough test cells project by carrying out regular sampling and analysis of the leachate pumped from the experimental cells and to provide technical advice and interpretation of the leachate chemistry to the Steering Group;

- to provide the Environment Agency, with technical feedback on the use of leachate monitoring protocols provided in a previous study[1] and to suggest improvements or amendments as they are identified.

1.3 Report structure and outline content

Our report begins with a brief overview of the field working programme, including the sampling plan adopted (Section 2). Precise details of the plan are provided in Appendix A.

Section 3 presents the results of the leachate sample handling investigations, designed to provide feedback on the application of leachate sampling techniques, whilst Section 4 presents the leachate chemistry of the trial. Discussion on the trends in leachate chemistry, and how this has provided insight into the status of waste stabilisation within the cells, can be found in Section 5.

Section 6 draws together the main issues raised in the report, and makes suggestions and recommendations relating to future studies on the stabilisation of refuse in landfill sites and the implementation of monitoring programmes.

Our comments on waste stabilisation are made in isolation of the information derived by the main contractors of the overall study (NETCEN) and therefore do not represent an in-depth assessment of all available information. This report, therefore, provides a specific contribution to the understanding of the landfill gas enhancement study as a whole.

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[1] See Blakey *et al* (1997) Guidelines for monitoring leachate and groundwater at landfill sites. Environment Agency report CWM 062/97C.

2. WORK PROGRAMME

2.1 Background

Prior to the summer of 1992, all leachate analyses were carried out on samples of free standing liquor collected from the base of each of the six Brogborough test cells. These analyses appeared to indicate that all the test cells had moved rapidly from acetogenic to methanogenic conditions, typified by low organic content and near neutral pH conditions. Beyond the summer of 1992, samples extracted under a revised sampling plan showed that this was not the case. Here, organic substrates, in the form of volatile acids, low pH conditions and increased concentrations of other inorganic constituents indicated that significant acetogenic conditions were still in existence within the waste mass.

Monitoring, under the revised sampling plan, ceased in December 1992, before trends in the data could be established. A short interim contract was agreed with ETSU, on behalf of the Department of Trade and Industry, in January 1994 which allowed the completion of five additional monitoring exercises up to May 1994. This additional monitoring was carried out using the revised sampling plan.

Although the study reported here primarily relates to sampling carried out between October 1994 and December 1997, the ETSU study results are reported for completeness.

2.2 Sampling visits

Samples were collected from the six cells approximately quarterly between October 1994 and December 1997. One of the planned sampling trips (January 1995) had to be cancelled because of localised flooding in the area of the experimental landfill cells.

2.3 Outline sampling plan

The aim of the sampling programme was to monitor the trends in leachate chemistry, at the Brogborough test cells, in a way that provided insight into the progress of waste stabilisation within each of the six cells.

Immediately prior to the planned monitoring trips, Shanks and McEwan personnel assisted in purging the leachate monitoring boreholes, using on-site submersible pumps. Several well volumes of leachate were removed in order to purge the wells of 'stagnant' leachate. WRc staff visited the following day to collect samples for analysis and conduct on-site determinations.

A sampling plan, with associated record sheets, was devised and utilised by both WRc and Shanks and McEwan personnel. This plan was based on the previous work undertaken by WRc on behalf of ETSU (Blakey and Bradshaw 1994). An amended version of the generic plan is provided at Appendix A, for reference. While the general detail of the sampling plan remained consistent throughout this reported phase of the project, specific details of sample handling were adjusted from trip to trip. This was necessary to allow investigations on filtration strategy.

Parameters measured at the time of on-site sampling included leachate pH, temperature and electrical conductivity.

The recovered leachate samples were submitted for laboratory analyses at WRc Medmenham for a range of determinands, namely: chloride, sulphate, total alkalinity as $CaCO_3$, ammoniacal nitrogen, nitrite-nitrogen, nitrate-nitrogen, phosphate, sodium, potassium, calcium, magnesium, iron, manganese, cadmium, copper, nickel, zinc, BOD, COD, TOC, and volatile fatty acids.

Samples collected for nitrogen, phosphorus, volatile fatty acids and heavy metal determinations were collected in separate bottles containing appropriate preservatives.

3. LEACHATE SAMPLE HANDLING INVESTIGATIONS

3.1 Preamble

Leachates are highly complex, chemically unstable solutions which change on contact with air. To minimise the effect of storage on the quality of leachate from the Brogborough test cells, WRc have traditionally carried out the determination of the unstable parameters pH, electrical conductivity (and latterly temperature) as soon as possible after sampling, usually at the well head. Samples collected between 1989 and 1992 were always filtered through 1.2 µm pore size filters in order to calculate suspended solids content; the filtrate was then sub-sampled and preserved as appropriate, prior to submission to the analytical laboratory for analysis. Landfill leachates are difficult matrices to filter due to their high organic content and suspended solids load. Consequently, the filtration of sufficient sample is a time consuming process. The filtering was therefore conducted in the laboratory, not in the field.

Traditionally the dividing line between the dissolved and suspended fraction of a **groundwater** sample has been taken to be 0.45 µm. This is an arbitrary value but the use of 0.45 µm pore size filters to collect groundwater samples for dissolved metal determinations is standard. The addition of an acid preservative is usually carried out prior to analysis, preferably immediately after filtration in the field, to prevent the precipitation of heavy metals from solution. By removing the suspended fraction the impact of material that may have fallen into the borehole during sampling or generated by reaction with the borehole lining material is eliminated.

For leachates, sample handling practices have been variable and clear-cut guidance unavailable. For example, whether determinations of the total or just the dissolved metal contaminants are required is often not questioned. WRc, in common with other laboratories that analyse waste waters, conducts an acid digestion on landfill leachate samples prior to analysis. This process ensures that any materials which may have precipitated out of solution are re-dissolved prior to analysis. Where unfiltered samples are digested and analysed for heavy metals, ‘total’ rather than ‘dissolved’ metals will be determined.

As disposable filter capsules with large surface areas have become available, it has now become feasible to undertake the filtration of leachate samples in the field, in much the same way as for groundwaters. But, for those with the responsibility for developing a sampling plan before the start of a leachate sampling exercise, a decision needs to be made on:

- whether the samples should be filtered;
- if filtering is considered necessary, which portion(s) of the sample submitted for different determinands would benefit from this sample pre-treatment.

In order to provide an element of quality assurance in a sampling programme, responsible parties are encouraged to include comprehensive analytical suites which allow ion balances to be calculated. These provide the means of checking the validity of the laboratory analyses. Varying the sample handling techniques could cause ionic imbalances that would go unnoticed if not investigated.

In summary therefore, the long-term monitoring programme at the Brogborough test cells has been used as a vehicle for testing the ease of use of field filtration techniques, the effect of a range of sample handling and pre-treatment methods on the analytical data and to determine which combination of pre-treatments would least disrupt the ion balance of the analyses.

3.2 Objectives

The objectives of the programme were to determine whether the filtration and digestion of samples prior to analysis would significantly affect the ion balance calculation and to modify the leachate monitoring protocols to ensure that variations in analytical results, and therefore the ion balance calculations, were not due to errors introduced by sampling handling techniques.

3.3 Sample handling and treatment options investigated

3.3.1 Filtration

Three filtration options are available to field technicians undertaking landfill monitoring:

1. *No filtration:* Samples are collected in one or two bottles and passed to the analytical laboratory for sub-sampling and analysis, with no further pre-treatment.

2. *Laboratory filtration:* Samples are filtered and transferred to pre-preserved bottles as appropriate on return to the laboratory (i.e. within 4 to 8 hours of sample collection). This had been our approach for the Brogborough leachates up until the start of the reported working programme. Samples were processed on return to the laboratory by vacuum filtration, using 150 mm diameter GF/C filter papers. This procedure may also reflect the practice of field technicians who deliver leachate samples untreated, but where the analytical laboratory sub-divides and filters/preserves the sample on receipt.

3. *On-site filtration:* the samples can be filtered at the well-head using:

    - vacuum filtration or pressure filtration using portable filtration apparatus; or

    - a small diameter 0.45 µm filter paper in an on-line reusable filter holder; or

- on-line single-use 1.2 or 0.45 µm filter capsules with pleated membranes which offer a large surface area for filtration.

All three main filtration options have been compared using the Brogborough leachates.

3.3.2 Digestion of sample prior to analysis

Landfill leachates are commonly digested prior to analysis. The samples have 5 ml of 5M nitric acid per 50 ml of sample added to them. The 55 ml of acidified sample is then boiled down to about 5 ml and then made up to 50 ml with deionised water. This is carried out particularly when samples collected for heavy metals have not been preserved. This procedure ensures that heavy metal precipitates are taken back into solution prior to analysis.

For certain sampling trips, duplicate samples were collected for each type of filtration option, with one sample digested prior to analysis and the other treated as received. Where unfiltered samples have been collected, these have generally been digested prior to analysis. The necessity of digesting samples when they have been appropriately prepared in the field has been assessed.

3.3.3 Selection of end-point pH for alkalinity titration

The standard protocol for the distribution of alkalinity in relatively clean water samples dictated that the end-point for the titration is taken to be pH 4.5. However, a lower end-point is suggested for leachates due to additional contribution to alkalinity from ammoniacal nitrogen and volatile fatty acids. Both these constituents can be present in significant concentrations in landfill leachates. An experiment was therefore devised whereby duplicate samples for alkalinity determinations at pH 4.5 and pH 3 were taken. The ion balance calculations, using both sets of results, were compared to allow a recommendation on the best approach.

3.4 Field protocols used for each sampling event (October 1994 - December 1997)

3.4.1 Methodology

Shanks and McEwan personnel purged the leachate monitoring boreholes before each sampling event - usually the day before. Boreholes were pumped until three well volumes of the leachate column had been removed or until the borehole ran dry, whichever occurred first. The sampling plan record sheets detailing the borehole purging for each visit are included in Appendix B. Boreholes were then left overnight to recharge before being sampled by WRc personnel the following day.

Unstable parameters (EC, pH and temperature) were measured on the pumped leachate at the time of sampling.

The various sample handling procedures adopted on each visit are summarised below:

(a) *4 October 1994* - Several methods of filtration were tried to assess their ease of use:

- 0.45 µm filter papers in a re-usable portable pressure filtration unit;
- single-use small volume in-line units containing flat 0.45 µm membrane filters;
- single-use large-volume pleated filter capsules containing 1.2 µm pore size filters.

Duplicate samples were collected to examine quality assurance aspects connected with sample pre-treatment prior to laboratory submission.

(b) *2 March 1995* - This planned winter trip was delayed by poor ground conditions on site. Sample handling techniques on this occasion included the use of both 1.2 and 0.45 µm disposable in-line filter capsules. These were attached directly to the end of the discharge tubing from the *in situ* pumps.

Samples were analysed for the full analytical suite (including volatile fatty acids) so that the ion balance could be calculated for the analytical data. This was to provide an additional check on the overall integrity of the sample handling and analytical work associated with landfill leachate monitoring.

(c) *6 July 1995* - Samples collected for BOD, COD and TOC determinations were not filtered. Leachates collected for heavy metal determinations were filtered using 0.45 µm disposable filter capsules attached to the pump discharge line. Remaining samples (major anions) were filtered through 1.2 µm filters.

(d) *8 November 1995* - Samples collected for BOD, COD and TOC determinations were not filtered. All other samples were passed through in-line 1.2 µm pore size filters.

(e) *29 February 1996* - The effects of various filter pore size - 1.2 and 0.45 µm, were investigated further to confirm the trends in ion balance and sample integrity which were observed in earlier results. Samples collected for BOD and TOC determinations were not filtered. Samples collected for other parameters, including COD, were filtered through both 1.2 and 0.45 µm filter capsules. An ion balance of both sets of analyses was calculated.

(f) *25 April 1996* - Samples were collected according to the sampling plan with in-line filtration being carried out with 1.2 µm filters, where appropriate.

(g) *20 June 1996* - Field filtration of appropriate samples was carried out at both 1.2 µm and 0.45 µm pore size. A duplicate 1.2 µm filtered sample was also collected from one of the cells for comparison. Samples for determinations of BOD, COD and TOC samples were collected directly from the discharge tubing without filtration.

(h) *11 December 1996* - Field filtration of appropriate samples was carried out using 0.45 µm pore size. At one cell, duplicate filtered samples and a range of unfiltered samples were collected to study the effects of not filtering in the field and the difference in results obtained due to various sample handling by the lab, for example immediate analysis, analysis following storing for two days and the effects of digestion.

(i) *6 February 1997* - Field filtration of appropriate samples was carried out using 0.45 µm pore size. Further studies on digestion of samples and the effect on ion balance were assessed.

(j) *10 July 1997* - Field filtration of appropriate samples was carried out using 0.45 µm pore size. Unfortunately a number of cells were now difficult to purge due to collapse or distortion of the boreholes. Only Borehole 3 could be purged for three well volumes. Borehole 6 was blocked at about 9 metres and neither purging nor sampling were possible. Borehole 2 had been infilled.

(k) *23 September 1997* - Field filtration of appropriate samples was carried out using 0.45 µm pore size. Duplicate metals and volatile fatty acid samples were collected from Cell 5. Cells 1, 3, 4 and 5 sampled.

(l) *7 November 1997* - Field filtration of appropriate samples was carried out using 0.45 µm pore size. Cells 1, 3, 4 and 5 sampled.

3.4.2 Comment

The use of the low-volume portable filtration system used in October 1994 proved difficult to use for two reasons:

- the small diameter (approximately 4 cm) membrane filter papers, having a low cross sectional area, did not perform well due to clogging. The filters had to be replaced numerous times to prepare sufficient leachate from each borehole for analysis, and;

- rinsing equipment between samples was time consuming and introduced opportunities for contamination of the samples.

From March 1995 filter capsules of 1.2 and 0.45 µm were used as appropriate. Both types performed well, enabling sufficient volumes of samples to be filtered directly into sample bottles. A considerable amount of field technician time was saved by using this equipment. Although only one unit could be used per sample, single use ensured that cross-contamination between boreholes was avoided. These advantages more than compensated for the additional consumable cost of the filter capsules, in comparison with more conventional equipment.

3.5 Results (October 1994 - December 1997)

3.5.1 Presentation of data

The full results of the Brogborough monitoring programme are presented in Appendix C.

To summarise the various handling techniques adopted, a coding system has been applied to the tabulated data. This is explained as follows:

- UF = unfiltered sample;
- 1.2 μm = pore size of filter through which sample was passed;
- 0.45μm = pore size of filter through which sample was passed;
- G and W = refer to different makes of filter;
- D = metals sample was digested in the laboratory prior to analysis;
- a & b = duplicate samples with the same sample handling procedures;

The most detailed investigation into the effect of sample handling on major and trace metal determinations was carried out in March 1995: duplicate samples, filtered through 1.2 and 0.45 μm capsules, were submitted for analysis together with an unfiltered sample. Each filtered sample was subdivided in the laboratory, with one part digested and the other not digested prior to analysis by ICP. These results are presented in Table 3.1, and graphically in Figures 3.1 and 3.2, and provide the basis of the following narrative.

Table 3.1 Data for March 1995 showing the effects of on-site filtration and laboratory pre-treatment options on landfill leachate analyses

Test cells leachate analysis : Cell No. 1 - metal results (mg l^{-1})

Date	Filter	Na	Mg	K	Ca	Cr	Mn	Fe	Ni	Cu	Zn	Cd
01/03/95	UF	1360	123	1170	114	0.07	0.28	25.4	0.30	<=0.02	2.69	<=0.02
01/03/95	D 1.2μm	1490	132	1260	115	0.06	0.20	15.9	0.28	<=0.02	2.09	<=0.02
01/03/95	1.2μm	1490	132	1260	114	<=0.05	0.20	15.5	0.21	<=0.02	2.05	<=0.02
01/03/95	D 0.45μm	1470	133	1260	114	0.06	0.20	11.4	0.27	<=0.02	0.07	<=0.02
01/03/95	0.45μm	1500	136	1290	116	0.06	0.20	11.4	0.29	<=0.02	0.04	<=0.02

Test cells leachate analysis : Cell No. 2 - metal results (mg l^{-1})

Date	Filter	Na	Mg	K	Ca	Cr	Mn	Fe	Ni	Cu	Zn	Cd
01/03/95	UF	1660	162	1270	99.5	<=0.05	0.10	9.80	0.19	<=0.02	1.27	<=0.02
01/03/95	D 1.2μm	1580	155	1210	91.0	<=0.05	0.08	8.30	0.17	<=0.02	0.64	<=0.02
01/03/95	1.2μm	1660	164	1270	95.3	<=0.05	0.07	8.20	0.12	<=0.02	0.62	<=0.02
01/03/95	D 0.45μm	1630	161	1250	94.4	<=0.05	0.08	5.24	0.15	<=0.02	0.09	<=0.02
01/03/95	0.45μm	1680	164	1290	97.1	<=0.05	0.07	4.69	0.14	<=0.02	0.08	<=0.02

Test cells leachate analysis : Cell No. 3 (Recirculation) - metal results (mg l^{-1})

Date	Filter	Na	Mg	K	Ca	Cr	Mn	Fe	Ni	Cu	Zn	Cd
01/03/95	UF	738	122	557	269	<=0.05	1.26	58.1	0.21	<=0.02	3.16	<=0.02
01/03/95	D 1.2μm	647	118	463	268	<=0.05	0.81	2.26	0.11	<=0.02	0.19	<=0.02
01/03/95	1.2μm	685	123	490	282	<=0.05	0.84	2.13	<=0.05	<=0.02	0.15	<=0.02
01/03/95	D 0.45μm	645	118	462	269	<=0.05	0.82	1.54	0.10	<=0.02	0.10	<=0.02
01/03/95	0.45μm	689	125	494	287	<=0.05	0.87	1.55	0.08	<=0.02	0.08	<=0.02

Test cells leachate analysis : Cell No. 4 (Gas Collection) - metals results (mg l^{-1})

Date	Filter	Na	Mg	K	Ca	Cr	Mn	Fe	Ni	Cu	Zn	Cd
01/03/95	UF	1830	154	1560	70.1	0.13	0.43	45.3	0.24	<=0.02	2.61	<=0.02
01/03/95	D 1.2μm a	1790	148	1520	49.3	0.12	0.10	2.52	0.18	<=0.02	0.16	<=0.02
01/03/95	1.2μm	1860	152	1570	50.2	<=0.05	0.08	2.39	<=0.05	<=0.02	0.14	<=0.02
01/03/95	D 0.45μm G	1880	156	1590	51.6	0.14	0.10	2.80	0.16	<=0.02	0.08	<=0.02
01/03/95	D 0.45μm W	1810	149	1530	50.2	0.08	0.11	4.37	0.11	<=0.02	0.09	<=0.02
01/03/95	0.45μm G	1870	153	1580	50.7	0.08	0.09	2.55	0.11	<=0.02	0.05	<=0.02
01/03/95	0.45μm W	1870	154	1580	51.3	<=0.05	0.09	1.95	0.09	<=0.02	<=0.02	<=0.02

Test Cells Leachate Analysis : Cell No. 5 (Sewage Sludge) - metal results (mg l^{-1})

Date	Filter	Na	Mg	K	Ca	Cr	Mn	Fe	Ni	Cu	Zn	Cd
01/03/95	UF	1160	80.4	869	57.6	0.13	0.06	6.53	0.25	<=0.02	0.31	<=0.02
01/03/95	D 1.2μm	1180	80.7	881	54.8	0.09	0.03	4.08	0.20	<=0.02	0.16	<=0.02
01/03/95	1.2μm	1240	84.4	925	57.0	0.08	0.03	4.14	0.17	<=0.02	0.14	<=0.02
01/03/95	D 0.45μm G	1230	84.8	920	58.0	0.10	0.04	4.49	0.24	<=0.02	0.09	<=0.02
01/03/95	D 0.45μm W	1190	83.0	891	56.0	0.14	0.04	3.73	0.26	<=0.02	0.04	<=0.02
01/03/95	0.45μm G	1240	84.3	923	58.0	0.08	0.03	4.24	0.19	<=0.02	0.04	<=0.02
01/03/95	0.45μm W	1260	85.1	936	58.1	<=0.05	0.03	3.43	0.15	<=0.02	<=0.02	<=0.02

Test cells leachate analysis : Cell No. 6 (Industrial Waste) - metal results (mg l^{-1})

Date	Filter	Na	Mg	K	Ca	Cr	Mn	Fe	Ni	Cu	Zn	Cd
01/03/95	UF	1200	87.3	847	52.2	0.18	0.10	7.09	0.12	<=0.02	0.41	<=0.02
01/03/95	D 1.2μm	1170	84.6	821	50.0	0.14	0.08	4.46	0.09	<=0.02	0.17	<=0.02
01/03/95	1.2μm	1220	88.9	863	52.2	0.15	0.08	4.32	0.10	<=0.02	0.16	<=0.02
01/03/95	D 0.45μm	1160	84.2	818	50.6	0.15	0.08	3.55	0.10	<=0.02	0.04	<=0.02
01/03/95	0.45μm	1250	89.5	881	54.0	0.12	0.08	3.17	0.07	<=0.02	<=0.02	<=0.02

KEY

UF	Unfiltered sample
D 1.2μm	Sample filtered through 1.2μm filter and digested prior to analysis
1.2μm	Sample filtered through 1.2μm filter, but NOT digested prior to analysis
D 0.45μm	Sample filtered through 0.45μm filter and digested prior to analysis
0.45μm	Sample filtered through 0.45μm filter but NOT digested prior to analysis
G & W	Different makes of filter

NOTE: Nickel detection limit 0.05 mg l^{-1} compared to 0.1 mg l^{-1} on other occasions

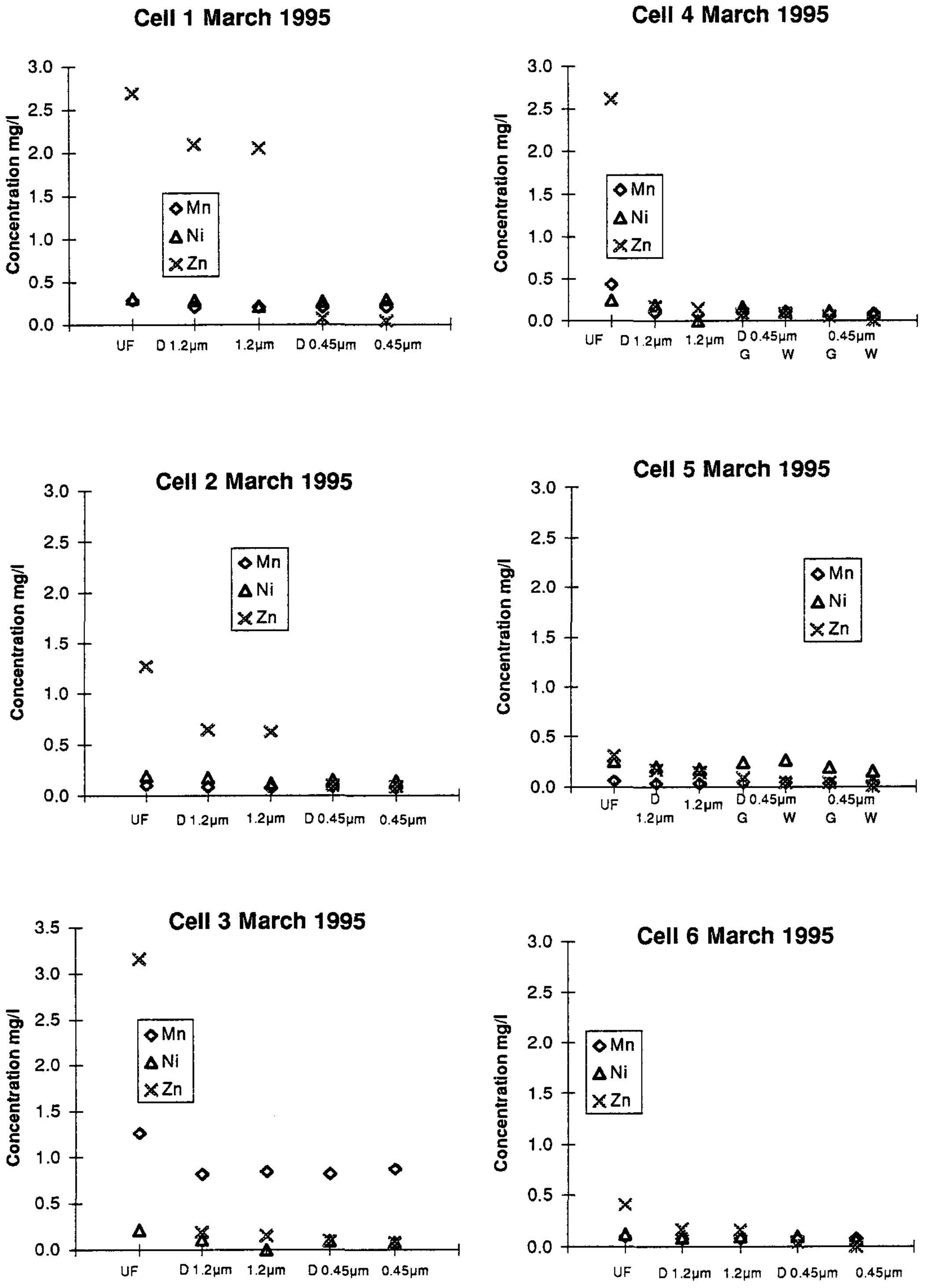


Figure 3.1 The effects of on-site filtration and laboratory pre-treatment options on the analysis of manganese, nickel and zinc in landfill leachate (for code interpretation, see Table 3.1)

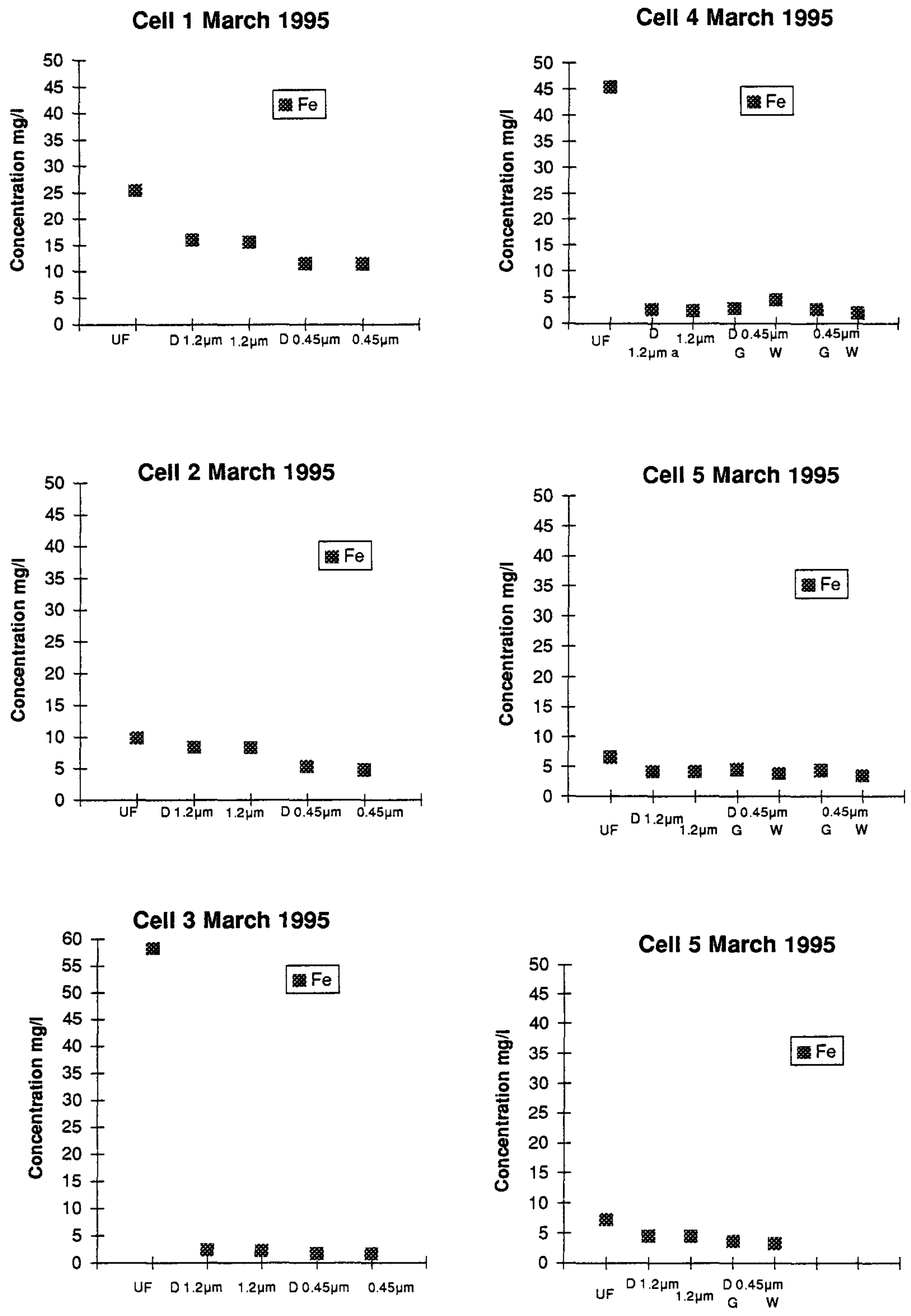


Figure 3.2 **The effects of on-site filtration and laboratory pre-treatment options on the analysis of iron in landfill leachate (for code interpretation, see Table 3.1)**

To check on the validity of the various laboratory analyses, following the different sample handling techniques investigated, ion balance calculations were carried out. The method for the calculations are presented in Appendix D, with selected summary data presented in Table 3.2, Table 3.3, and Table 3.4, below. Again, these summary data are used in the following narrative (see Section 3.6.5).

Table 3.2 Ion balance summary data for the March 1995 *unfiltered* samples showing the effect of alkalinity determinations carried out at pH 3 and pH 4.5

Cell No.	Percentage cation deficiency for end point titrations at	
	pH 3	pH 4.5
1	54.5	33.6
2	48.4	30.5
3	53.2	23.9
4	38.8	16.6
5	54.8	27.5
6	51.4	28.9

Table 3.3 Ion balance summary data for the February 1996 samples showing the effect of 1.2 and 0.45 µm filters

Cell No.	Percentage cation deficiency after filtering samples at	
	0.45 µm	1.2 µm
1	20.7	21.0
2	n/a	15.4
3	16.7	16.3
4	17.8	15.9
5	18.6	22.2
6	8.6	20.1

Notes:
n/a - data not available

Table 3.4 **Ion balance summary data for the February 1997 samples, prepared using 0.45 µm filters and then either analysed undigested or analysed after settlement and digestion or after direct digestion without settlement**

Cell No.	Percentage cation deficiency after the following preparations		
	Undigested	**Settled & Digested**	**Digested**
1	19.9	12.7	11.8
2	15.4	10.1	10.2
3	16.2	12.5	12.4
4	11.8	8.5	8.0
5	33.3	28.1	25.7

3.6 Discussion

3.6.1 Trace metals

Filtration is likely to have the greatest effect on trace metal determinations. Despite the fact that chromium, copper, cadmium and lead were found to be at concentrations less than the detection limits of the analytical method used, good data was obtained for the determinations of nickel, zinc, iron and manganese. Table 3.1, including Figure 3.1 and Figure 3.2, presents the results obtained from the March 1995 exercise, where duplicate filtered samples (either digested or undigested) were submitted for analysis together with unfiltered samples. The following points emerge.

a) Unfiltered samples

All samples were acidified in the field. As expected, there was a large increase in the concentration of metals in the unfiltered samples in comparison with the filtered samples, not least because any particulate metals in the unfiltered sample would have been solubilised during sample preservation.

- nickel was the least affected;
- manganese was generally higher in the unfiltered samples from four of the six cells, but higher by factors of 2 and 4-5 in Cells 5 and 4 respectively;

- iron concentrations were higher in unfiltered samples compared with 1.2 µm samples in four cells (up to two times higher than the 0.45 µm samples from the same cells). For Cells 3 and 4, iron levels were over twenty times higher in the unfiltered samples in comparison with the filtered samples;

- zinc, the element most likely to adsorb to suspended material in the sample, was between 20 and 50 times higher in the unfiltered samples in comparison with the 1.2 and 0.45 µm samples respectively.

b) Comparison of 1.2 and 0.45 µm filters on heavy metal determinations

- for chromium (when detectable) and nickel, the difference was negligible;

- manganese and iron were higher in 1.2 than 0.45 µm samples;

- zinc concentrations were 2-5 times higher in 1.2 µm samples from Cells 3-6, and factors of 7 and 37 times higher from Cells 2 and 1. (The same trends were exhibited by further testing in February and June 1996);

- copper was expected to follow the trend observed for zinc, however, in Brogborough leachates, copper levels are <20 µg l^{-1}, below the detection limit of analysis;

- two different brands of 0.45 µm filter had no consistent effect on leachate quality, with the exception of dissolved iron levels in leachate from Cell 5. The two samples passed through the G filter ranged from 4.2-4.5 mg l^{-1} Fe and those passed through the W filter ranged from 3.4-3.7 mg l^{-1} Fe.

c) Effect of sample digestion prior to analysis

Table 3.1 presents the results of duplicate filtered samples either digested prior to analysis or analysed direct.

- **Samples filtered through 1.2 µm filters:** in most cells, digestion of the samples slightly raised iron, nickel and zinc concentrations, probably largely attributable to analytical precision. However, nickel was significantly higher in digested samples from Cells 1 and 2 and **two to four times** higher in Cells 3 and 4. The leachate from Cells 5 and 6 seemed to be less affected by this sampling handling procedure than that from other cells.

- **Samples filtered through 0.45 µm filters:** iron, nickel and zinc sometimes showed a slightly raised concentration in the digested sample relative to the undigested sample. However, this cannot really be distinguished from sample variability. The result from Cells 4 and 5 demonstrate that the impact of different filtration products was more significant than the effect of digestion (see last bullet point of (b) above). Again the leachate from Cells 5 and 6 seemed to be less affected than other cells.

For those metals detected at levels significantly above detection limit, we draw the following conclusions about their determination in landfill leachate:

- filtration removed a significant quantity of the suspended iron and zinc particles which were taken up into solution during the sample digestion phase. Filtration had little or no effect on nickel and manganese levels;

- the digestion of samples that were filtered through 1.2 µm filters resulted in the dissolution of fine grained nickel and iron particles, resulting in up to 40% increases in comparison with the undigested samples. However, the minor differences between most of the analyses was probably less than sample variability.

- the digestion of samples that were filtered through 0.45 µm filters made no consistent impact on the metal analyses, the choice of filter brand had more impact. The additional step of sample digestion on 0.45 µm samples is therefore not required.

- the leachates from Cells 5 and 6 were less affected by sample treatment methods than leachate from other cells.

For additional comment on the preferred field/laboratory sample pre-treatment approach see Section 3.6.5, where ion balance is discussed.

3.6.2 Major cations

Table 3.1 illustrates the effect of sample handling on sodium, magnesium, potassium and calcium determinations. The leachate from each cell responds slightly differently to the use of different filters and to digestion.

In general, the use of 0.45 and 1.2 µm filters and sample digestion made no difference to the analytical results. In addition, no significant effects were observed between the different brands of filter used. The precision of the four (or six) filtered samples (whether digested or analysed direct) ranged from 0.8 to 1.4% RSD (relative standard deviation) for the four determinands in Cell 1, to 3.2 to 3.7% RSD in Cell 6. In most instances this is the same reproducibility that would be achieved from repeatedly analysing one leachate sample for major cations.

For most samples, including the results of the unfiltered sample, filtration only increased the RSD by 1% (i.e. on average to 2-4% RSD). We consider this to be an insignificant effect. However, a single unfiltered sample from Cell 4 returned an analysis of 70 mg l^{-1} Ca as opposed to the 49-51 mg l^{-1} reported for the six filtered samples, increasing the RSD to 13.9%. In comparison the reproducibility of calcium in Cell 1 was excellent, being 0.8% RSD, whether the unfiltered sample was included or not.

To sum up, the investigation of the impact of different sample pre-treatment approaches on the major cations showed that:

- the type of filter used makes no discernible difference to the results (whether pore size or product);
- direct analysis of the sample produces as reproducible a result as analysis of a digested sample.

3.6.3 Major anions

Usually samples collected for major anions would not be filtered but would be transferred into bottles direct from the pump discharge tubing. However, in order to determine whether filtration had a significant effect on anion concentrations and to establish whether it would impact on the ion balance calculation, samples were collected following 1.2 and/or 0.45 µm filtration to compare with the unfiltered samples. Otherwise the samples were treated in the normal way with transfer at the well-head to bottles containing preservative as appropriate (sulphuric acid for nitrate and nitrite-nitrogen samples) and mercuric chloride (ammoniacal nitrogen), phosphoric acid (volatile fatty acids) and no preservative (remaining anions). The samples were **not** digested on return to the laboratory.

The results are presented in Appendix C and are summarised as follows:

- *Chloride and sulphate* - determinations were generally unaffected by filtration. Samples from Cell 2 (February 96) and Cell 3 (March 95) provide the exception.
- *Ammoniacal nitrogen* - determinations were generally unaffected by the different filtration procedures. Good reproducibility was obtained (<1.5% RSD) regardless of whether the samples were unfiltered or passed through 0.45 µm or 1.2 µm filters. This may in part be due to the addition of preservative immediately after sampling to prevent bacterial oxidation of determinand.
- *Nitrate and nitrite-nitrogen* - levels were generally too low to determine any consistent trends. For example samples filtered through 1.2 µm tended to contain higher concentrations of nitrate and nitrite than samples filtered through 0.45 µm (notably Cell 5, June 1996 and Cell 6, February and June 1996). However, on some occasions, levels of both determinands were higher in 1.2 µm samples than in unfiltered samples (Cells 2, 4 and 5, October 1996).
- *Soluble reactive phosphorus (SRP)* - results generally show no discernible effects from the use of different filters. Cell 2 shows some variation between the 1.2 µm and 0.45 µm samples, although no consistent trend is present. Because of the inherent analytical difficulties associated with the determination of SRP in leachates, these variations are considered to be insignificant.

- *Alkalinity* - was measured in unfiltered samples and 1.2 µm-filtered samples and found to be higher in the latter by 2 to 24% in five of the six samples compared. The difference between samples filtered at 1.2 µm and 0.45 µm was similar to that found between duplicates. Therefore, for alkalinity determinations we can make no distinction between the use of either 1.2 or 0.45 µm filters. Further comment on the ion balance implications is made in Section 3.6.5, below.

3.6.4 BOD, COD, TOC and volatile fatty acids

BOD and TOC were only analysed on unfiltered samples. COD was analysed on filtered 1.2 µm and unfiltered samples. Although differences in concentrations were identified, these were generally no more significant than the variations reported between duplicate samples (cf. March 1995 data with October 1994 data).

In February 1996, COD was analysed on filtered 1.2 µm and 0.45 µm samples. The results are similar with perhaps a slight trend of decreasing concentration with 0.45 µm filter, compared to the 1.2 µm filter. For volatile fatty acids analysis, neither filter was found to perform better than the other.

To summarise, the use of either 0.45 µm or 1.2 µm filters had no discernible effect on the analysis of COD and volatile fatty acids.

3.6.5 Ion balances

An ion balance provides an indication of the collective quality of the analyses, assuming that a sufficiently comprehensive suite of determinands has been analysed.

The ionic balance compares the sum of the major cations (sodium, potassium, calcium and magnesium) with the sum of the major anions (chloride, sulphate, carbonate, phosphate, ammoniacal-nitrogen, nitrate and nitrite-nitrogen), both being expressed in such a way that the respective numbers of ions in solution are compared (as meq l^{-1}).

If the liquid being analysed is unstable and undergoing reactions that change individual determinands (for example suspended matter becomes dissolved, precipitation of previously dissolved solids occurs or biological activity changes the organic content etc.) the ionic balance will be poor. For leachates, the contribution of carboxylic acids (volatile fatty acids) and ammoniacal nitrogen to the alkalinity determination should be taken into account. In addition, appropriate sample handling techniques can reduce imbalances which can occur during transport and storage.

Summary ion balance data is presented in Table 3.2, Table 3.3, and Table 3.4. These data illustrate various effects, of different sample pre-treatment or analytical approaches, on ion balances for landfill leachates. These include:

1. different end points for alkalinity titrations (pH 3 or pH 4.5);

2. use of different filtration apparatus (0.45 or 1.2 µm pore size);
3. the adoption of a digestion pre-treatment step prior to metals analysis.

Alkalinity end point

Alkalinity is a measure of the volume of acid of known strength, required to neutralise the alkaline ions in solution (carbonate, hydrogen carbonate and hydroxide ions) at a specified end point pH. This can be affected by:

- dissolved gases (for example CO_2, H_2S and NH_3) which contribute towards the total alkalinity of the sample, and may be lost (or gained) during sampling, storage or filtration;
- carboxylic acids which dissociate as pH is reduced during the alkalinity titration. The effect shifts the end-point and compensation should be made, particularly for leachates;
- oils, fats and soaps, as well as suspended material, may cause the alkalinity electrode to respond slowly, if used in preference to indicator solutions. Sufficient time must be allowed for the measurement to stabilise;
- drifting endpoints may also occur as the result of the presence of oxidisable or hydolysable ions (e.g. ferrous/ferric iron, manganese and aluminium).

Table 3.2 shows the results of an experiment carried out on duplicate *unfiltered* samples of leachate taken in March 1995, where alkalinity determinations were carried out at pH 3 and pH 4.5, respectively. As a general guide, investigations into the sources of ionic imbalance should be made where this exceeds ± 15%.

The results show that titration to pH 4.5, rather than pH 3, for the determination of alkalinity returned the better ion balances. Nevertheless, there was considerable discrepancy from the 15% yardstick, and this needed to be investigated further. One of the obvious sources of error was thought to be the determination of major cations, and in particular the alkali earth metals. The solubility of these determinands can be affected significantly by aeration. For example, a highly anoxic leachate sample can become aerated during the process of sampling. If the sample remains unfiltered at the well head, and no account is taken of material which might precipitate in the bottle during sample transfer to the laboratory, then what is analysed as dissolved material will not have taken into account the precipitated material which was in solution at the time of sampling.

An experiment was therefore carried out to examine the effect of on-site filtration and acidification of leachate samples destined for Na, Mg, K, Ca and heavy metals analysis.

Sample pre-treatment (filtration and acidification)

In this experiment, a field filtration exercise was carried out using 0.45 and 1.2 µm filtration apparatus. Duplicate samples, requiring the determination of dissolved alkali earth metals and other heavy metals, were filtered using either option and then acidified prior to submission for analysis. The results are shown in Table 3.3.

The main conclusion we draw from the limited test data is that the ion balances were much improved (cf. unfiltered samples) by incorporating a filtration and acidification stage into the field sample pre-treatment procedure, particularly in relation to the subsequent analysis of the major cations. No advantage was gained in using any one particular filtration device. Because 0.45µm is generally accepted as being the 'cut-off' between dissolved and suspended material, we suggest that these filters are used in preference to the 1.2 µm alternative.

Further tests were then devised to explore the possibility for additional improvements in ion balance by carrying out a sample digestion pre-treatment step prior to analysis.

Sample pre-treatment (digestion)

These tests were carried out on samples taken from the test cells in February 1997. Triplicate samples were filtered in the field using the 0.45µm filter apparatus and then returned to the laboratory in separate bottles, containing acid preservative, for determination of dissolved alkali earth metals and other heavy metals. Three sample pre-treatment steps were investigated:

- no sample digestion;
- sample settled and the supernatant liquor digested;
- sample vigorously shaken to suspend settled solids and a sub-sample digested.

The results of the subsequent laboratory analyses are shown in Table 3.4.

Although marginal improvements in the ion balance were achieved by adding the digestion step to the analytical procedure, in general the undigested samples (cf. the February 1996 data - Table 3.3) returned adequate ion balances. This suggests that, in the interests of cost saving for routine monitoring of landfill leachate samples, the only important pre-treatment step is well-head filtration on samples being submitted for alkali earth and heavy metal analyses.

4. LONG TERM LEACHATE MONITORING AT BROGBOROUGH

4.1 General comment on the presentation of analytical data

Two sets of data are used in the following discussion about leachate chemistry at the Brogborough test cell project:

- monthly data gathered between January and May 1994;
- quarterly (approximate) data gathered between June 1994 and November 1997.

All these samples were collected following comparable and consistent field monitoring procedures (see Section 2).

The experimental cell variables are listed in Table 4.1 below.

Table 4.1 Experimental variables for the Brogborough test cells

Cell number	Description
1	Domestic waste only control - thin layer *'Onion-skin' method adopted, placing waste in thin layers with a minimum cover layer.*
2	Domestic waste only control - 'push over' *Waste compacted in 2 metre lifts, resulting in lower waste compaction compared to Cell 1.*
3	Domestic waste with leachate recirculation *As Cell 1, but allowing for leachate recirculation to encourage more rapid stabilisation.*
4	Domestic waste with air injection *As Cell 1, but allowing for air injection into the waste to encourage aerobic decomposition.*
5	Domestic waste with sewage sludge co-disposal *As Cell 1, but with sewage sludge co-disposed at a ratio of 10.3:1.*
6	Domestic waste/commercial and non-hazardous waste mix *As Cell 1, but commercial and non-hazardous waste co-disposed at 53% by weight.*

In past reports, WRc has used two basic data comparisons to illustrate discussion on progressive changes in leachate chemistry:

- all 'control' trials (Cells 1 to 4);
- average data for those trials thought to exhibit 'control' characteristics, compared with equivalent compositional data from the two co-disposal trials (Cells 5 and 6).

With the exception of Cell 2, Cells 1, 3 and 4 were filled using the same site operational strategy designed to achieve relatively high compaction of waste. However, with the additional 10-metre lift of waste added to the cells in late 1988, Cell 2 was thought to be as equally compacted as the other cells and therefore data on leachate characteristics in Cell 2 has often been used with that derived from Cells 1 to 4 to illustrate the progressive stabilisation of waste in the trials. Significant perturbations in operational practice (injections of liquid and air to Cells 3 and 4 respectively) have now led to demonstrable changes in gas production profiles from these latter two cells. Because of these changes, baseline data for comparison with leachate composition in the two co-disposal cells has only been derived from Cells 1 and 2.

The results of the leachate analyses are shown in Appendix Table C1, with volatile fatty acids results shown in Appendix Table C2. A selection of results have been plotted to show the overall trends in leachate chemistry. Figures 4.1 to 4.8 show the pH, temperature, COD, TVA, chloride, ammoniacal nitrogen, zinc and nickel concentrations in Cells 1 to 4 since January 1994. In like manner Figures 4.9 to 4.16 show the same determinands in the leachates from Cells 5 and 6 plotted against the notional baseline average data derived from Cells 1 and 2. Individual volatile fatty acid results are shown in Figure 4.17 and 4.18.

The leachate levels are recorded by WRc on each visit, the day after purging by Shanks & McEwan staff, who also record the level prior to purging. The results of both are shown in Appendix Table C3 and Figure 4.19.

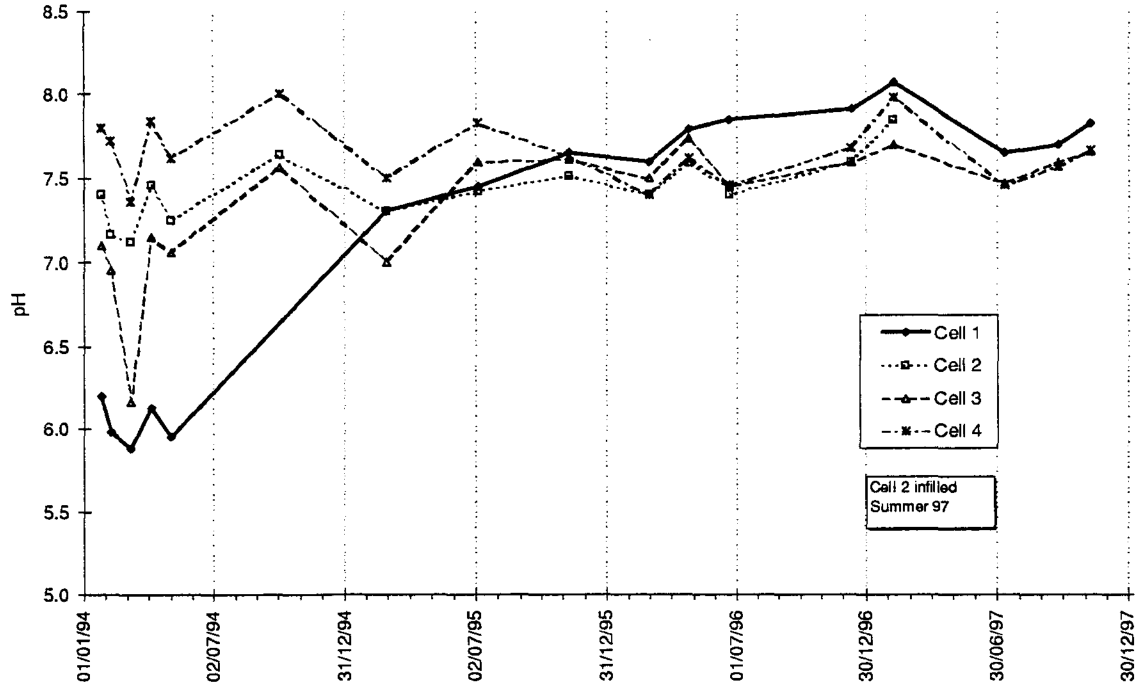


Figure 4.1 pH - Cells 1 - 4

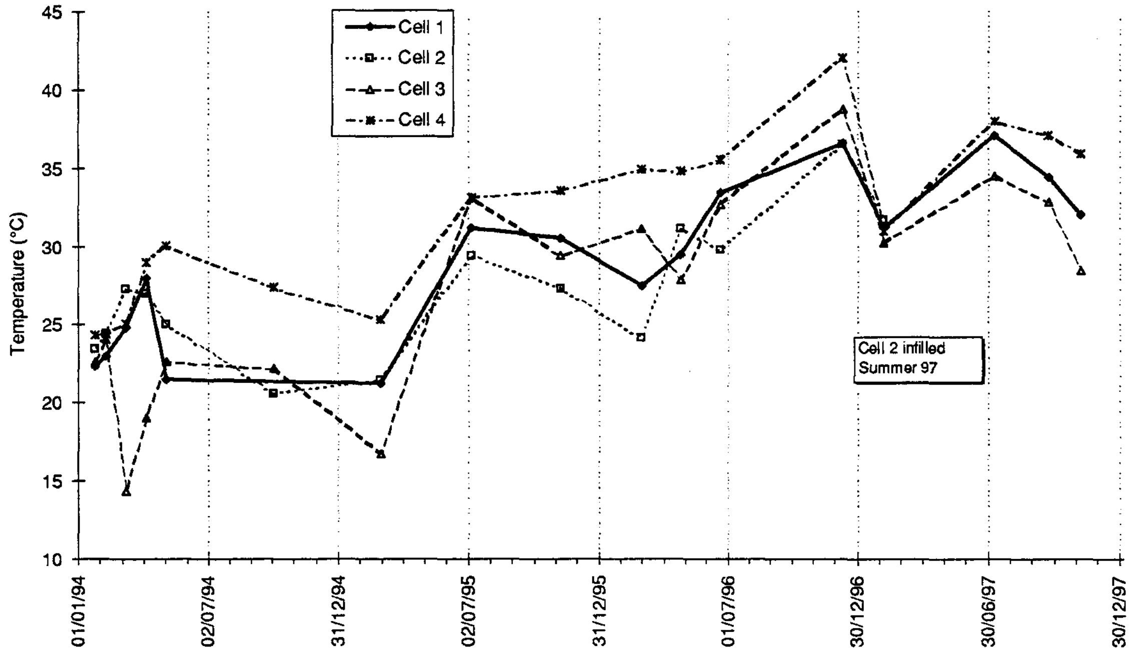


Figure 4.2 Temperature of leachate - Cells 1 - 4

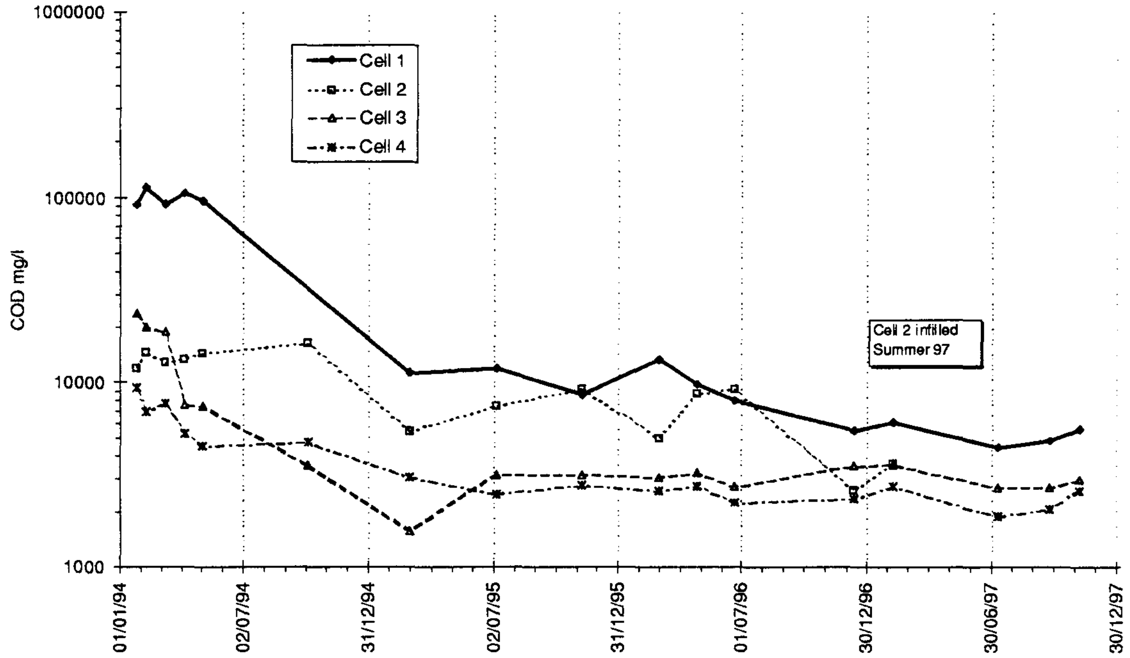


Figure 4.3 COD concentrations - Cells 1 - 4

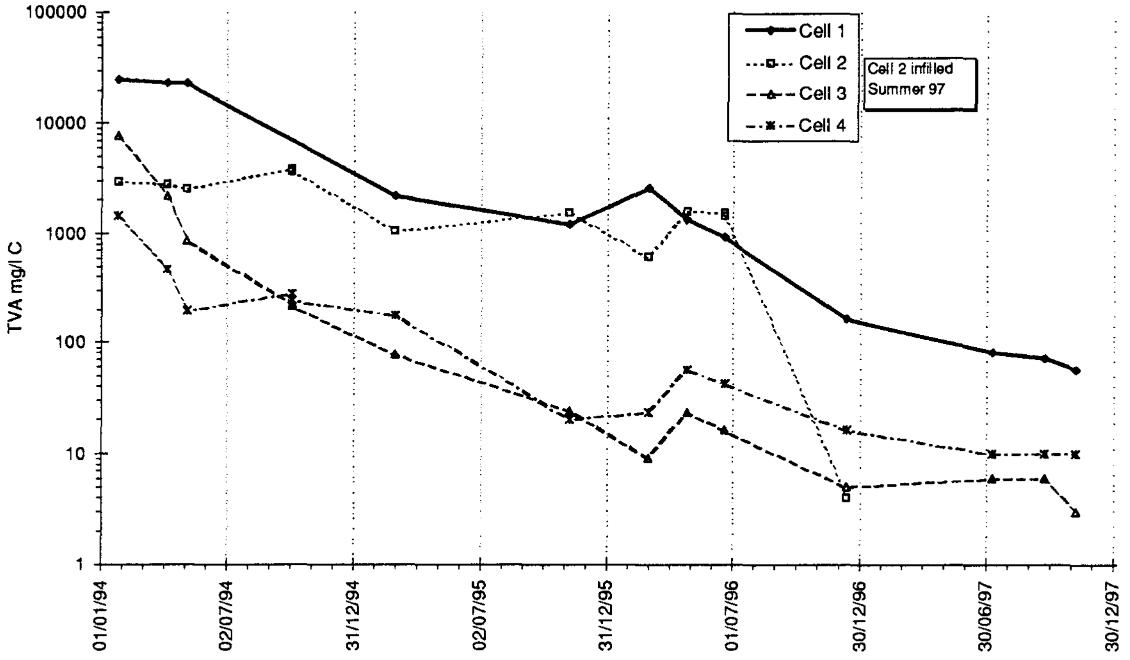


Figure 4.4 TVA concentrations - Cells 1 - 4

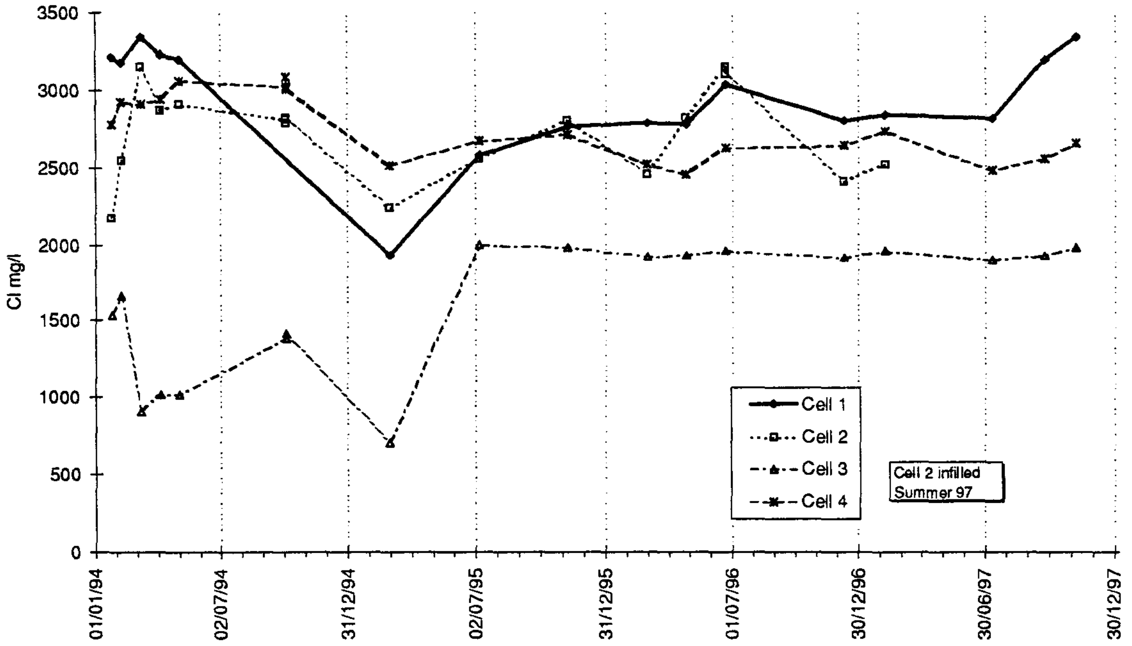


Figure 4.5 Chloride concentrations - Cells 1 - 4

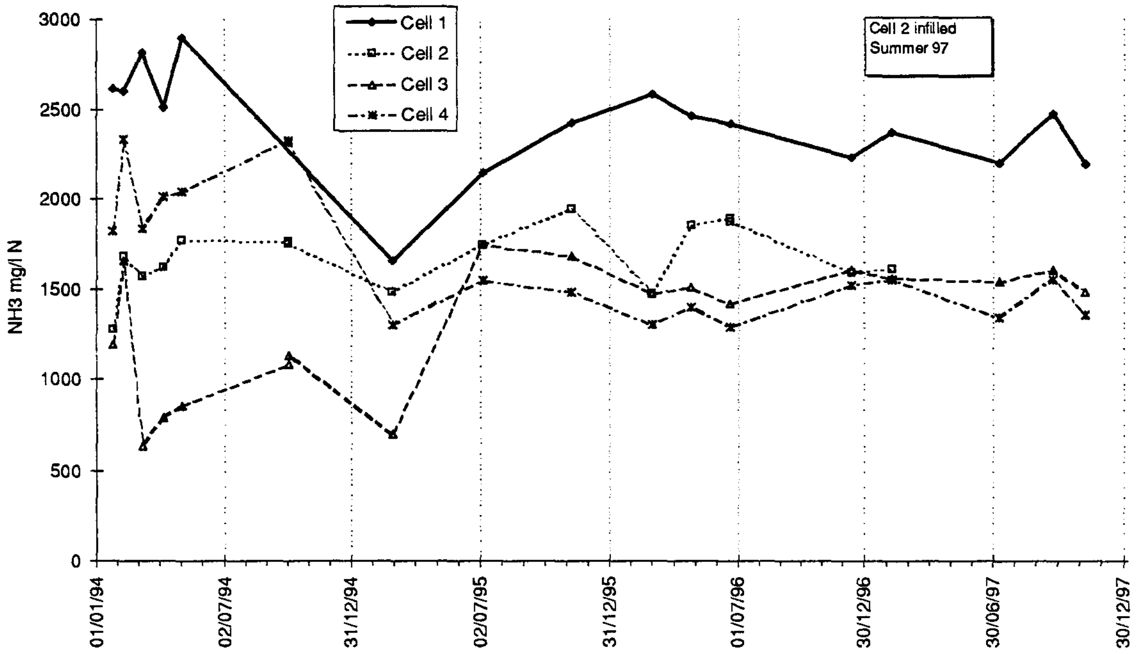


Figure 4.6 Ammonia concentrations - Cells 1 - 4

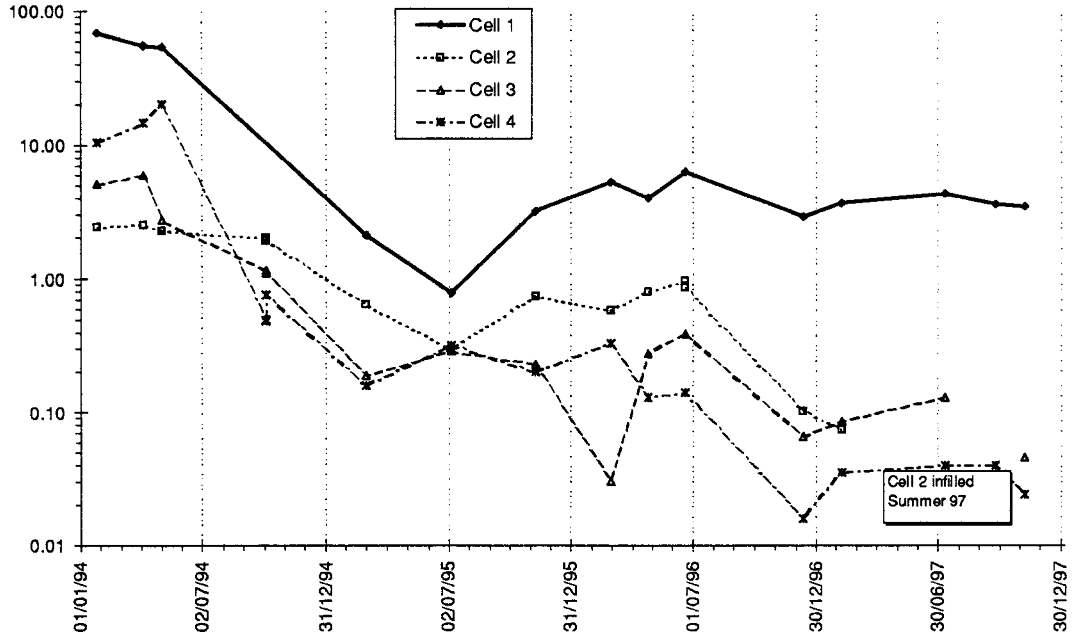


Figure 4.7 Zinc concentrations - Cells 1 - 4

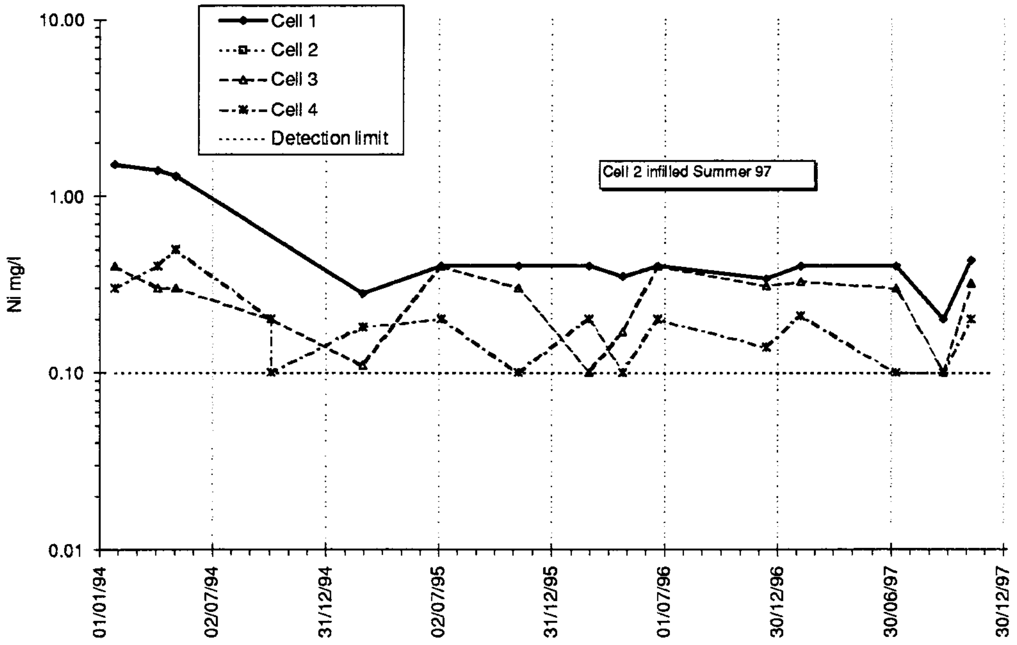


Figure 4.8 Nickel concentrations - Cells 1 - 4

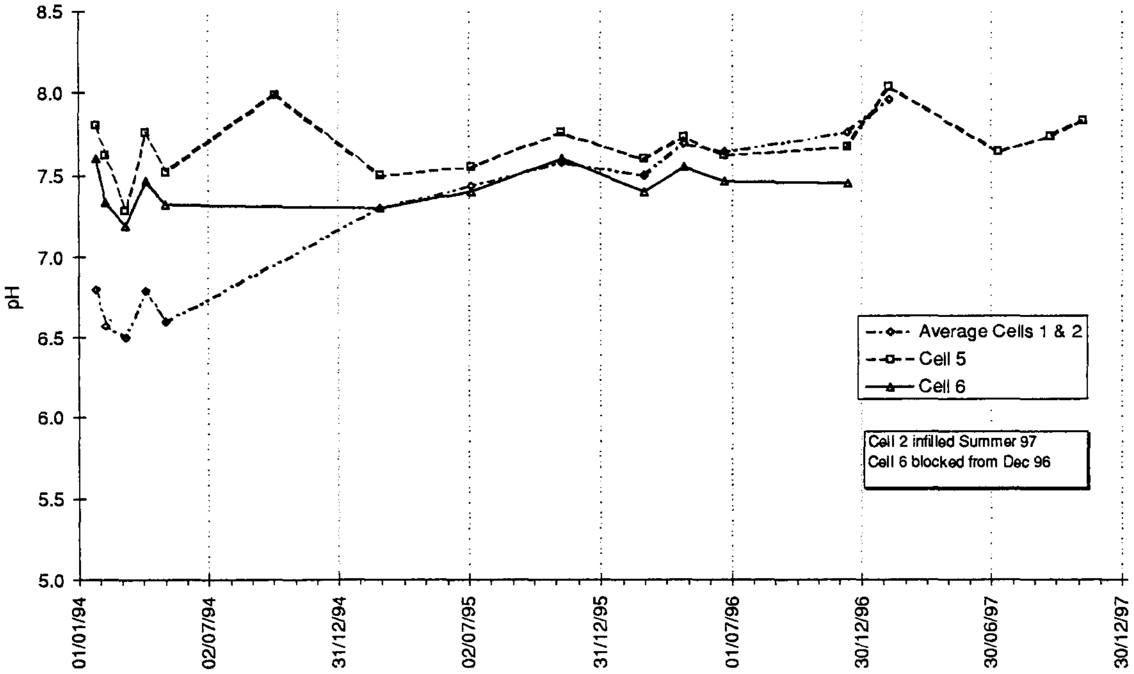


Figure 4.9 pH - Cells 5 and 6 compared to the average of Cells 1 and 2

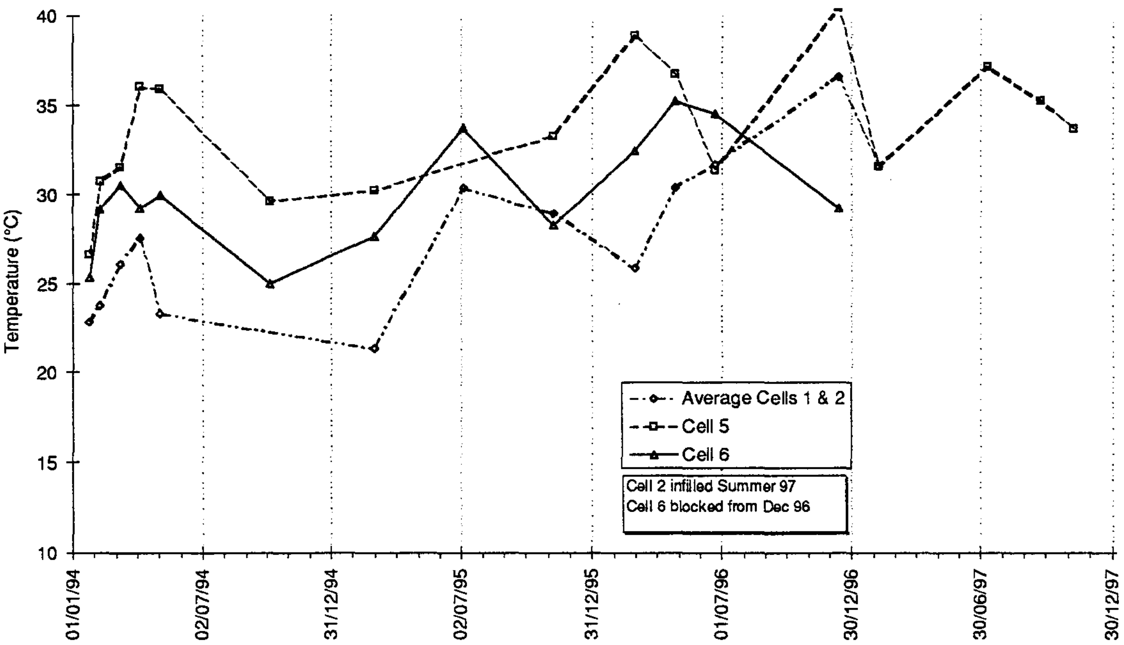


Figure 4.10 Temperature of leachate - Cells 5 and 6 compared to the average of Cells 1 and 2

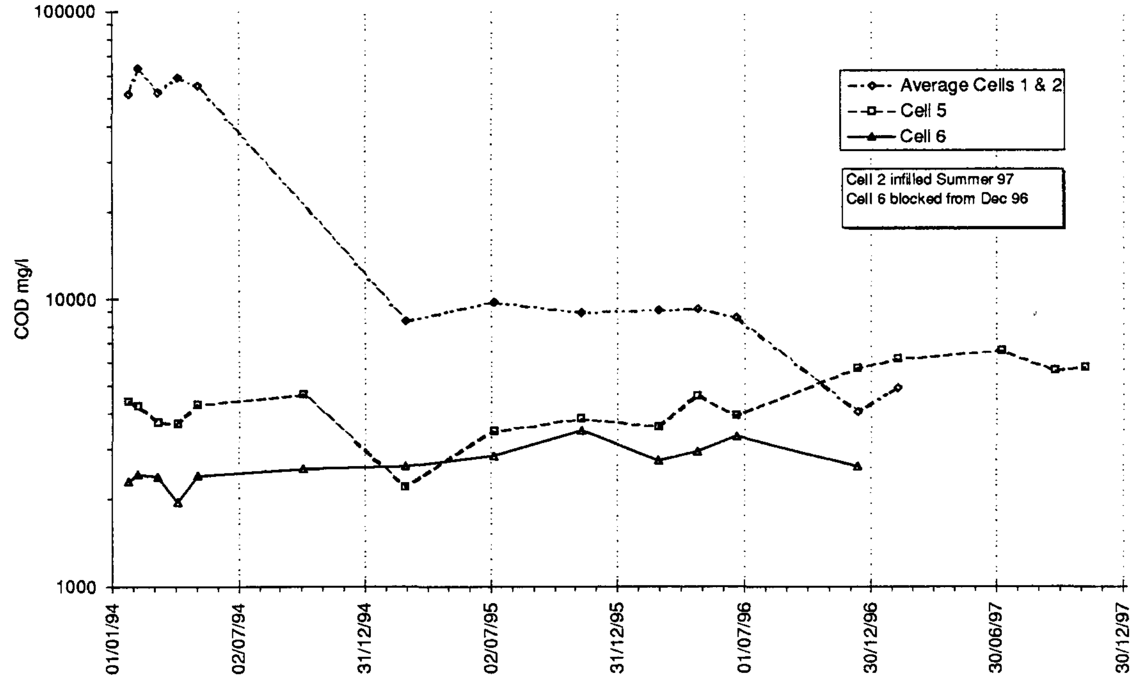


Figure 4.11 COD concentrations - Cells 5 and 6 compared to the average of Cells 1 and 2

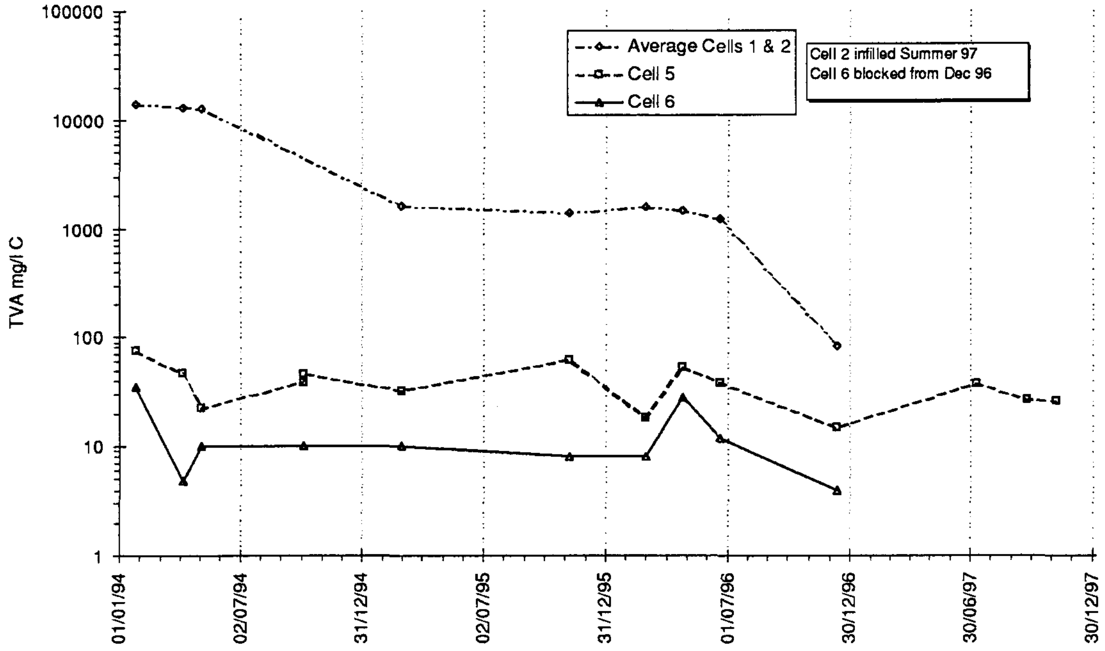
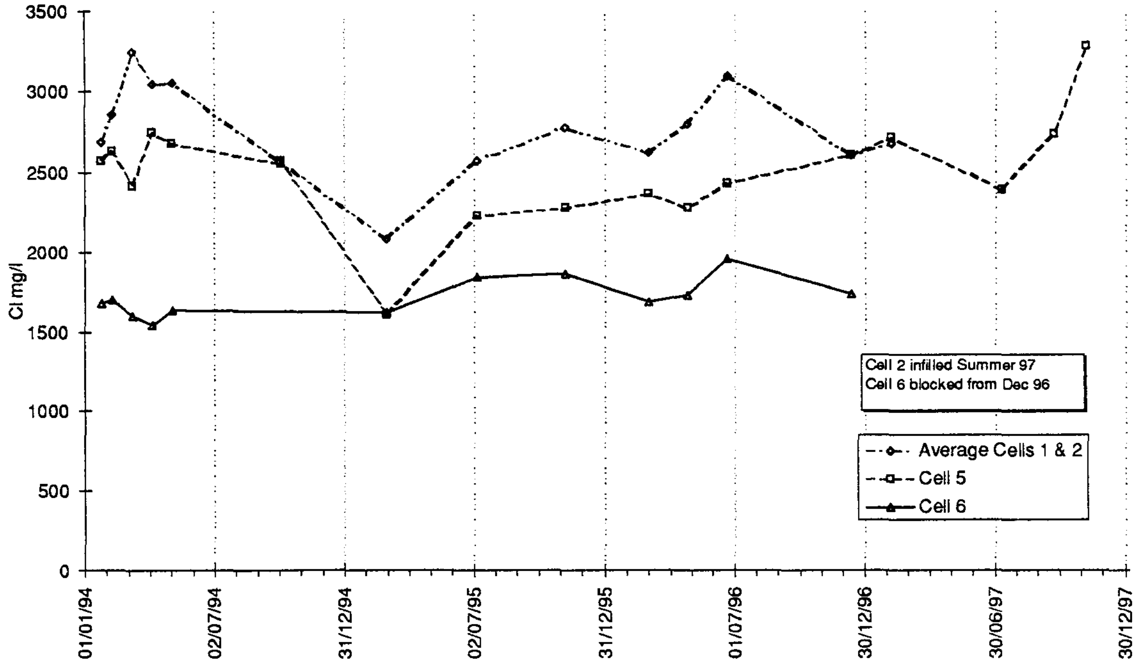


Figure 4.12 TVA concentrations - Cells 5 and 6 compared to the average of Cells 1 and 2



Cell 2 infilled Summer 97
Cell 6 blocked from Dec 96

Figure 4.13 Chloride concentrations - Cells 5 and 6 compared to the average of Cells 1 and 2

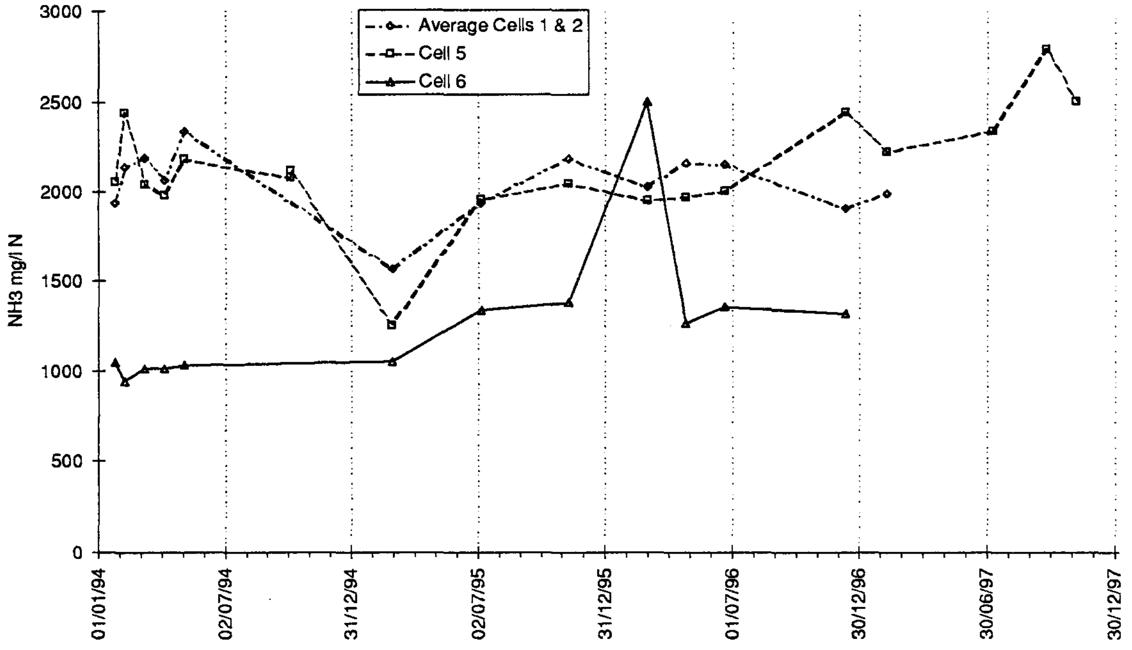


Figure 4.14 Ammonia concentrations - Cells 5 and 6 compared to the average of Cells 1 and 2

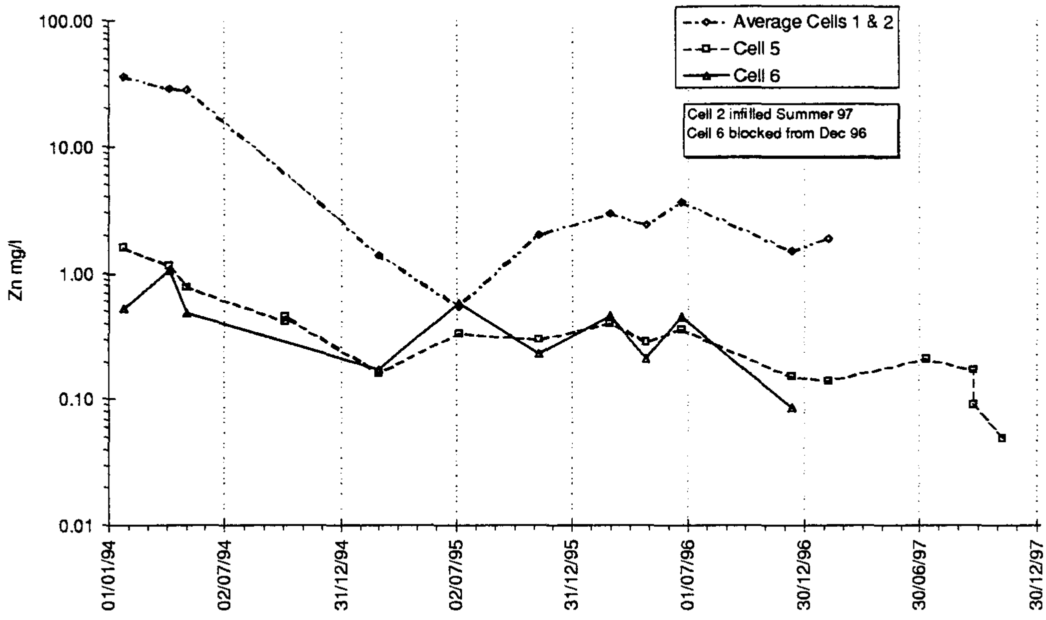


Figure 4.15 Zinc concentrations - Cells 5 and 6 compared to the average of Cells 1 and 2

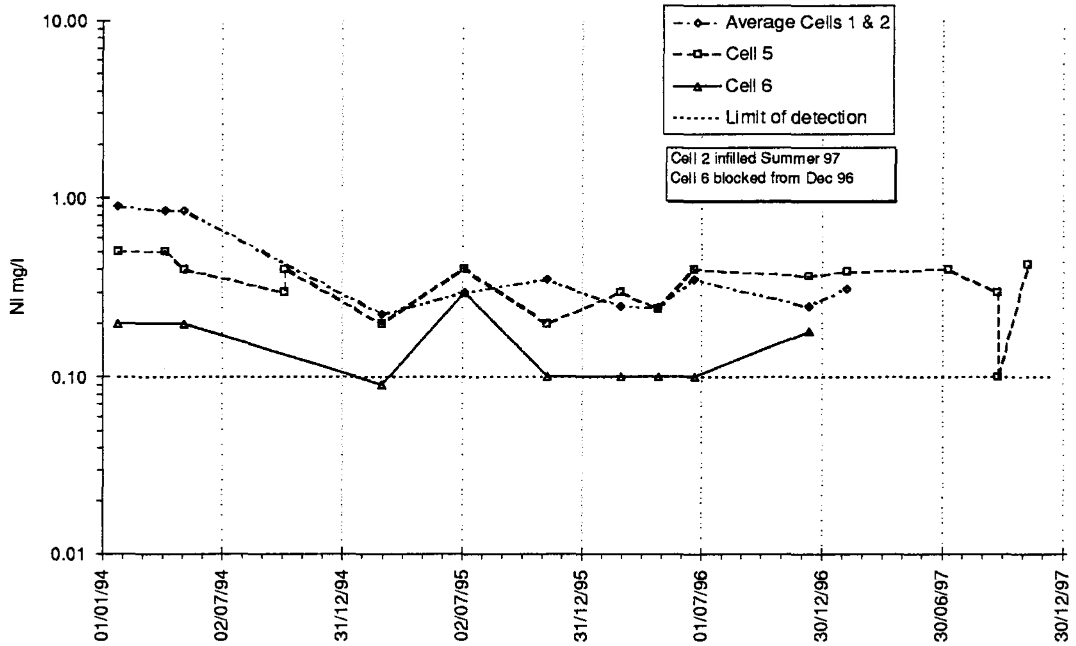


Figure 4.16 Nickel concentrations - Cells 5 and 6 compared to the average of Cells 1 and 2

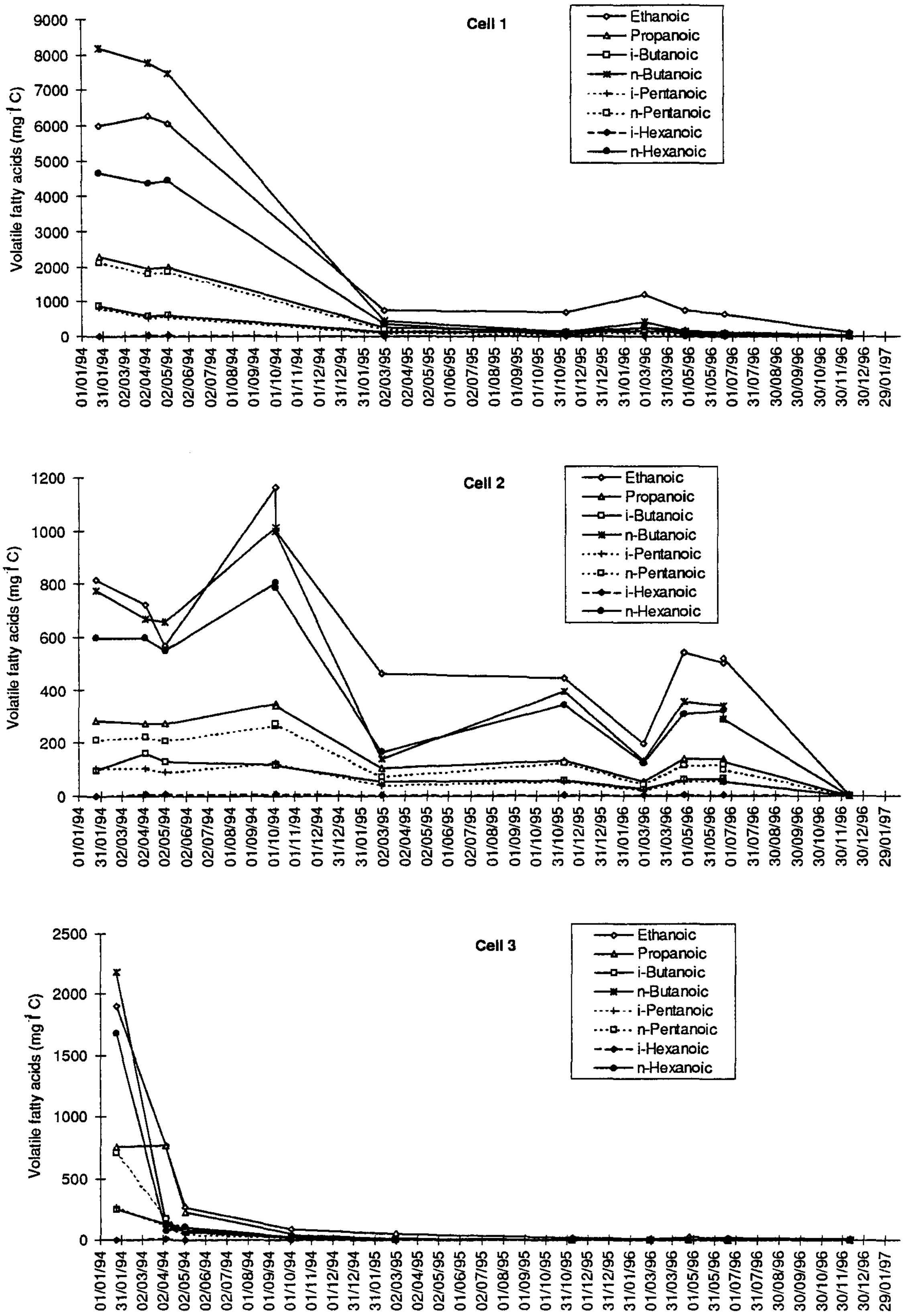


Figure 4.17 Volatile fatty acid concentrations - Cells 1 to 3

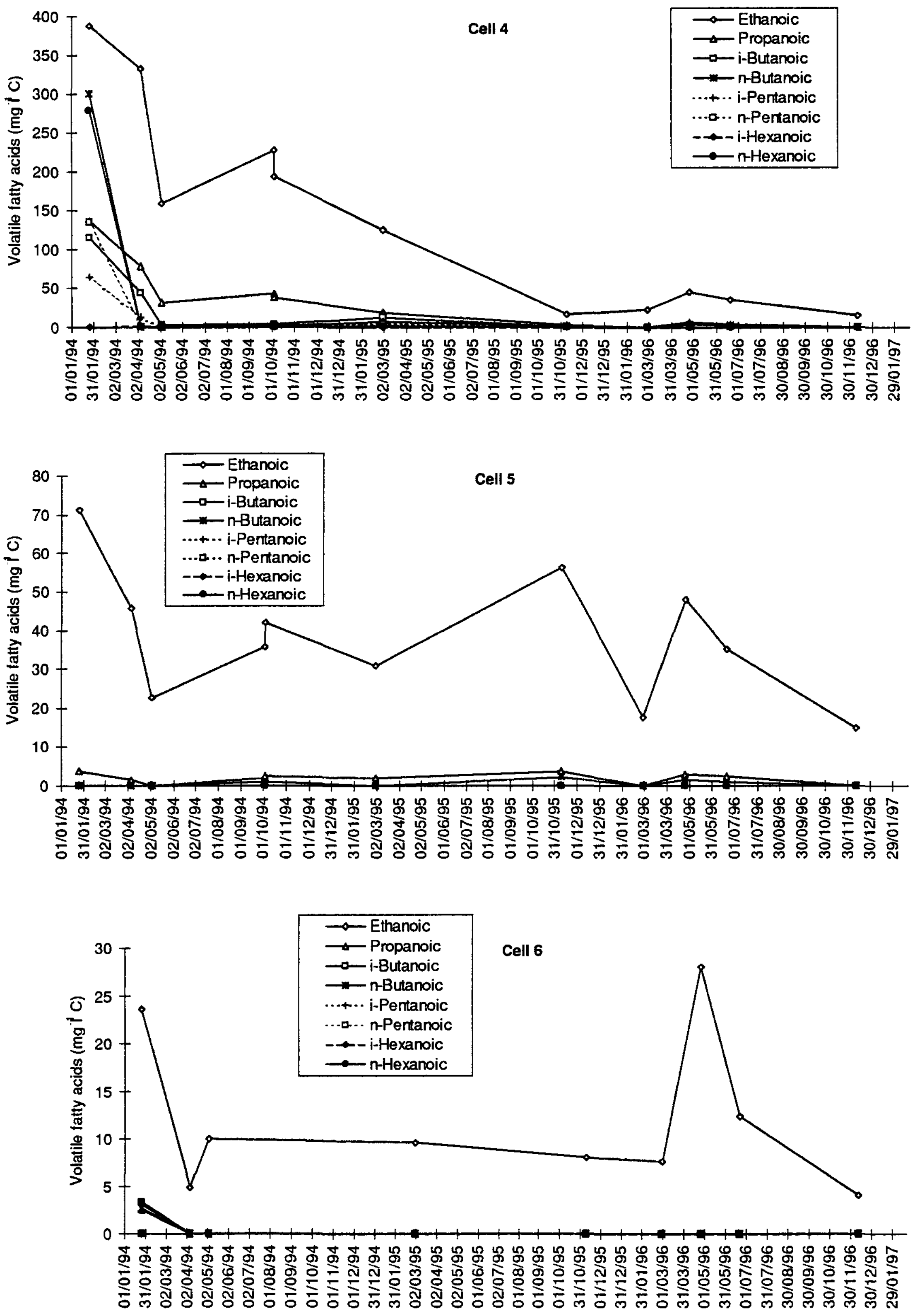


Figure 4.18 Volatile fatty acid concentrations - Cells 4 to 6

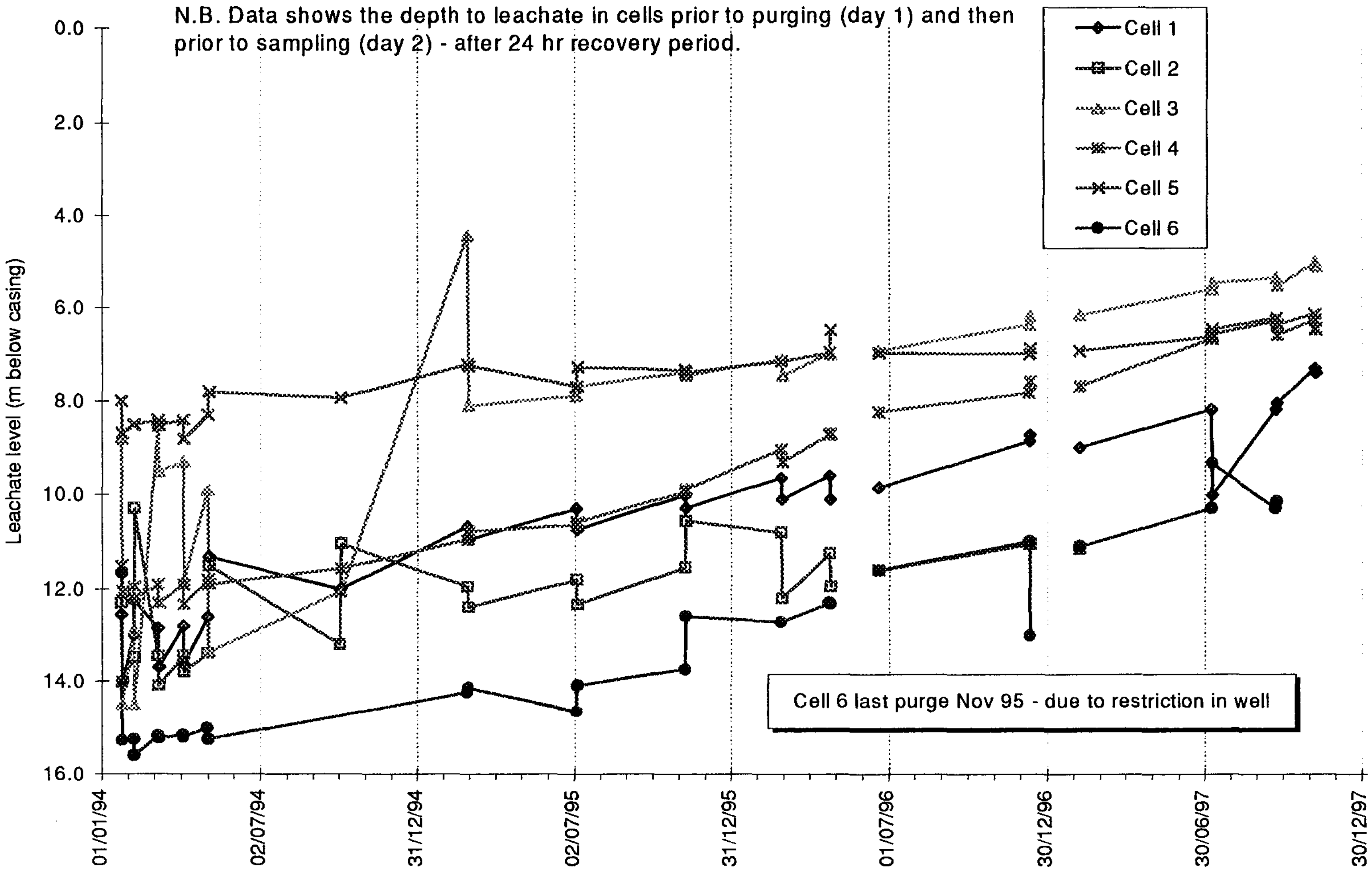


Figure 4.19 Leachate levels in borehole C in Cells 1 - 6

5. DISCUSSION

5.1 Trends in leachate chemistry

5.1.1 Leachate levels

Before looking at the compositional data in detail, some comment is needed on the progressive increase in the depth of leachate within the cells. Figure 5.1 illustrates the levels prior to purging and forms the basis of the following discussion. Other data, showing the leachate levels both before and following borehole purging, is shown graphically in Figure 4.19 (see also Appendix C, Table C3).

Although leachate levels in all the cells are unique, the underlying trends exhibited in Cells 1, 2, 4 and 6 have been similar. At the point where the leachate purging strategy was initiated (January 1994), leachate levels generally lay within the range of 11 to 16 metres below the capping material. Since January 1994, these levels have continued to rise approximately 1-2 m yr^{-1} during 1994 and 1-1.5 m yr^{-1} during 1995. In the year July 1995 to July 1996, Cell 6 has shown a rise in leachate level of about 3 m. Although the reasons for this are unclear, an obstruction in the well has prevented purging since November 1995 and this might be a contributory factor. Cells 1, 2 and 4 (July 95 to July 96) continue to show similar trends with Cells 1 and 2 at about 1 m yr^{-1} rise and Cell 4 at about 2 m yr^{-1}.

The leachate level in Cell 5, at the start of the revised monitoring strategy (January 1994), was higher than in the other cells, at about 8 m below the capping material. Over the first year the leachate level increased by about 0.5 m, but during 1995 and 1996 the rate of increase has declined.

Leachate level behaviour in Cell 3 is less easily explained. Recovery following purging and the effects of liquid injection to the cell in February 1994 (231 m^3) complicate the picture.

Although leachate levels have been recorded at frequent intervals during the study, the results are not as informative as they might be, principally because no survey data is available to compare one cell with another to common ordnance datum. Nevertheless, if this could be rectified, the data provide the means of carrying out a relative assessment of the effects of limited infiltration (say <100 mm through the clay capping) and waste settlement characteristics on the development of leachate levels in the test cells.

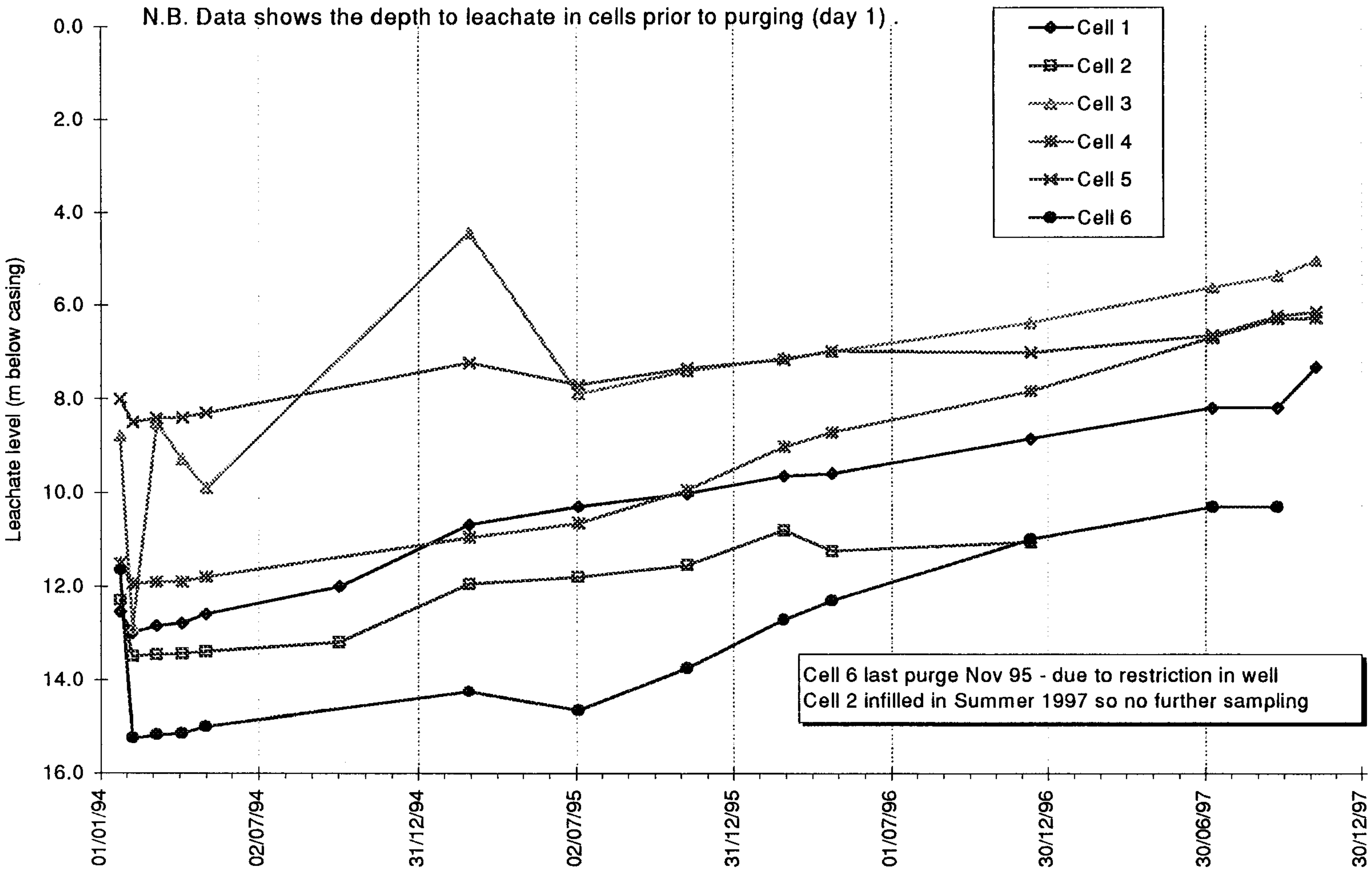


Figure 5.1 Depth of leachate in the cells prior to purging (c.f. Figure 4.19)

Using 'ball-park' estimates, a rise in leachate levels of approximately 1 to 2 $m.yr^{-1}$ could be attributed to an infiltration of 100 $mm.yr^{-1}$ if the active porosity[2] of saturated wastes at the base of each cell lies somewhere between 5 and 10 % (v/v). Nevertheless, the effect of active settlement in each of the cells will progressively decrease porosity. What remains unknown is the relative effects of reducing porosity and the level of infiltration.

We therefore recommend that each of the access wells, used in the monitoring programme, is surveyed to common ordnance datum and that the leachate level data, along with the settlement data, is made available to a suitable project team involved in the modelling of the mixing and hydrodynamics of water flow within landfills.

5.1.2 'Control' trials

Compositional analysis of leachate constituents for Cells 1 to 4 are presented in Figure 4.1 to Figure 4.8. Of particular significance is the decline in organic strength (and establishment of more neutral conditions) of the leachate abstracted from Cell 1, relative to Cells 2 and 4. In this respect, a shift from acetogenic conditions to more optimised methanogenic conditions within the saturated regions of all four cells is assumed.

Chloride concentrations in three of the cells (Cells 1, 2 and 4) have remained broadly similar, fluctuating about a mean of around 2700 mg l^{-1}. The general fluctuations are believed to be influenced in the most part by solubility and dilution of salts controlled by changes in the month by month fluctuations of infiltration. Nevertheless, the underlying trend is relatively static. This is not wholly unexpected since no substantial removal of leachate occurs in any of the cells. Essentially, this large body of liquid, at the base of each cell, remains relatively unaffected by the comparatively small additional load of inactive dissolved salts, mediated by the rate of infiltration.

Chloride concentrations in Cell 3 have always been atypical and thought to be influenced significantly by surface ponding of rainwater on the cap which may have encouraged short-circuiting down the well casing and into the saturated zone at the bottom of the cell. Although the chloride levels have been recovering since January 1994, a further influence on concentration has been the liquid injection trial in February 94. Since the occurrence of this event, chloride levels have remained remarkably stable at around 2 000 mg l^{-1}.

Similar trends reported for chloride are apparent for ammoniacal nitrogen in all 4 cells, with concentrations remaining relatively persistent in comparison to the degradable components of the leachate. Since the initiation of the well purging strategy back in January 1994, ammoniacal nitrogen concentrations have to some extent become more comparable between cells, although Cell 1 levels are now significantly higher. This may reflect the general delay in stabilisation within this cell, evidenced by the presence of relatively high concentrations of organics in the leachate up until the end of 1994.

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[2] Active porosity - the volume of liquid that may drain under gravity from unit volume of a porous media.

Although concentrations are declining slowly in the other cells, Cell 1 levels still remain relatively high.

Heavy metal leaching is influenced by pH conditions as well as by the presence of organic ligands. The pH conditions in the leachate at the start of monitoring were varying, with Cell 1 having the lowest pH, at around 6, and the highest organic content (see Figure 4.7 - zinc and Figure 4.8 - nickel). Cells 2, 3 and 4 were near neutral (pH 7 to 7.7) hence lower heavy metal concentrations than Cell 1.

With no substantial removal of leachate from any of the four cells that is likely to influence the characteristics of leachate contained in the basal saturated layer of each cell, the only long-term influence must be driven by infiltration. In Cell 1, where metal solubility would have been higher between January and December 1994, in comparison with other cells (lower pH; more dissolved organic carbon), leachate concentrations would be expected to reflect this supposition. With the establishment of more neutral conditions beyond this point, metal concentrations are likely to remain relatively static, although at a higher level than in the other cells, where the combined effect of low pH and presence of dissolved organic carbon is not present.

The steady reduction in metal concentrations in Cells 2,3 and 4 can only be influenced by dilution effects and therefore it must be assumed that the pH conditions measured in the leachate of these cells must be roughly the same as those in the unsaturated zones. If this was not the case, solubilised metal would be added to the basal saturated levels with infiltrating water, resulting in static or rising concentrations (cf. chloride data). Because concentrations are dropping, it must be assumed that neutral pH conditions and low dissolved organic carbon concentrations are generally manifest throughout the waste mass.

Different effects can be seen in Cell 1. Here, zinc concentrations remain two orders of magnitude higher than in the other cells, and remain persistent. With infiltration bringing about dilution effects, it can only be assumed that the rate of release of zinc from the waste in this cell must be higher than in the other cells, with the principal control being pH and dissolved organic carbon. We surmise, therefore, that low pH conditions remain relatively persistent within the upper reaches of this cell. This can only mean that the level of organic stabilisation in this cell is not as advanced as in Cells 2, 3 and 4.

The leachate temperature (Figure 4.2) at the start of monitoring was between 22 to 25°C, rising to between 27 and 30 °C in April 1994 in all but Cell 3. Here, the temperature was still recovering following the liquid injection event at the end of February 1994. Seasonal ambient air temperatures have influenced the development of the temperature profiles in all the cells, with declining temperatures being recorded over winter months and increasing temperatures over summer months. Since January 1994, the general trend in leachate temperature has been upward, with all control cells reaching the highest recorded levels of between 35 - 40 °C during the autumn of 1996. Since that date, the temperatures have declined slightly and at the time of writing this report are between 30 - 35 °C. With such an upward and persistent trend, it can only be assumed that this is the result of significant biological activity within each of the cells, that appears not to be declining.

5.1.3 'Control' versus sludge (Cell 5) and commercial, non-hazardous (Cell 6) co-disposal trials

Data are plotted in Figures 4.9 to 4.16. The average from Cells 1 and 2 combined is compared with results from Cells 5 and 6.

Of note is the lower chloride and ammoniacal nitrogen concentrations in Cell 6 leachate. This reflects the lower level of municipal solid waste in this cell, in comparison with the other trial cells, and the 'diluting' influence of the 'inert' trade waste materials added to this cell to encourage landfill gas production.

Other influences are related to the much higher organic strength and lower pH of the leachate contained in Cell 1 during 1994, which has since declined and neutralised rapidly. This serves to illustrate the much more rapid assimilation of readily degradable organics in Cells 5 and 6, in comparison with the collective control cell data.

The leachate temperatures in Cells 5 and 6 have consistently been higher than the average temperature for Cells 1 and 2. The general trend for the development of temperature in the co-disposal cells remains upward, with temperatures ranging between the cells from 30-35 °C.

In general, the addition of digested sewage sludge has assisted the waste stabilisation processes by 'switching on' the gas production at an early stage, following waste emplacement. Ammoniacal nitrogen concentrations in the leachate, which might have been expected to rise in direct response to the sludge addition, have remained remarkably similar to the levels observed in the control trials. One additional and notable feature of the sludge cell leachate composition is the low levels of mobile heavy metals; in particular nickel and zinc. Concentrations of these metals are lower in the sludge cell than in the collective control cells. Allowing for the assumption that the total metal content of Cell 5, at the outset of the trials, was higher than in the 'control' cells, this observation warrants further investigation. The long-term controlling influences over heavy metal mobility in landfills need to be examined and in particular what appears to be the strong solubility controls, influenced by pH and dissolved organic carbon.

Like the sludge co-disposal trial, there is some evidence that the addition of commercial and non-hazardous (more inert) waste to Cell 6 had a beneficial effect in accelerating the onset of methanogenic conditions, with organic 'burn out' in the leachate being more rapid in this cell compared with the collective control trials. To assist the process, pH has generally been well buffered in the leachate, remaining neutral to alkaline since the spring of 1990 and very stable during this latter monitoring phase. It should however be noted that this cell contained proportionately less putrescible waste than the other cells, the balance being made up of less degradable components. This feature may have been responsible for the lower than average chloride and ammoniacal nitrogen concentrations observed in the leachate, and may have had some bearing on the 'lower than average' level of organics too.

In conclusion, monitoring data of the kind described above should be put into perspective with the characterisation of leaching behaviour of wastes in a range of different landfills.

A new presentation of the metals data, as a function of the main release controlling parameter - pH, could lead to fresh insights, in which leachate characteristics can be classified in chemical, rather than biological, terms. Such an approach could help to demonstrate consistency in the way materials leach in the long term in landfills and thus provide a basis for acceptance criteria and waste pre-treatment prior to disposal.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Sample pre-treatment in the field

The effects of various filtration techniques and filter pore size - 1.2 and 0.45 µm - have been investigated.

The use of separate filtration apparatus, rather than in-line disposable filters, proved difficult because the apparatus is designed to work on a low cross sectional area. Although suited to relatively clean water filtration applications, this kind of apparatus is seldom appropriate for leachates because numerous filter paper changes are required to prepare sufficient leachate from each borehole for analysis. In addition the need to rinse equipment between samples is time-consuming and presents unacceptable opportunities for sample contamination.

The use of disposable in-line filters, which have a pleated membrane with a large surface area proved a more attractive option. Filter pore sizes of 1.2 and 0.45 µm were used successfully in the field. This procedure enabled rapid sampling and filtration directly into sample bottles. The integrity of the samples was not compromised by cross-contamination between boreholes and the filters were discarded after use. One 1.2 µm filter per borehole proved sufficient for the volume of sample required for analysis (150 ml). A 0.45 µm filter was also able to filter the volume required. The ease of use, time saved on site, the lack of cross contamination and immediate preservation of samples more than compensates for the additional consumables cost of the filters.

6.1.1 Recommendation

From the fieldwork carried out during this project, the use of in-line disposable filters are recommended in preference to either on-site filtration apparatus or filtration on return to the laboratory. BOD, COD and TOC determinations, however, should still be carried out on unfiltered samples.

The filter pore sizes assessed were 0.45 µm or 1.2 µm, both of these large capacity filters were capable of producing the volume of filtrate required for analysis. The approximate cost of the 0.45 µm filters are currently £12 each (1997), compared with £23 for the 1.2 µm filters.

On the basis of the results reported in Section 3, the over riding opinion was that there appeared to be little evidence to suggest that one filtration device was any better than another. Because the 0.45 µm filters are cheaper and of a pore size generally recognised as representing the boundary between dissolved or suspended matter, WRc recommend that a 0.45µm filter is used for field based filtration of landfill leachates. However, it is essential that the large capacity filters which are now available are used as these are the only ones which can cope with leachates.

On site measured parameters should include pH, conductivity and leachate temperature. These ideally need to be measured using a flow-through cell. If this is not possible, readings should be carried out on a bulk sample immediately following its recovery from the well. This will minimise any changes in characteristics, particularly the influence of the ambient air temperature on the leachate temperature.

6.2 Sample handling in the field and laboratory

- *Metals*

For calcium, magnesium, sodium and potassium there is no difference between digested and undigested samples and the various filters used. For other metals if there is any major difference then the unfiltered digested sample gives the highest concentration, as would be expected. There appears to be no significant difference between digested and undigested samples, for the same filter pore size. However, the concentrations of iron and zinc, are significantly reduced when using 0.45 µm filter pore size.

- *Major anions, BOD, COD and TOC*

There are no significant differences between unfiltered samples and those filtered through 1.2 µm or 0.45 µm filters. Some results, however, are too low for any assessment to be made, or were inconclusive.

- *Volatile fatty acids*

There are no significant differences between leachate samples filtered through 0.45 µm and 1.2 µm filters.

6.2.1 Recommendations

These results reinforce the conclusion that it is more important to use appropriate filtration techniques on-site than to put undue emphasis on sample pre-treatment in the laboratory. Significant improvements in sample integrity, and the resulting quality of data (particularly heavy metals), can be achieved by employing on-site filtration during landfill monitoring exercises. WRc recommend that in order to achieve these improvements, routine ion balance checks should be incorporated into the sampling plan of a monitoring exercise. The results of these check samples should be reviewed by the responsible officer and then discussed with the field monitoring staff.

6.3 Sample pre-treatment (field and laboratory) effects on ion balance calculations

Sample preparation methods can play an important part in obtaining a stable sample in which cations and anions are roughly balanced. Our research has indicated that the following sample pre-treatment measures can have a significant bearing on ion balance. We make the following recommendations:

- samples for major and minor cations (i.e. Na, K, Ca, Mg plus heavy metals and other trace metals) should be:
  - filtered through 0.45 µm filters on site and preserved immediately. Filtration removes suspended material from the sample which may or may not be 'foreign'. If not removed this suspended material is liable to be dissolved following acidification;
  - although our research has demonstrated that a digestion step prior to analysis improves ion balance, the effect is marginal and far outweighed by the in-field activity of filtration. The choice of digesting the sample, or otherwise, is therefore a matter of professional judgement at the time of developing the sampling plan.
- Samples collected for major anions, BOD, COD, TOC and volatile acids do not require filtration. This is particularly relevant for the determination of alkalinity where filtration tends to increase the alkalinity of the sample. Although not specifically examined as part of this study, it is also recommended that samples collected for the determination of organic parameters such as pesticides and hydrocarbons, do not require field filtration.

6.4 Summary recommendations

The best approach to sample pre-treatment is:

- *for cations* - filter on sampling, using a 0.45 µm in-line disposable filter. Bottle the sample using an acid preservative. Analyse the sample 'at leisure' (a digestion step is not generally required).
- *for anions* (including BOD, COD, TOC, volatile acids and organic parameters such as pesticides and hydrocarbons) - no filtration required, but use preservatives for biologically sensitive determinands, particularly where the analysis may be delayed beyond a period of up to 12 hours. The use of a cold box, during sample transit between site and laboratory, is also recommended.

An alternative, but less desirable, approach would be:

- filter the sample in the field and bottle un-preserved. Return the sample to the laboratory in a cool box. The analytical laboratory must carry out the sample splitting and preservation as appropriate. NOTE: This alternative approach should only be adopted if the sample can be delivered to the analytical laboratory within a period of 4 hours.

6.5 Design considerations and indicators for efficient bio-reactive landfills

A bio-reactive landfill is characterised by the following main features:

- strongly methanogenic conditions, achieved relatively rapidly;
- associated high landfill gas production rates;
- generally high moisture content, often significant depths of saturated wastes;
- alkaline leachate pH-values, generally greater than 7.5;
- high temperatures, typically 30-50 °C, but can be lower.

As pointed out by Robinson (1995), the development of efficient bioreactor landfills, under UK conditions has in general been - "a fortuitous process, assisted in most cases by the inadvertent, relatively uncontrolled ingress of large quantities of water into wastes at some stage during or following waste deposition". Such ingress of water can occur as infiltration through the surface capping material, or as rising water level within the landfill as a result of groundwater inflow at depth or perhaps by collapsing pore space and settlement of the wastes with age.

Evidence presented by Robinson (1995) suggests that relatively high, persistent temperatures (often in excess of 40 °C) have been observed and maintained for periods as long as 13 years by rising water levels from the base of landfilled wastes. In contrast, waste saturation and bio-reactive conditions, solely brought about by surface infiltration, give rise to more modest temperatures in the range 30-35 °C. Cooling effects and the mobility of acetogenic leachates are thought to influence these conditions.

It is clear therefore that the distribution and development of saturated moisture conditions within wastes is regarded as essential for the optimisation of conditions conducive to rapid anaerobic digestion under landfill conditions. The Brogborough test cells have provided further evidence to back up these claims and have provided some important indicators as to how a more optimised, bioreactor approach could be developed through further research and development work.

Leachate monitoring at the cells has indicated that acetogenic and methanogenic conditions co-exist without detriment to gas production. However, methanogenic conditions were generally found to be associated with the saturated basal layers of waste in each cell. This contrasts with acetogenic conditions, which tend to be associated with the drier, unsaturated upper layers of waste.

It follows that controlled irrigation or recirculation of methanogenic leachate to capped waste should be one way of bringing about a more rapid stabilisation of landfilled waste in a sustainable landfill development. In recognition that the saturated basal layers of landfills could be encouraged to become more efficient in methane production, and irrigation or recirculation of leachate is one way that this could be brought about, studies should concentrate on the engineering requirements that would enable this to be achieved in a controlled and predictable way.

In order to understand the relative significance of infiltration and waste settlement characteristics, we suggest that each of the leachate monitoring wells are surveyed to common ordnance datum and that the leachate level data, along with the waste settlement data, is made available to a suitable project team studying the mixing and hydrodynamics of water flow in landfills.

In addition, process control 'tools' need to be developed which will allow a degree of feedback control on the process. Previous work carried out by WRc on the Landfill 2000 controlled recirculation trials (Blakey *et al* 1996) indicated that the measurement of *in situ* hydrogen within the unsaturated and saturated zones of waste may provide some means of achieving this objective. Indications of organic overload are generally considered to occur when hydrogen concentrations exceed 200-300 ppm in the gas phase. These conditions were readily achieved in the non-recycle trial by withdrawing the saturated zone leachate and encouraging more rapid flow of fresh substrate into the basal layers of the waste mass. In contrast, in the recirculation cell, a similar activity did not induce the same effects. This led to the conclusion that the saturated zone in the recirculation trial was more optimised to a greater supply of substrate and hence was operating more efficiently.

Field sampling strategies designed to monitor the development and progress of bio-reactive conditions within a modern landfill should incorporate a leachate purging requirement prior to any sampling activity. Over-reliance on baling techniques during earlier phases of the Brogborough trials emphasised the ease with which erroneous conclusions were reached concerning the status of conditions within the wastes. If this is not appreciated, use of data of this kind can mislead site management, or those with regulatory responsibilities, and incur significant wastage of time and resources. Leachate data, of the kind generated in this study, should be used more widely in the characterisation of leaching behaviour of wastes in a range of landfill circumstances. A new presentation of the metals data, as a function of the main release controlling parameter - pH, could expose consistency in the way materials leach in the long term in landfills. Such information could be used to develop acceptance criteria and waste pre-treatment requirements for landfill disposal.

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APPENDIX A

WRc PROTOCOLS AND RECORD SHEETS

PROTOCOL FOR SAMPLING FROM A LEACHATE MONITORING BOREHOLE BY PUMPING

Equipment/apparatus

The following list is not exhaustive but includes the main elements:

- Site map and borehole diagram (background information on the monitoring array is highly desirable);
- Tool kit (to serve the monitoring equipment as well as the closure cover of the borehole);
- pH meter and probe;
- Conductivity meter and probe;
- Dissolved oxygen (DO) meter and probe (optional);
- Eh meter and probe (optional);
- Flow through cell for pH, conductivity, Eh and DO measurements (optional);
- Sample bottles;
- Plastic sheet;
- Leachate level dipper;
- Sample recovery equipment;
- Totalising water meter (optional);
- Deionised or distilled water for rinsing equipment.

Preparation for sampling

The requirements of the sampling exercise will be documented in the Sampling Plan. Before developing the Sampling Plan, the objectives of the exercise must be defined. This protocol only covers the basic sampling methodology, but the following check list will assist the development of the Sampling Plan and hence the preparations for the sampling exercise.

1. Read the Company/organisation health and safety policy statement and prepare a Site Operating Procedure (SOP) for inclusion in the Sampling Plan. (NOTE: The SOP should take account of the employer's responsibility with respect to the Control of Substances Hazardous to Health (COSHH) Regulations 1988. Each SOP should be assigned a specific hazard/risk code which can be used to identify appropriate Personal Protective Equipment (PRE) for the task.)

2. Check the access route and ground conditions for the field vehicle and discuss with the site owner or other responsible person. Agree conditions of entry to the site in writing and add these to the Sampling Plan.

3. Discuss the sample analytical requirements with the analyst (e.g. determinands, sample type and condition, bottles, sample storage, reception arrangements) and collect the prepared bottles in good time for the sampling exercise. (NOTE: Other sample requirements such as filtration, preservation, bottle head space should be discussed at this stage).
4. Obtain all information relating to borehole construction and leachate levels.
5. Calculate the volume of leachate standing within the borehole (a single well volume). (NOTE: It is often helpful at this stage to create a quick look up table for later use in the field.)
6. Decide on the depth at which the pump is to be set. (NOTE: the decision will be based on the borehole characteristics, the position of the screen, the type of pump and the objectives of the exercise. Always check the Sampling Plan and discuss with the supervisor.)
7. Before packing the sample recovery equipment, check the cleaning procedure records and repeat to the appropriate standard, if not satisfied.
8. Check the calibration of the pH, temperature, conductivity, Eh and DO probes. (NOTE: Ensure that calibration and standard solutions are taken on the sampling exercise.)

Procedure for sampling a leachate monitoring borehole

1. Open the observation borehole and check the depth to the leachate and the total depth of the borehole using a leachate level dipper. Record the results in the field log. (NOTE: It is often difficult to obtain an accurate measurement of leachate level in an actively gassing landfill borehole. Pressure transducers provide an alternative means of making this measurement.)
2. Lay out all the sample recovery equipment on clean plastic sheet or on trays/boxes.
3. Check the volume of leachate to be pumped (see Preparation for Sampling, item 5) and set up arrangements for disposing of the purged leachate (see the Sampling Plan).
4. Assemble the sample recovery equipment and lower the assembly into the borehole. Tape all cables and rising main together to avoid tangling and damage to cables. At the required depth, secure in position (e.g. by locking the cable drum or by using a catch plate).
5. Connect the discharge hose between the top of the rising main and a suitable discharge point. This might be:
    - a reception tank, sized to contain at least three well volumes of leachate;
    - a down-gradient leachate borehole; or
    - surface discharge, if agreed with the site operator/supervisor.

    (NOTE: It is inadvisable to freely discharge leachate in the vicinity of the borehole head works in a way that is likely to result in leachate returning to the borehole or other boreholes to be sampled.)

    (NOTE: In all cases the Sampling Plan will be explicit in the approach to be taken here. If not seek further guidance from your superior.)

A totalising water meter can be fitted onto the discharge hose to aid the measurement of discharge volume.

6. Consult the Sampling Plan for the required purge volume, start the pump and run until three well volumes of leachate have been purged. (NOTE: see item 3 above.) If the borehole runs dry, note the pump time and calculate the volume of leachate which has been purged. If recharge is very slow, samples may have to be obtained by bailing.
7. Check the calibration of all instrument probes for on-site determinations. Measurements of temperature, pH, conductivity, Eh, and DO should all be carried out in a flow-through cell connected to the reduced-flow discharge line, after removing air bubbles from the cell. Alternatively pH, temperature and conductivity can be measured in a clean beaker full of leachate, but on no account should Eh and DO be measured in this way. Record the results in the field log, with any comments on appearance and odour.
8. Fill the sample bottles direct from the discharge tubing where possible, as follows:
    - rinse the bottles which do not contain preservative (e.g. TOC, COD, pesticides, hydrocarbons) with leachate and fill to the top. No field filtration required;
    - bottles containing preservatives (e.g. NH_3-N) should not be rinsed and only filled to the 'fill-to-mark'. No field filtration required;
    - samples for **dissolved** metal determinations should be filtered through 0.45μm filters, and the first aliquot of filtered sample discarded, prior to filling the preservative-containing bottle to the fill-to mark. Samples for **total** metal determinations are not filtered. Commit filtration details to the sampling plan;
    - before collecting samples for volatile determinands, reduce the pumping rate to $<2\ l\ min^{-1}$. Fill the glass vial to the rim and screw on the cap with PTFE-lined septum. There should be no headspace. Store the vials upside down in a coolbox to minimise loss of volatiles.
9. Check that the sample bottles are labelled correctly, then pack them into a coolbox containing chilled freezer blocks for transport.
10. When QA/QC samples are needed, 'trip' blanks should remain unopened and 'field' blanks should be transferred from their bottles into fresh bottles containing the relevant preservative.
11. Slowly withdraw the sample recovery equipment form the borehole so as to avoid damage to the rising main or any cables. Disassemble the equipment on the plastic sheet, rinse with deionised or distilled water and pack the equipment away.
12. Secure the closure cover of the borehole.
13. Deliver the sample bottles to the laboratory, completing sample custody forms.
14. All field equipment should be thoroughly cleaned using a proprietary cleaning fluid on return to the laboratory (NOTE: It is prudent practice to set up a record of this activity and get a colleague to certify the completion of the cleaning before the equipment is returned to storage.)

ADDITIONAL INFORMATIVE NOTES

- Pump sets used for sampling landfill leachate should be appropriately marked and must not be used for routine 'clean' groundwater monitoring.
- The same protocol can be followed using a bailer or *in situ* inertial pump. However, it is advisable to carry out the well purging the day before sampling using a submersible pump. Additional personnel can assist in this preparatory work (e.g. site operator or owner), but it is important that their activities are agreed and included in the Sampling Plan.
- It is not possible to purge leachate sumps and their use as monitoring structures is not recommended.
- Conditions in the borehole (e.g. presence of silt or other heavy particulates) may affect the temporal variations in the data, or be responsible for systematic trends. Where changes in borehole conditions are encountered, the field technician must discuss his observations with his superior and any agreed changes in monitoring strategy logged in the Sampling Plan.
- The principle of removing three well volumes of leachate to purge a borehole is a good general guide. However, detailed knowledge obtained during a monitoring programme might indicate that a change to this strategy is appropriate.

REFERENCE

Clark, L. (1992) Methodology for monitoring and sampling groundwater. NRA R&D Note 126

APPENDIX B

BOREHOLE PURGING RECORD SHEETS, AS COMPLETED BY SHANKS & McEWAN

WRc

Brogborough Leachate Sampling - Protocol 1
Well Purging prior to sampling

Date :
Completed by:

Borehole No. C	**Cell 1**	**Cell 2**	**Cell 3**	**Cell 4**	**Cell 5**	**Cell 6**
Depth of borehole/m below top of casing (A) (measured - 24 Jan 94)	**19.30**	**16.80**	**19.32**	**17.80**	**18.15**	**18.50**
Depth **TO** leachate/m below top of casing (B)						
Depth of leachate/m: (**d** = A - B)						
PURGING: Pump Flow rate (l/min) (C). If approx. 66l/min consult look-up table.						
Purge volume **required** for 3 well volumes: (**d** x 200 = D litres). **NB.** No need to calculate if using look-up table						
Pump time **required:** (D/C = E mins) (if pump at approx. 66l/min refer to look-up table)						
Actual Time pump on (mins) (F)						
Did borehole pump **dry? (Y/N)**						
Actual purge volume (litres): (C x F = G litres)						
No. of well volumes purged:						
Purged Leachate discharged to Borehole no:						

Please Complete (at least the non-shaded sections) And Return To:
Karen Bradshaw or Robert Oliver
WRc
Henley Road, Medmenham,
Marlow,
BUCKS SL7 2HD Tel: 0491 571531

Purge Volume Calculation:

Volume of Liquid in Borehole (1 well volume) = v (m^3) = $\pi r^2 \times d$, where d = depth of leachate (m) and r = radius of borehole (m)
Borehole Diameter = 30cm = 0.30m, therefore borehole radius r = 0.15m
Therefore v (m^3) = $\pi (0.15)^2 \times d$
= $0.071 \times d$
Therefore 3 well volumes = $0.212 \times d$ m^3
1 m^3 = 1000 litres
Therefore 3 well volumes = $212 \times d$ litres
Approximate to purge $200 \times d$ litres

WELL PURGING LOOK-UP TABLE :

Assuming 66 litres/min (pump on maximum)

⇨ Number of minutes to purge for 1,2, and 3 well volumes

Depth of leachate/m➔ Purge volumes 🡻	2m	3m	4m	5m	6m	7m
1 well volume	2 mins	3 mins	4 mins	5 mins	6 mins	7 mins
2 well volumes	4 mins	6 mins	8 mins	10 mins	12 mins	14 mins
3 well volumes	6 mins	9 mins	12 mins	15 mins	18 mins	21 mins

Depth of leachate/m➔ Purge volumes 🡻	8m	9m	10m	11m	12m
1 well volume	8 mins	9 mins	10 mins	11 mins	12 mins
2 well volumes	16 mins	18 mins	20 mins	22 mins	24 mins
3 well volumes	24 mins	21 mins	30 mins	33 mins	36 mins

Brogborough Leachate Sampling Protocol - Table 2
Borehole sampling by inertial pump method

Date :
Present :

Borehole No. C	**Cell 1**	**Cell 2**	**Cell 3**	**Cell 4**	**Cell 5**	**Cell 6**
Date of well purging:						
Leachate level (m below top of casing)						
On-site measurements:						
pH						
Temperature °C						
Conductivity mS						
Any additional comments: (or add to notebook)						
Lab measurements:	**If unable to determine in field**					
pH						
Temperature °C						
Conductivity mS						
Any additional comments: (or add to notebook)						

Brogborough Leachate Sampling - Protocol 1
Well Purging prior to sampling

WRc

Date : 24 January 1994
Completed by: Karen Bradshaw (WRc) and Steve Wheeler (SME)

Borehole No. C	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
Depth of borehole/m below top of casing (A) (measured - 24 Jan 94)	**19.30**	**16.80**	**19.32**	**17.80**	**18.15**	**18.50**
Depth **TO** leachate/m below top of casing (B)	12.55	12.30	8.80	11.50	* Frothy * 8.00	11.65
Depth of leachate/m: (**d** = A - B)	6.75	4.50	10.52	6.30	10.15	6.85
PURGING: Pump Flow rate (l/min) (= C)	66 l/min →			24 l/min →		
Purge volume **required** for 3 well volumes: (**d** x 200 = D litres)	1350	900	2104	1260 ~~[illegible]~~	2030	1370
Pump time **required:** (D / C = E mins)	21	14	32	52	85	57
Actual Time pump on (mins) (F)	19 → DRY	8 ½ → DRY	20 → DRY	52	⊛ 17 → DRY	20½ → DRY
Actual purge volume (litres): (C x F = G litres)	1254	561	1320	1260	408	492
No. of well volumes purged:	2.8	1.9	1.9	3	0.6	1.1
Purged Leachate discharged to Borehole no:						

⊛ Obstruction in borehole ∴ pump not near bottom

Purge Volume Calculation:

Volume of Liquid in Borehole (1 well volume) = **v (m^3) = πr^2 x d**, where d = depth of leachate (m) and r = radius of borehole (m)
Borehole Diameter = 30cm = 0.30m, therefore borehole radius **r = 0.15m**
Therefore v (m^3) = $\pi (0.15)^2$ x **d**
= 0.071 x **d**
Therefore 3 well volumes = 0.212 x **d** m^3
1 m^3 = 1000 litres
Therefore 3 well volumes = 212 x **d** litres
Approximate to purge 200 x **d** litres

Please Complete And Return To:
Karen Bradshaw or Robert Oliver

WRc
WATER RESEARCH CENTRE
P.O. BOX 16
MARLOW
BUCKINGHAMSHIRE
SL7 2HD
TEL: 0491 571531

WELL PURGING LOOK-UP TABLE :

Assuming 66 litres/min (pump on maximum) ⇨ Number of minutes to purge for 1,2, and 3 well volumes

Depth of leachate/m ➔ Purge volumes ⬇	2	3	4	5	6	7	8	9	10	11	12
1 well volume	2 mins	3 mins	4 mins	5 mins	6 mins	7 mins	8 mins	9 mins	10 mins	11 mins	12 mins
2 well volumes	4 mins	6 mins	8 mins	10 mins	12 mins	14 mins	16 mins	18 mins	20 mins	22 mins	24 mins
3 well volumes	6 mins	9 mins	12 mins	15 mins	18 mins	21 mins	24 mins	21 mins	30 mins	33 mins	36 mins

Brogborough Leachate Sampling - Protocol 1
Well Purging prior to sampling

Date : 7ND FEBRUARY 94
Completed by: STEVE WHEELER

Borehole No. C	**Cell 1**	**Cell 2**	**Cell 3**	**Cell 4**	**Cell 5**	**Cell 6**
Depth of borehole/m below top of casing (A) (measured - 24 Jan 94)	19.30	16.80	19.32	17.80	18.15	18.50
Depth **TO** leachate/m below top of casing (B)	13·00	13·50	12·90	11·95	8·50	15·25
Depth of leachate/m: (d = A - B)	6·30	3·30	6·42	5·85	9·65	3·25
PURGING: Pump Flow rate (l/min) (C). If approx. 66l/min consult look-up table.	66 l/m.	66 l/m.	66 l/m.	66 l/m.	66 l/m.	TIME TRIAL 66 l/M
Purge volume **required** for 3 well volumes: (d x 200 = D litres). **NB.** No need to calculate if using look-up table	1260	660	1284	1170	1930	650
Pump time **required:** (D/C = E mins) (if pump at approx. 66l/min refer to look-up table)	19.00	10·0	19·5	18·0	29·5	9·0
Actual Time pump on (mins) (F)	19.00	9·0	19·5	18·0	* 7·45	9·0
Did borehole pump dry? (Y/N)	NO	YES	NO	NO	YES	NO
Actual purge volume (litres): (C x F = G litres)	1260	594	1284	1170	492.	650
No. of well volumes purged:	3	2·7	3	3	·77	3
Purged Leachate discharged to Borehole no:	23A.	31	31	39.	45	45.

* OBSTRUCTION STILL IN BOREHOLE

FLOW REDUCING AFTER 15 MINS.

FLOW REDUCING AFTER 15 MINS.

Please Complete (at least the non-shaded sections) And Return To:
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Henley Road, Medmenham,
Marlow,
BUCKS SL7 2HD Tel: 0491 571531

NB. SAMPLES ARE IN COLD STORE AT SME LAB.

Brogborough Leachate Sampling - Protocol 1
Well Purging prior to sampling

Date : 7TH MARCH 1994.
Completed by: STEVE WHEELER.

Borehole No. C	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
Depth of borehole/m below top of casing (A) (measured - 24 Jan 94)	19.30	16.80	19.32	17.80	18.15	18.50
Depth **TO** leachate/m below top of casing (B)	12·85	13·46	8·53	11·91	8·41	15·18
Depth of leachate/m: (d = A - B)	6·45	3·34	10·79.	5·89	9·74	3·32
PURGING: Pump Flow rate (l/min) (C). If approx. 66l/min consult look-up table.	66 l/m.	66 l/m.	66 l/m.	66 l/m.	66 l/m.	TIME TRIAL. 66 l/min
Purge volume **required** for 3 well volumes: (d x 200 = D litres). **NB.** No need to calculate if using look-up table	1290	668	2158	1078	1948	664
Pump time **required:** (D/C = E mins) (if pump at approx. 66l/min refer to look-up table)	19·5	10·25	32·5	16·5	29·5	10·0
Actual Time pump on (mins) (F)	16·5	8·5	33·00	18·00	* 7·15	10·0
Did borehole pump **dry?** (Y/N)	YES	YES	NO	NO	YES.	NO
Actual purge volume (litres): (C x F = G litres)	1089	561	2178	1188	472.	660
No. of well volumes purged:	2·63	2·52	3	3·3	·72	3
Purged Leachate discharged to Borehole no:	30	31	37.	39.	39.	45.

44,000 GALS OF FRESH WATER PUMPED INTO THIS WELL LAST WEEK.

* OBSTRUCTION IN WELL BENT CASING.

Please Complete (at least the non-shaded sections) And Return To:
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Marlow,
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COLD + SHOWERY.

Brogborough Leachate Sampling - Protocol 1
Well Purging prior to sampling

Date: 5TH APRIL 94.
Completed by: STEVE WHEELER.

Borehole No. C	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
Depth of borehole/m below top of casing (A) (measured - 24 Jan 94)	19.30	16.80	19.32	17.80	18.15	18.50
Depth **TO** leachate/m below top of casing (B)	12·80	13·45	9 30	11·90	8 40	15·15
Depth of leachate/m: (d = A - B)	6·50	3·35	10·02	5·90	9·75	3·35
PURGING: Pump Flow rate (l/min) (C). If approx. 66l/min consult look-up table.	66 lt/m.	66lt/m.	66lt/m.	66lt/m	66lt/m.	66lt/m.
Purge volume **required** for 3 well volumes: (d x 200 = D litres). **NB.** No need to calculate if using look-up table	1,300	670	2004.	1180	1850	670
Pump time **required:** (D/C = E mins) (if pump at approx. 66l/min refer to look-up table)	19·5	10	30	18	28	10
Actual Time pump on (mins) (F)	17·0	8·5	27	18	15	8·0
Did borehole pump dry? (Y/N)	YES	YES	YES	NO	YES	YES
Actual purge volume (litres): (C x F = G litres)	1122	561	1782	1180	990	528
No. of well volumes purged:	2·59.	2·51	2·66	3	1·6	2·36
Purged Leachate discharged to Borehole no:	30	31	37	37	39	45.

Please Complete (at least the non-shaded sections) And Return To:
Karen Bradshaw or Robert Oliver
WRc
Henley Road, Medmenham,
Marlow,
BUCKS SL7 2HD Tel: 0491 571531

Brogborough Leachate Sampling - Protocol 1
Well Purging prior to sampling

Date: 3RD. MAY. 94.
Completed by: STEVE WHEELER.

DRY SPELL - WARM + SUNNY.

Borehole No. C	**Cell 1**	**Cell 2**	**Cell 3**	**Cell 4**	**Cell 5**	**Cell 6**
Depth of borehole/m below top of casing (A) (measured - 24 Jan 94)	19.30	16.80	19.32	17.80	18.15	18.50
Depth **TO** leachate/m below top of casing (B)	1260	1340	990	1180	830	1500
Depth of leachate/m: (d = A - B)	670	340	1042	590	985	350
PURGING: Pump Flow rate (l/min) (C). If approx. 66l/min consult look-up table.	66LT/M.	66LT/M.	66LT/M.	66LT/M.	66LT/M.	66LT/M.
Purge volume required for 3 well volumes: (d x 200 = D litres). NB. No need to calculate if using look-up table	1340	680	2084	1180	1970	700
Pump time required: (D/C = E mins) (if pump at approx. 66l/min refer to look-up table)	19·6	10 5	31	18	29	10·5
Actual Time pump on (mins) (F)	18·0	7·5	27·5	5·0	9·0	9·0
Did borehole pump dry? (Y/N)	JUST	YES	YES	YES	YES.	YES.
Actual purge volume (litres): (C x F = G litres)	1188	495	1815	330	594	594
No. of well volumes purged:	2·66	2·18	2·61	·83	·90	2·55
Purged Leachate discharged to Borehole no:	30	30	31.	39.	39.	45.

Please Complete (at least the non-shaded sections) And Return To:
Karen Bradshaw or Robert Oliver
WRc
Henley Road, Medmenham,
Marlow,
BUCKS SL7 2HD Tel: 0491 571531

WRc

Brogborough Leachate Sampling - Protocol 1
Well Purging prior to sampling

Date: 1ST NOVEMBER. 94.
Completed by: J. HUMBERT.

	HYDRAINER PUMP.	HYDRAINER PUMP.	HYDRAINER PUMP.	ELECTRIC PUMP.	ELECTRIC PUMP	ELECTRIC PUMP.
Borehole No. C	**Cell 1**	**Cell 2**	**Cell 3**	**Cell 4**	**Cell 5**	**Cell 6**
Depth of borehole/m below top of casing (A) (measured - 24 Jan 94)	19.30	16.80	19.32	17.80	18.15	18.50
Depth TO leachate/m below top of casing (B)	11.90	13.05	10.20	11.80	7.95	15.0
Depth of leachate/m: (d = A - B)	7.40	3.75	9.12	6.00	10.20	3.50
PURGING: Pump Flow rate (l/min) (C). If approx. 66l/min consult look-up table.	66l/m.	66l/m.	66l/m	12l/m.	12l/m	12l/m.
Purge volume required for 3 well volumes: (d x 200 = D litres). NB. No need to calculate if using look-up table	1480	750	1824	1200	2040	700
DEPTH TO LEACHATE AFTER PUMPING - / MT.	13MT	16.35MT	14.00MT	14.00MT	9 MT	18.30.
Actual Time pump on (mins) (F)	3.5	10.0	10.0	25.0	9.0	25.0
Did borehole pump dry? (Y/N)	YES.	YES	YES	NO	YES.	YES.
Actual purge volume (litres): (C x F = G litres)	231	660	660.	300	108.	209.
No. of well volumes purged:						
Purged Leachate discharged to Borehole no:	23	30	31	37.	39	45.
DEPTH OF LEACHATE DISCHARGED.	1.10	3.30	3.80.	2.20	1.05	3.30.

Please Complete (at least the non-shaded sections) And Return To:
Karen Bradshaw or Robert Oliver

WRc
Henley Road, Medmenham,
Marlow,
BUCKS SL7 2HD Tel: 0491 571531

Brogborough Leachate
Well Purging pr

Date : 3RD OCTOBER.
Completed by: STEVE WHEELER

Borehole No. C	Cell 1	Cell 2
Depth of borehole/m below top of casing (A) (measured - 24 Jan 94)	19.30	16.80
Depth TO leachate/m below top of casing (B)	12.00	13.25
Depth of leachate/m: (d = A - B)	7.30	3.55
PURGING: Pump Flow rate (l/min) (C). If approx. 66l/min consult look-up table.	66 Lt/MIN.	66 Lt/MIN.
Purge volume required for 3 well volumes: (d x 200 = D litres). NB. No need to calculate if using look-up table	1460	710
Pump time required: (D/C = E mins) (if pump at approx. 66l/min refer to look-up table)	22MIN.	10MIN.
Actual Time pump on (mins) (F)	3.5	9.0
Did borehole pump dry? (Y/N)	YES	YES
Actual purge volume (litres): (C x F = G litres)	231	594
No. of well volumes purged:	·47	2.52
Purged Leachate discharged to Borehole no:	23A.	30

BSTRUCTION
13.20 MTS

Please Complete (at least the non-shaded sections) And Return To:
Karen Bradshaw or Robert Oliver
WRc
enley Road, Medmenham,
Marlow,
BUCKS SL7 2HD Tel: 0491 571531

WET WINDY. → DRY.

WRc

Brogborough Leachate Sampling - Protocol 1
Well Purging prior to sampling

Date : 1ST MARCH 1995.
Completed by: STEVE WHEELER. c/w HYDRAINER PUMP

Borehole No. C	Cell 1 WELL BLOCKED	Cell 2	Cell 3	Cell 4	Cell 5 WELL BLOCKED.	Cell 6
Depth of borehole/m below top of casing (A) (measured - 24 Jan 94)	13.10 ~~19.30~~	16.70 16.80	19.10 19.32	17.50 ~~17.80~~	8.00. ~~18.15~~	16.35. ~~18.50~~
Depth TO leachate/m below top of casing (B)	10.68	11.95	4.45	10.95	7.23.	14.25
Depth of leachate/m: (d = A - B)	2.42.	4.75	14.65	6.55	6.77	2.10
PURGING: Pump Flow rate (l/min) (C). If approx. 66l/min consult look-up table.	66 l/MIN.	66 l/MIN	66 l/MIN	66 l/MIN.	66 l/MIN.	66 l/MIN.
Purge volume required for 3 well volumes: (d x 200 = D litres). NB. No need to calculate if using look-up table	~~495~~.	~~924~~.	2640.	1287.		462.
Pump time required: (D/C = E mins) (if pump at approx. 66l/min refer to look-up table)	7.5 MIN.	14 MIN.	40 MIN.	19.5 MIN.	NOT A LOT	7 MIN
Actual Time pump on (mins) (F)	7.5 MIN	11.5 MIN	40 MIN.	19.5 MIN.	4 MIN.	7 MIN
Did borehole pump dry? (Y/N)	NO	YES.	NO	NO	YES.	NO.
Actual purge volume (litres): (C x F = G litres)	495	759.	2640.	1287	264.	462.
No. of well volumes purged:	3.	2.46.	3	3.		3.
Purged Leachate discharged to Borehole no:	23.	30.	31	37.	39.	45

Please Complete (at least the non-shaded sections) And Return To:
Karen Bradshaw or Robert Oliver

WRc
Henley Road, Medmenham,
Marlow,
BUCKS SL7 2HD Tel: 0491 571531

WEATHER :- WARM + DRY DURING A LONG DRY SPELL

WRc

Brogborough Leachate Sampling - Protocol 1
Well Purging prior to sampling

Date : 5 JULY 95

Completed by: STEVE WHEELER.

NO WATERRA

Borehole No. C	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
Depth of borehole/m below top of D(P. casing (A) (measured - 24 Jan 94)	13·10 19.30	16·10 16.80	19·90 19.32	14·80 17.80	9·45 18.15	18·18 18.50
Depth TO leachate/m below top of casing (B)	10·30	11·80	7·90	10·65	7·70	14·65
Depth of leachate/m: (d = A - B)	2·80	4·90	12·00	4·15	1·75	3·53
PURGING: Pump Flow rate (l/min) (C). If approx. 66l/min consult look-up table.	66·lts	66lts	66lts	66lts	66lts	66lts
Purge volume required for 3 well volumes: (d x 200 = D litres). NB. No need to calculate if using look-up table						
Pump time required: (D/C = E mins) (if pump at approx. 66l/min refer to look-up table)	8·5 MIN	15 MIN	36 MIN	13 MIN.	5 MIN.	11·5 MIN.
Actual Time pump on (mins) (F)	8·5 MIN.	15 MIN.	2 MIN.	13 MIN.	5 MIN	6·5 MIN.
Did borehole pump dry? (Y/N)	NO	NO	YES	NO	NO	YES.
Actual purge volume (litres): (C x F = G litres)	561 lts.	980 lts	132 lts.	1675 lts	330 lts	429 lts
No. of well volumes purged:	3	3	·0135	3	3	1·7
Purged Leachate discharged to Borehole no:	E23A	G.30	31	G37	G37	9.45.

Please Complete (at least the non-shaded sections) And Return To:

Karen Bradshaw or Robert Oliver

WRc
Henley Road, Medmenham,
Marlow,
BUCKS SL7 2HD Tel: 0491 571531

WRc

Brogborough Leachate Sampling - Protocol 1
Well Purging prior to sampling

Date : 8TH NOVEMBER. '95
Completed by: S. WHEELER.
DRY + COOL + CLOUDY. - DURING A DRY AUTUMN.

Borehole No. C	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
Depth of borehole/m below top of casing (A) (measured - 24 Jan 94)	13·08 19.30	16·50 16.80	8·35 19.32	14·65 17.80	9·40 18.15	18·10 18.50
Depth TO leachate/m below top of casing (B)	10·02	11·54	7·40	9·95	7·35	13·75
Depth of leachate/m: (d = A - B)	3·06	4·96.	·95	4·70	2·05	4·35
PURGING: Pump Flow rate (l/min) (C). If approx. 66l/min consult look-up table.	66 LTS/M	66 LTS/M	66 LTS/M	66 LTS/M.	66 LTS/M.	66 LT/M.
Purge volume required for 3 well volumes: (d x 200 = D litres). NB. No need to calculate if using look-up table	~~9 MINS.~~					
Pump time required: (D/C = E mins) (if pump at approx. 66l/min refer to look-up table)	9 MINS.	15 MIN.	3 MIN.	14 MIN.	6 MIN.	13 MIN.
Actual Time pump on (mins) (F)	7.27	15·00	2·40	12·0	·6 MIN.	7.3 MIN
Did borehole pump dry? (Y/N)	YES	NO	YES.	YES	NO	YES
Actual purge volume (litres): (C x F = G litres)	479.82	990	158.4.	792.	396.	481·8.
No. of well volumes purged:	1·24	3	1·25	1·17	3	1·78
Purged Leachate discharged to Borehole no:	E23A.	G.30	G.31	G.37.	38	G.45

Please Complete (at least the non-shaded sections) And Return To:
Karen Bradshaw or Robert Oliver
WRc
Henley Road, Medmenham,
Marlow,
BUCKS SL7 2HD Tel: 0491 571531

WEATHER:- BRIGHT SUNSHINE - CELLS BADLY FLOODED.

WRc

Brogborough Leachate Sampling - Protocol 1
Well Purging prior to sampling

Date: 28 FEBRUARY.
Completed by: STEVE WHEELER.

Borehole No. C	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
Depth of borehole/m below top of casing (A) (measured - 24 Jan 94)	18·90 19.30	16·70 16.80	8·10 19.32	14·60 17.80	9·30 18.15	18·00 18.50
Depth TO leachate/m below top of casing (B)	9·65	SLUDGY 10·80	7·13	9·03	7·17	12·72
Depth of leachate/m: (d = A - B)	9·25	5·9	0·97	5·57	2·13	5·28
PURGING: Pump Flow rate (l/min) (C). If approx. 66l/min consult look-up table. APPROX 35 LTS/MIN.	35 LT/M.	35 LT/M.	35 LT/M.	35 LT/M.	35 LT/M	PUMP DOES NOT PASS THRO RESTRICTED WELL TO LIQUID @ 12 MTS.
Purge volume required for 3 well volumes: (d x 200 = D litres). NB. No need to calculate if using look-up table	1850	1180	194	1114	426.	
Pump time required: (D/C = E mins) (if pump at approx. 66l/min refer to look-up table)						
Actual Time pump on (mins) (F)	6·5	10·3	4·30	20·0	11·0	—
Did borehole pump dry? (Y/N)	YES	YES	YES	NO	YES.	
Actual purge volume (litres): (C x F = G litres)	227·5	360·5	150·5	700	385	
No. of well volumes purged:	0·36	0·9	2·3	1·8	2·7	—
Purged Leachate discharged to Borehole no:						

Please Complete (at least the non-shaded sections) And Return To:
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WEATHER - COOL BREEZY, SUNSHINE + SHOWERS

WRc

Brogborough Leachate Sampling - Protocol 1
Well Purging prior to sampling

Date: 24-4-96.
Completed by: STEVE WHEELER

	HIGH PRESS	HIGH PRESS.	V.HIGH PRESS.	PRESS	POSS PRESS	POSS PRESS
Borehole No. C	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
Depth of borhole/m below top of casing (A) (measured - 24 Jan 94)	18·80 19.30	16·55 16.80	8·20 19.32	11·45 17.80	9·30 18.15	18·00 18.50
Depth TO leahate/m below top of casing (B)	9·60	11·24	6·99.	8·72	6·98	12·30
Depth of leachte/m: (d = A - B)	9·20	5·31	1·21	2·73	2·32	6·20
PURGING: Pump Flow rate (l/min) (C). If approx 66l/min consult look-up table. BETWEN 35-40 LTS/MIN	PUMP AT 12·70 m	PUMP AT 16·40 m	PUMP AT 7·65 m	PUMP AT 11·0 m	PUMP AT 9·00 M.	PUMP AT 12·00 M
Purge volume equired for 3 well volumes: (d x 00 = D litres). NB. No need to calculae if using look-up table	1840	1062	242.	546.	464	
Pump time recired: (D/C = E mins) (if pump at appro. 66l/min refer to look-up table)						
Actual Time pmp on (mins) (F)	6·5 MIN	13·5 MIN	6·0 MIN	16 MIN.	4·5 MIN.	NIL
Did borehole pmp dry? (Y/N)	YES	YES	YES	NO	YES	N/A.
Actual purge volume (litres): (C x F = G litrs) @ 40 LT/MIN.	260·0	540·0	240·0	640·0	180·0	N/A.
No. of well volmes purged:	0·42	1·5	3·0	3·5	1·2	—
Purged Leachat discharged to Borehole no:	23	30	37	37	OLD 39.	N/A.

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COOL CLOUDY + DRIZZLN.

WRc

Brogborough Leachate Sampling - Protocol 1
Well Purging prior to sampling

Date: 10-12-96.
Completed by: STEVE WHEELER

Borehole No. C	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
Depth of borehole/m below top of casing (A) (measured - 24 Jan 94)	11.15 ~~19.30~~	16.50 ~~16.80~~	7.90 ~~19.32~~	11.01 ~~17.80~~	9.20 ~~18.15~~	18.00 ~~18.50~~
Depth TO leachate/m below top of casing (B)	8.85	11.05	6.38	7.84	7.01	10.99.
Depth of leachate/m: (d = A - B)	2.30.	5.45.		3.17	PUMP	PUMP
PURGING: Pump Flow rate (l/min) (C). If approx. 66l/min consult look-up table.		PUMP AT 11.86.	PUMP ONLY	PUMP AT 10.80	ONLY TO	ONLY TO
Purge volume required for 3 well volumes: (d x 200 = D litres). NB. No need to calculate if using look-up table	460	1180	TO 5.80 MTS.		5.25MTS	9 MTS.
Pump time required: (D/C = E mins) (if pump at approx. 66l/min refer to look-up table)	11 MINS.	27 MINS.		15M.		
Actual Time pump on (mins) (F)	3½ MIN	3 MINS		16 MIN		
Did borehole pump dry? (Y/N)	YES.	YES.		NO		
Actual purge volume (litres): (C x F = G litres)	140	120		640.		
No. of well volumes purged:						
Purged Leachate discharged to Borehole no:	23A	C30		39		

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SORRY FOLKS - NOT A VERY GOOD SET OF READINGS THIS IS DUE TO THE WELL CASING COLLAPSING (USUALLY ON THE JOINTS, AND NOT ALLOWING A 4" PUMP PASSED. Regards

WARM DRY + SUNNY

WRc

Broghorough Leachate Sampling - Protocol 1
Well Purging prior to sampling

Date: 9-7-97.
Completed by: STEVE WHEELER.

Borehole No. C	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
Depth of borehole/m below top of casing (A) (measured - 24 Jun 94)	19.30	16.80	19.32	17.80	18.15	18.50
Depth TO leachate/m below top of casing (B)	8·20.	THE C	5·63.	6·70	6·65	10·30
Depth of leachate/m: (d = A - B)	POMP IN	WELL HAS	PUMP IN	PUMP IN	PUMP	PUMP
PURGING: Pump Flow rate (l/min) (C). If approx. 66l/min consult look-up table.	TO WELL @ 9·90	BEEN BENTONITED	TO WELL @ 5·75	TO WELL @ 8·60	ONLY TO	ONLY TO
Purge volume required for 3 well volumes: (d x 200 = D litres). NB. No need to calculate if using look-up table	POMPED FOR 3 MIN	UP NOW	POMPED FOR 2·5 MINS	860 LTS	5·30 MTS	9·50 MTS
Pump time required: (D/C = E mins) (if pump at approx. 66l/min refer to look-up table)	ONLY.		ONLY.	29 MIN.	CANNOT PURGE	CANNOT PURGE
Actual Time pump on (mins) (F)				29 MIN.		
Did borehole pump dry? (Y/N)				No		
Actual purge volume (litres): (C x F = G litres)	90 LTS.		75 LTS.	860 LTS		
No. of well volumes purged:				3		
Purged Leachate discharged to Borehole no:	23A.		30	39.		

81

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WRc

Brogborough Leachate Sampling - Protocol 1
Well Purging prior to sampling

Date : 22ND SEPT. 97.
Completed by: STEVE WHEELER.

WARM DRY SUNNY DAY
IN A DRY PERIOD.

Borehole No. C	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
Depth of borehole/m below top of casing (A) (measured - 24 Jan 94)	19.30	16.80	19.32	17.80	18.15	18.50
Depth TO leachate/m below top of casing (B)	8·20	C WELL	5·38	(FORMING). 6·30	6·25	10·30
Depth of leachate/m: (d = A - B)	PUMP IN	BENTONITED	PUMP AT 5·60	PUMP AT 8·60.	ELECTRICAL GRUNDFOS	PUMP
PURGING: Pump Flow rate (l/min) (C). If approx. 66l/min consult look-up table.	TO WELL @ 9.90MTS.	UP FOR			ONLY TO 5·3M TRY 12VOLT	ONLY TO
Purge volume required for 3 well volumes: (d x 200 = D litres). NB. No need to calculate if using look-up table		RECIRCULATION EXPERIMENT.			PUMP FOR 75MINS AT	9·5MTR..
Pump time required: (D/C = E mins) (if pump at approx. 66l/min refer to look-up table)					3LTS/MIN.	NOT PURGED.
Actual Time pump on (mins) (F)	3 MINS		3 MINS	29 MINS		
Did borehole pump dry? (Y/N)	YES.		YES.	NO		
Actual purge volume (litres): (C x F = G litres)	90 LTS.		90 LTS.	860 LTS.	225	
No. of well volumes purged:	NOT ENOUGH!		NOT ENOUGH.	3		
Purged Leachate discharged to Borehole no:	23A		30	39.	TO GROUND SURFACE	

Please Complete (at least the non-shaded sections) And Return To:
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BREAK TO WET WEATHER AFTER PROLONGED DRY SPELL

WRc

Brogborough Leachate Sampling - Protocol 1
Well Purging prior to sampling

Date : 6-11-97
Completed by: S WHEELER

Borehole No. C	Cell 1 41°C	Cell 2 —	Cell 3 38·0°C	Cell 4 43·2°C	Cell 5 39·2°C	Cell 6
Depth of borehole/m below top of casing (A) (measured - 24 Jan 94)	19.30	16.80	19.32	17.80	18.15	18.50
Depth TO leachate/m below top of casing (B)	7·33.	NO	5·06.	6·29	6·16	NOT PURGED.
Depth of leachate/m: 'd = A - B)	PUMP AT	'C' WELL		PUMP AT	PUMP DOWN	
PURGING: Pump Flow rate (l/min) C). If approx. 66l/min consult look-up ab	9·9 MTS.	DUG		8·50	WITH SMALL	
u. olume required for 3 well olumes: (d x 200 = D litres). NB. No eed to calculate if using look-up table		TO MOUCHEL			ELECTRIC PUMP.	
ump time required: (D/C = E mins) (if ump at approx. 66l/min refer to look-up able)		BIO REACTOR				
ctual Time pump on (mins) (F)	N/A.	TRIAL.	3½MIN.	29. MIN	3 HRS	
id borehole pump dry? (Y/N)	NO		YES.	NO		
ctual purge volume (litres): C x F = G litres)	75 LTS.		105 LTS	860 LTS.	540 LTS	
o. of well volumes purged:	TO ACA		NOT 3.	3		
urged Leachate discharged to orehole no:	AS SAMPLE.			39.	TO SITE	

16SE/LT!
4LT/MIN
9·46
3HRS.
1HR 6·80 TO 12·46

ease Complete (at least the non-shaded sections) And Return To:
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rlow,
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APPENDIX C

ANALYTICAL RESULTS

Appendix Table C1 Brogborough leachate analyses

Date	pH	filter size	Digest (D) or or not (U) for metals	Cond	Temp	Na	Mg	K	Ca	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb	BOD	COD	TOC	TVA	Alkal $CaCO_3$	Cl	SO_4	NH_3 As N	NO_3 As N	NO_2 As N	SRP As P
				mS/cm	°C	<------									Concentration =		mg/l											------>
Cell No. 1 (control thin layers)																												
25/01/94	6.2	-	-	33.2	22.3	2400	576	2250	3640	<=0.1	52.30	1970	1.5	<=0.04	68.30	0.05	<=0.5	68600	91400	30200	24931	16300	3210	1790	2610	<=0.50	<=0.50	0.8
08/02/94	6.0	-	-	31.9	23.0	2430	578	2310	3400	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	63700	112728	29900	#N/A	17100	3170	1890	2600	0.3	0.4	#N/A
08/03/94	5.9	-	-	17.5	24.8	2140	508	2020	2910	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	71900	91900	30600	#N/A	17500	3340	1950	2810	<=0.10	0.4	#N/A
06/04/94	6.1	-	-	15.5	28.0	2460	576	2370	3420	<=0.1	#N/A	#N/A	1.4	<=0.04	54.70	0.05	<=0.5	70500	104900	32300	23241	16900	3230	1840	2510	<=0.10	<=0.10	<0.01
04/05/94	6.0	-	-	34.6	21.5	2450	587	2380	3630	<=0.1	52.80	1580	1.3	<=0.04	53.50	<=0.04	<=0.5	72300	96000	33100	22954	17600	3200	1710	2900	0.14	0.32	1.44
04/10/94	#N/A	UF	D	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01/03/95	7.3	UF	D	15.3	21.2	1360	123	1170	114	0.07	0.28	25.4	0.30	<=0.02	2.69	<=0.02	<=0.3	6540	10800	3400	#N/A	8500	1920	141	1650	<=0.10	0.220	1.01
01/03/95	#N/A	1.2μm	D	#N/A	#N/A	1490	132	1260	115	0.06	0.20	15.9	0.28	<=0.02	2.09	<=0.02	<=0.3	#N/A	11300	#N/A	2158	10600	1930	142	1650	0.14	0.119	2.21
01/03/95	#N/A	1.2μm	U	#N/A	#N/A	1490	132	1260	114	<=0.05	0.20	15.5	0.21	<=0.02	2.05	<=0.02	<=0.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01/03/95	#N/A	0.45μm	D	#N/A	#N/A	1470	133	1260	114	0.06	0.20	11.4	0.27	<=0.02	0.07	<=0.02	<=0.3	#N/A	#N/A	#N/A	2104	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01/03/95	#N/A	0.45μm	U	#N/A	#N/A	1500	136	1290	116	0.06	0.20	11.4	0.29	<=0.02	0.04	<=0.02	<=0.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
06/07/95	7.5	-	D	#N/A	31.2	2210	158	1880	91	<=0.1	0.33	7.0	0.40	<=0.04	0.79	<=0.04	<=0.5	6940	12000	4000	#N/A	9810	2580	136	2140	<=0.10	<=0.10	0.32
08/11/95	7.7	1.2μm	D	>20	30.5	2230	107	2010	52	<=0.1	0.15	12.8	0.40	<=0.04	3.22	<=0.04	<=0.5	4200	8630	2620	1213	11200	2760	70	2420	0.24	<=0.10	0.97
29/02/96	7.6	UF	D	20	27.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	7670	#N/A	4510	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
29/02/96	#N/A	1.2μm	D	#N/A	#N/A	2230	133	2000	67	<=0.1	0.17	13.5	0.40	<=0.04	5.29	<=0.04	<=0.5	#N/A	13300	#N/A	2576	13000	2790	170	2580	<=0.10	0.17	1.36
29/02/96	#N/A	0.45μm	D	#N/A	#N/A	2140	128	1930	65	<=0.1	0.15	7.0	0.40	<=0.04	0.16	<=0.04	<=0.5	#N/A	12300	#N/A	2426	12200	2830	170	2540	<=0.10	0.12	1.10
25/04/96	7.8	1.2μm	D	24.8	29.5	2153	98.6	1873	50.8	0.17	0.13	13.6	0.35	<=0.04	4.02	<=0.04	<=0.5	3590	9698	2830	1320	12280	2780	110	2461	<=0.10	0.13	2.38
20/06/96	7.9	1.2μm	D	#N/A	33.4	2470	95.1	2170	45.0	<=0.1	0.10	15.9	0.4	<=0.01	6.30	<=0.04	<=0.5	2810	7965	2166	923	13330	3040	49	2411	<=0.10	0.20	2.59
20/06/96	7.9	0.45μm	D	#N/A	33.4	2310	89.9	2030	45.0	0.20	0.11	13.0	0.5	<=0.01	2.45	<=0.04	<=0.5	#N/A	#N/A	#N/A	903	12300	2990	42	2416	<=0.10	<=0.1	2.46
11/12/96	7.9	0.45μm	U	24.6	36.6	1770	64.9	1500	33.9	0.15	0.10	9.41	0.34	<=0.004	2.88	<=0.004	<=0.05	1550	5505	1645	162	11950	2800	31	2223	<=1.0	<=1.0	7.02
11/12/96	7.9	0.45μm	D/UP	24.6	36.6	2350	80.3	2000	61.2	0.24	0.37	42.6	0.57	0.035	24.30	0.014	0.09	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
06/02/97	8.1	0.45μm	U	24.6	31.2	2000	71.1	1650	34.6	0.21	0.09	8.86	0.40	0.024	3.69	#N/A	#N/A	#N/A	6090	1440	#N/A	11650	2840	<=30	2369	<=0.1	0.26	4.71
06/02/97		0.45μm	settle/D			2320	80.8	1910	39.4	0.22	0.10	9.96	0.43	<=0.004	4.19	#N/A	#N/A	#N/A			#N/A							
06/02/97		0.45μm	D			2360	82.1	1950	39.7	0.24	0.10	10.0	0.44	<=0.004	4.25	#N/A	#N/A	#N/A			#N/A							
10/07/97	7.7	0.45μm	D	23.9	37.1	2020	88.1	1670	44.0	0.30	0.13	11.7	0.40	#N/A	4.32	<=0.04	#N/A	698	4442	1416	80	11660	2820	<=30	2193	<=0.2	<=0.2	7.50
23/09/97	7.7	0.45μm	U	27.5	34.4	2150	78.9	1780	40.0	<=0.1	0.07	10.6	0.20	<=0.04	3.58	<=0.04	<=0.5	547	4830	1430	71	12000	3200	<=30	2470	<=0.1	0.21	9.10
07/11/97	7.8	0.45μm	U	26.4	32.0	2110	75.7	1720	42.0	0.20	0.11	12.1	0.44	<=0.01	3.45	<=0.004	<=0.05	593	5619	1523	56	11900	3340	<30	2185	0.31	<0.10	6.40

Appendix Table C1 continued Brogborough leachate analyses

Date	pH	filter size	Digest (D) or or not (U) for metals	Cond	Temp	Na	Mg	K	Ca	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb	BOD	COD	TOC	TVA	Alkal CaCO$_3$	Cl	SO$_4$	NH$_3$ As N	NO$_3$ As N	NO$_2$ As N	SRP As P
				mS/cm	°C <-----										Concentration =		mg/l ----->											
Cell No. 2 (Low Density)																												
25/01/94	7.4	-	-	16.3	23.4	1700	201	1280	282	<=0.1	0.68	59.1	0.3	<=0.04	2.42	<=0.04	<=0.5	8720	12000	4170	2884	10200	2170	230	1270	<=0.50	<=0.50	0.46
08/02/94	7.2	-	-	21.4	24.4	1960	231	1480	231	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	8530	14500	4610	#N/A	7840	2540	170	1680	<=0.10	<=0.10	#N/A
08/03/94	7.1	-	-	18.3	27.3	1800	204	1350	147	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	8630	12900	4340	#N/A	8390	3150	220	1570	0.2	<=0.10	#N/A
06/04/94	7.5	-	-	17.0	27.0	2140	240	1620	142	<=0.1	#N/A	#N/A	0.3	<=0.04	2.51	<=0.04	<=0.5	8890	13300	4390	2756	9190	2870	230	1620	<=0.10	<=0.10	0.44
04/05/94	7.3	-	-	26.6	25.0	2230	257	1700	133	<=0.1	0.23	22.3	0.4	<=0.04	2.25	<=0.04	<=0.5	9530	14300	4930	2486	9680	2910	230	1770	<=0.10	<=0.10	0.44
04/10/94	7.4	UF a	D	18.4	20.6	1980	208	1440	182	<=0.1	0.26	25.8	0.3	<=0.04	1.87	<=0.04	<=0.5	10500	18000	5280	#N/A	5690	3410	270	1750	0.067	0.137	0.62
04/10/94	#N/A	UF b	D	#N/A	#N/A	2070	218	1510	186	<=0.1	0.25	28	0.3	<=0.04	1.98	<=0.04	<=0.5	10500	16300	5380	#N/A	5600	2790	250	1800	0.060	0.133	0.58
04/10/94	7.6	1.2µm a	D	14.4	18.3	2080	217	1520	187	<=0.1	0.23	26.1	0.3	<=0.04	1.97	<=0.04	<=0.5	#N/A	#N/A	#N/A	3850	#N/A	2810	300	1760	0.260	0.110	#N/A
04/10/94	#N/A	1.2µm b	D	#N/A	#N/A	2140	224	1570	193	<=0.1	0.26	28.7	0.3	<=0.04	2.02	<=0.04	<=0.5	#N/A	#N/A	#N/A	3647	#N/A	2790	260	1750	0.437	0.134	#N/A
04/10/94	#N/A	1.2µm c	D	#N/A	#N/A	2070	216	1510	185	<=0.1	0.23	25.1	0.3	<=0.04	1.90	<=0.04	<=0.5	#N/A	#N/A	#N/A	#N/A	#N/A	2820	310	#N/A	#N/A	#N/A	#N/A
04/10/94	#N/A	1.2µm a	U	#N/A	#N/A	2120	218	1560	188	<=0.1	0.22	18.9	0.2	<=0.04	1.80	<=0.04	<=0.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04/10/94	#N/A	1.2µm b	U	#N/A	#N/A	2120	222	1560	189	<=0.1	0.25	26.7	0.3	<=0.04	1.54	<=0.04	<=0.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04/10/94	#N/A	1.2µm c	U	#N/A	#N/A	2120	220	1560	190	<=0.1	0.22	19.9	0.3	<=0.04	1.74	<=0.04	<=0.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04/10/94	#N/A	0.45µm	D	#N/A	#N/A	2050	212	1490	177	<=0.1	0.16	13.6	0.2	0.06	0.74	<=0.04	<=0.5	#N/A	#N/A	#N/A	3878	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04/10/94	#N/A	0.45µm	U	#N/A	#N/A	2180	224	1590	188	<=0.1	0.16	15.0	0.2	<=0.04	0.62	<=0.04	<=0.5	#N/A	#N/A	#N/A	3656	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01/03/95	7.3	UF	D	15.9	21.4	1660	162	1270	99.5	<=0.05	0.10	9.80	0.19	<=0.02	1.27	<=0.02	<=0.3	2730	6140	1900	#N/A	9480	2260	42.0	1450	<=0.10	0.14	3.15
01/03/95	#N/A	1.2µm	D	#N/A	#N/A	1580	155	1210	91.0	<=0.05	0.08	8.30	0.17	<=0.02	0.64	<=0.02	<=0.3	#N/A	5410	#N/A	1041	11300	2240	41.0	1480	<=0.10	0.15	3.04
01/03/95	#N/A	1.2µm	U	#N/A	#N/A	1660	164	1270	95.3	<=0.05	0.07	8.20	0.12	<=0.02	0.62	<=0.02	<=0.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01/03/95	#N/A	0.45µm	D	#N/A	#N/A	1630	161	1250	94.4	<=0.05	0.08	5.24	0.15	<=0.02	0.09	<=0.02	<=0.3	#N/A	#N/A	#N/A	981	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01/03/95	#N/A	0.45µm	U	#N/A	#N/A	1680	164	1290	97.1	<=0.05	0.07	4.69	0.14	<=0.02	0.08	<=0.02	<=0.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
06/07/95	7.4	0.45µm	D	#N/A	29.4	2150	199	1600	126	<=0.1	0.11	3.85	0.20	<=0.04	0.30	<=0.04	<=0.5	3660	7480	2260	#N/A	9000	2560	97.0	1740	<=0.10	<=0.10	1.2
08/11/95	7.5	1.2µm	D	19	27.3	2180	198	1670	114.0	0.2	0.09	12.30	0.30	<=0.04	0.74	<=0.04	<=0.5	5200	9260	3090	1559	9160	2800	114.0	1940	0.18	<=0.10	2.07
29/02/96	7.4	UF	D	>20	24.1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	1870	#N/A	1590	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
29/02/96	#N/A	1.2µm	D	#N/A	#N/A	1770	153	1310	75.0	<=0.1	0.06	2.83	<=0.1	<=0.04	0.58	<=0.04	<=0.5	#N/A	4980	#N/A	606	8230	2450	35.0	1470	<=0.10	<=0.10	5.84
29/02/96	#N/A	0.45µm	D	#N/A	#N/A	1740	153	1290	75.0	<=0.1	0.07	3.29	0.20	<=0.04	0.07	<=0.04	<=0.5	#N/A	3500	#N/A	#N/A	6880	2020	19.0	1350	<=0.10	<=0.10	0.62
25/04/96	7.6	1.2µm	D	21.4	31.1	2241	186	1626	111.0	0.13	0.09	12.40	0.14	<=0.04	0.81	<=0.04	<=0.5	3750	8723	2638	1581	9804	2820	94.0	1854	<=0.10	<=0.10	5.10
20/06/96	7.4	1.2µm	D	#N/A	29.8	2320	183	1690	97.0	0.2	0.11	10.9	0.3	<=0.01	0.97	<=0.04	<=0.5	4110	9221	2748	1552	10270	3150	80.0	1891	<=0.10	0.13	1.70
20/06/96	7.4	1.2µm DUP	D	#N/A	29.8	2360	185	1720	98.0	<=0.1	0.08	10.8	0.2	<=0.01	0.87	<=0.04	<=0.5	#N/A	#N/A	#N/A	1444	10730	3105	87.0	1871	0.14	<=0.10	0.54
20/06/96	7.4	0.45µm	D	#N/A	29.8	2340	185	1720	97.0	0.2	0.11	10.9	0.3	<=0.01	0.37	<=0.04	<=0.5	#N/A	#N/A	#N/A	1492	10130	3130	79.0	1934	<=0.10	<=0.10	4.82
11/12/96	7.6	0.45µm	U	19.35	36.5	1660	102	1130	25.0	0.05	0.018	6.42	0.16	<=0.004	0.102	<=0.004	<=0.05	249	2564	766	4	7971	2410	<=30	1588	<=1.0	<=1.0	6.48
11/12/96	7.6	0.45µm	D/UP	19.35	36.5	1920	111	1310	28.6	0.13	0.057	10.4	0.26	0.023	0.507	0.006	<=0.05	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
06/02/97	7.9	0.45µm	U	19.1	31.7	1740	100	1150	26.6	0.11	0.026	6.04	0.22	<=0.004	0.074	#N/A	#N/A	#N/A	3650	744	#N/A	7920	2520	<=30	1604	<=0.1	<=0.1	5.92
06/02/97		0.45µm	settle/D			1940	111	1280	29.5	0.11	0.028	6.71	0.23	<=0.004	0.097	#N/A	#N/A	#N/A			#N/A							
06/02/97		0.45µm	D			1930	111	1280	29.2	0.13	0.030	6.66	0.25	<=0.004	0.104	#N/A	#N/A	#N/A			#N/A							

Cell 2 borehole infilled Summer 97

Appendix Table C1 continued Brogborough leachate analyses

Date	pH	filter size	Digest (D) or or not (U) for metals	Cond	Temp	Na	Mg	K	Ca	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb	BOD	COD	TOC	TVA	Alkal CaCO$_3$	Cl	SO$_4$	NH$_3$ As N	NO$_3$ As N	NO$_2$ As N	SRP As P
				mS/cm	°C <------										Concentration =		mg/l ------											------>
Cell No. 3 (Recirculation)				08/03/94 Addition of 44,000 gallons of water has taken place																								
25/01/94	7.1	-	-	16.7	22.6	1390	292	1160	1030	<=0.1	5.79	299	0.4	<=0.04	5.07	<=0.04	<=0.5	18500	23900	8240	7726	7970	1530	460	1190	<=0.50	<=0.50	<0.01
08/02/94	7.0	-	-	17.9	24.0	1460	279	1240	565	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	12600	20100	6510	#N/A	8680	1660	320	1650	0.3	<=0.10	#N/A
08/03/94	6.2			10.6	14.3	703	171	615	1030	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	14500	18900	6500	#N/A	5210	900	770	630	<=0.10	<=0.10	#N/A
06/04/94	7.2	-	-	9.2	19.0	959	204	833	531	<=0.1	#N/A	#N/A	0.3	0.06	5.92	<=0.04	<=0.5	6380	7490	2870	2158	5960	1020	65	785	0.17	<=0.10	<0.01
04/05/94	7.1	-	-	11.7	22.6	946	184	813	262	<=0.1	0.69	42.9	0.3	<=0.04	2.70	<=0.04	<=0.5	4100	7410	1710	861	6090	1020	68	849	0.17	<=0.10	0.34
04/10/94	7.5	UF a	D	13.8	22.2	1210	139	1010	109	<=0.1	0.24	19.0	0.3	<=0.04	1.90	<=0.04	<=0.5	926	2510	950	#N/A	6580	1270	<=10	1110	<=0.05	0.120	0.34
04/10/94	#N/A	UF b	D	#N/A	#N/A	1230	143	1040	109	<=0.1	0.22	17.0	0.3	<=0.04	1.74	<=0.04	<=0.5	896	3550	1000	#N/A	6950	1360	22	1190	<=0.05	0.112	1.06
04/10/94	7.6	1.2µm a	D	14.1	17.4	1170	134	987	103	<=0.1	0.19	11.1	0.2	<=0.04	1.15	<=0.04	<=0.5	#N/A	#N/A	#N/A	225	#N/A	1380	33	1080	<=0.05	0.104	#N/A
04/10/94	#N/A	1.2µm b	D	#N/A	#N/A	1180	136	995	103	<=0.1	0.19	11.4	0.2	<=0.04	1.10	<=0.04	<=0.5	#N/A	#N/A	#N/A	214	#N/A	1410	25	1130	0.095	0.107	#N/A
04/10/94	#N/A	1.2µm a	U	#N/A	#N/A	1250	143	1060	108	<=0.1	0.17	11.4	0.2	<=0.04	1.02	<=0.04	<=0.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04/10/94	#N/A	1.2µm b	U	#N/A	#N/A	1250	143	1060	108	<=0.1	0.19	10.7	0.3	<=0.04	0.94	<=0.04	<=0.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01/03/95	7.0	UF	D	7.3	16.7	738	122	557	269	<=0.05	1.26	58.1	0.21	<=0.02	3.16	<=0.02	<=0.3	398	2320	567	#N/A	5850	1010	<=10	704	<=0.10	0.110	2.20
01/03/95	#N/A	1.2µm	D	#N/A	#N/A	647	118	463	268	<=0.05	0.81	2.26	0.11	<=0.02	0.19	<=0.02	<=0.3	#N/A	1550	#N/A	77	6350	701	53.0	689	<=0.10	0.120	1.75
01/03/95	#N/A	1.2µm	U	#N/A	#N/A	685	123	490	282	<=0.05	0.84	2.13	<=0.05	<=0.02	0.15	<=0.02	<=0.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01/03/95	#N/A	0.45µm	D	#N/A	#N/A	645	118	462	269	<=0.05	0.82	1.54	0.10	<=0.02	0.10	<=0.02	<=0.3	#N/A	#N/A	#N/A	75	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01/03/95	#N/A	0.45µm	U	#N/A	#N/A	689	125	494	287	<=0.05	0.87	1.55	0.08	<=0.02	0.08	<=0.02	<=0.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
06/07/95	7.6	0.45µm	D	#N/A	33.1	1800	150	1530	129	<=0.1	0.51	3.08	0.40	<=0.04	0.29	<=0.04	<=0.5	360	3130	972	#N/A	9800	2000	<=10	1740	<=0.10	<=0.10	3.2
08/11/95	7.6	1.2µm	D	17	29.4	1620	115	1400	77	0.2	0.28	5.37	0.30	<=0.04	0.23	<=0.04	<=0.5	222	3160	984	24	8710	1980	<=10	1680	0.18	<=0.10	4.0
29/02/96	7.5	UF	D	>20	31.1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	137	#N/A	872	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
29/02/96	#N/A	1.2µm	D	#N/A	#N/A	1430	103	1190	51	<=0.1	0.11	2.33	<=0.1	<=0.04	0.03	<=0.04	<=0.5	#N/A	3040	#N/A	9	7830	1920	<=10	1470	<=0.10	<=0.10	7.2
29/02/96	#N/A	0.45µm	D	#N/A	#N/A	1480	107	1230	53	<=0.1	0.13	1.80	0.20	<=0.04	0.05	<=0.04	<=0.5	#N/A	2740	#N/A	10	7990	1930	<=10	1410	<=0.10	<=0.10	7.1
25/04/96	7.7	1.2µm	D	17.5	27.8	1580	101	1257	51.3	0.24	0.11	3.85	0.17	<=0.04	0.28	<=0.04	<=0.5	118	3236	933	23	8440	1930	<=10	1504	<=0.10	0.11	8.7
20/06/96	7.5	1.2µm	D	#N/A	32.7	1720	104	1370	52	0.4	0.13	4.30	0.4	<=0.01	0.39	<=0.04	<=0.5	107	2732	930	16	8468	1960	<=10	1416	2.92	<=0.1	8.9
20/06/96	7.5	0.45µm	D	#N/A	32.7	1640	98.1	1300	48	0.2	0.09	4.27	0.2	<=0.01	0.14	<=0.04	<=0.5	#N/A	#N/A	#N/A	10	8545	1980	<=10	1406	<=0.10	<=0.1	8.9
11/12/96	7.6	0.45µm	U	18.47	38.7	1550	88.9	1190	38.1	0.27	0.082	6.46	0.31	<=0.004	0.066	<=0.004	<=0.05	101	3537	944	5	8267	1910	<=30	1600	<=1.0	<=1.0	11.6
11/12/96	7.6	0.45µm	D/UP	18.47	38.7	1730	93.2	1330	43.5	0.37	0.112	9.34	0.38	0.220	0.332	0.005	<=0.05	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
06/02/97	7.7	0.45µm	U	17.9	30.2	1510	81.5	1130	37.2	0.31	0.085	6.10	0.33	<=0.004	0.085	#N/A	#N/A	#N/A	3560	921	#N/A	7910	1960	<=30	1553	<=0.1	<=0.1	9.49
06/02/97		0.45µm	settle/D			1630	87.3	1220	39.9	0.33	0.089	6.56	0.34	0.011	0.107	#N/A	#N/A	#N/A			#N/A							
06/02/97		0.45µm	D			1630	87.8	1220	39.8	0.36	0.091	6.54	0.36	0.011	0.108	#N/A	#N/A	#N/A			#N/A							
10/07/97	7.5	0.45µm	D	17.6	34.5	1520	95.2	1140	38.0	0.30	0.07	7.12	0.30	#N/A	0.13	<=0.04	#N/A	134	2673	866	6	8324	1900	<=30	1537	<=0.2	<=0.2	8.4
23/09/97	7.6	0.45µm	U	17.5	32.8	1430	83.3	1070	34.0	<=0.1	<=0.02	6.2	<=0.1	<=0.04	<=0.04	<=0.04	<=0.5	104	2670	826	6	7870	1930	<=30	1600	<=0.1	0.26	5.13
07/11/97	7.7	0.45µm	U	16.7	28.4	1360	80.6	1020	35.0	<=0.1	0.07	6.7	0.32	<=0.01	0.05	<=0.004	<=0.05	119	2977	792	3	8073	1980	<30	1475	<0.1	<0.1	8.25

Appendix Table C1 continued Brogborough leachate analyses

Date	pH	filter size	Digest (D) or or not (U) for metals	Cond	Temp	Na	Mg	K	Ca	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb	BOD	COD	TOC	TVA	Alkal $CaCO_3$	Cl	SO_4	NH_3 As N	NO_3 As N	NO_2 As N	SRP As P
				mS/cm	°C <------									-------Concentration =			mg/l-------											------->
Cell No. 4 (Gas Collection)																												
25/01/94	7.8	-	-	23.8	24.3	2200	208	1950	272	<=0.1	3.70	185	0.3	<=0.04	10.40	<=0.04	<=0.5	4860	9410	2620	1418	10200	2780	180	1820	<=0.50	<=0.50	0.26
08/02/94	7.7	-	-	26.5	24.4	2070	173	1880	147	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	3210	6930	2370	#N/A	11400	2920	105	2330	0.2	<=0.10	#N/A
08/03/94	7.4	-	-	23.6	25.1	1970	163	1760	152	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	3360	7630	1930	#N/A	11100	2910	86	1830	<=0.10	<=0.10	#N/A
06/04/94	7.8	-	-	20.9	29.0	2360	177	2170	166	<=0.1	#N/A	#N/A	0.4	<=0.04	14.6	<=0.04	<=0.5	1850	5270	1410	469	11500	2940	<=10	2010	<=0.10	<=0.10	0.06
04/05/94	7.6	-	-	31.8	30.1	2370	147	2260	144	<=0.1	2.36	275	0.5	<=0.04	20.0	<=0.04	<=0.5	1740	4480	1390	194	13600	3060	<=10	2040	<=0.10	<=0.10	0.9
04/10/94	7.8	UF a	D	>20	27.4	2220	124	2020	108	<=0.1	1.64	226	0.3	<=0.04	13.7	<=0.04	<=0.5	1330	4700	1310	#N/A	13700	2920	<=10	2330	0.078	0.123	0.74
04/10/94	#N/A	UF b	D	#N/A	#N/A	2250	126	2050	110	<=0.1	1.68	230	0.4	<=0.04	13.9	0.18	<=0.5	#N/A	#N/A	#N/A	#N/A	5230	2940	<=10	2370	<=0.05	0.190	1.00
04/10/94	8.0	1.2µm a	D	>20	24.2	2120	110	1920	35	<=0.1	0.12	3.81	0.2	<=0.04	0.50	<=0.04	<=0.5	#N/A	#N/A	#N/A	278	#N/A	3020	<=10	2320	<=0.05	0.178	#N/A
04/10/94	#N/A	1.2µm b	D	#N/A	#N/A	2130	110	1920	34	<=0.1	0.11	3.88	<=0.1	<=0.04	0.49	<=0.04	<=0.5	#N/A	#N/A	#N/A	240	#N/A	3080	11	2310	<=0.05	0.067	#N/A
04/10/94	#N/A	1.2µm c	D	#N/A	#N/A	1990	105	1800	33	<=0.1	0.11	5.12	<=0.1	<=0.04	0.75	<=0.04	<=0.5	#N/A	#N/A	#N/A	#N/A	#N/A	3010	22	#N/A	#N/A	#N/A	#N/A
04/10/94	#N/A	1.2µm a	U	#N/A	#N/A	2220	117	2000	34	<=0.1	0.10	3.43	<=0.1	<=0.04	0.50	<=0.04	<=0.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04/10/94	#N/A	1.2µm b	U	#N/A	#N/A	2240	119	2020	35	<=0.1	0.10	3.61	<=0.1	<=0.04	0.51	<=0.04	<=0.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04/10/94	#N/A	1.2µm c	U	#N/A	#N/A	2260	119	2060	37	<=0.1	0.13	5.56	0.20	<=0.04	0.83	<=0.04	<=0.5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04/10/94	#N/A	0.45µm	D	#N/A	#N/A	2140	112	1940	33	<=0.1	0.12	5.54	<=0.1	<=0.04	0.27	<=0.04	<=0.5	#N/A	#N/A	#N/A	224	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04/10/94	#N/A	0.45µm	U	#N/A	#N/A	2270	121	2050	35	<=0.1	0.12	5.66	0.20	<=0.04	0.31	<=0.04	<=0.5	#N/A	#N/A	#N/A	248	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01/03/95	7.5	UF	D	17.2	25.3	1830	154	1560	70.1	0.13	0.43	45.3	0.24	<=0.02	2.61	<=0.02	<=0.3	525	2730	830	#N/A	8740	2590	22.0	1310	<=0.10	<=0.10	1.39
01/03/95	#N/A	1.2µm	D	#N/A	#N/A	1790	148	1520	49.3	0.12	0.10	2.52	0.18	<=0.02	0.16	<=0.02	<=0.3	#N/A	3080	#N/A	174	8910	2510	20.0	1300	<=0.10	<=0.10	1.91
01/03/95	#N/A	1.2µm	U	#N/A	#N/A	1860	152	1570	50.2	<=0.05	0.08	2.39	<=0.05	<=0.02	0.14	<=0.02	<=0.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01/03/95	#N/A	0.45µm G	D	#N/A	#N/A	1880	156	1590	51.6	0.14	0.10	2.80	0.16	<=0.02	0.08	<=0.02	<=0.3	#N/A	#N/A	#N/A	176	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01/03/95	#N/A	0.45µm W	D	#N/A	#N/A	1810	149	1530	50.2	0.08	0.11	4.37	0.11	<=0.02	0.09	<=0.02	<=0.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01/03/95	#N/A	0.45µm G	U	#N/A	#N/A	1870	153	1580	50.7	0.08	0.09	2.55	0.11	<=0.02	0.05	<=0.02	<=0.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01/03/95	#N/A	0.45µm W	U	#N/A	#N/A	1870	154	1580	51.3	<=0.05	0.09	1.95	0.09	<=0.02	<=0.02	<=0.02	<=0.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
06/07/95	7.8	0.45µm W	D	#N/A	33.1	2200	165	1810	49	<=0.1	0.08	1.15	0.20	<=0.04	0.32	<=0.04	<=0.5	268	2480	734	#N/A	9560	2670	<=10	1540	<=0.10	<=0.10	1.25
08/11/95	7.6	1.2µm	D	19	33.6	2000	148	1730	37	<=0.1	0.05	2.40	<=0.1	<=0.04	0.20	<=0.04	<=0.5	158	2750	739	20	8520	2710	<=10	1480	0.12	<=0.10	1.53
29/02/96	7.4	UF	D	>20	34.9	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	188	#N/A	735	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
29/02/96	#N/A	1.2µm	D	#N/A	#N/A	1780	146	1540	45	0.2	0.08	2.55	0.20	<=0.04	0.33	<=0.04	<=0.5	#N/A	2580	#N/A	23	8440	2520	<=10	1300	<=0.10	<=0.10	1.84
29/02/96	#N/A	0.45µm	D	#N/A	#N/A	1810	147	1570	43	<=0.1	0.07	2.82	<=0.1	<=0.04	<=0.04	<=0.04	<=0.5	#N/A	2480	#N/A	31	8950	2560	<=10	1330	<=0.10	<=0.10	2.28
25/04/96	7.6	1.2µm	D	18.6	34.8	1913	142	1608	48	<=0.1	0.05	3.40	<=0.1	<=0.04	0.13	<=0.04	<=0.5	216	2719	788	56	8069	2450	<=10	1395	<=0.10	<=0.10	2.13
20/06/96	7.5	1.2µm	D	#N/A	35.5	2030	145	1710	43	0.20	0.06	3.53	0.20	<=0.01	0.14	<=0.04	<=0.5	194	2221	723	42	8484	2630	<=10	1281	<=0.10	<=0.10	1.97
20/06/96	7.5	0.45µm	D	#N/A	35.5	1870	133	1570	40	<=0.1	0.05	3.89	<=0.1	<=0.01	0.07	<=0.04	<=0.5	#N/A	#N/A	#N/A	46	8207	2620	<=10	1399	<=0.10	<=0.10	1.91
11/12/96	7.7	0.45µm A	U/P	19.40	42.0	1660	112	1370	23.9	0.11	0.023	3.37	0.14	<=0.004	0.016	<=0.004	<=0.05	146	2342	780	7	8441	2640	<=30	1518	<=1.0	<=1.0	3.33
11/12/96	7.7	0.45µm B	U/P	18.80	42.0	1760	117	1450	25.0	0.12	0.019	3.49	0.15	<=0.004	0.009	<=0.004	<=0.05	144	2762	782	16	8438	2640	<=30	1528	<=1.0	<=1.0	3.36
11/12/96	7.7	0.45µm A	D/UP	19.40	42.0	2130	135	1770	61.7	0.21	0.516	22.2	0.25	0.020	1.00	<=0.004	<=0.05	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	<=1.0	<=1.0	
11/12/96	7.7	0.45µm B	D/UP	18.80	42.0	2170	136	1800	49.2	0.21	0.319	17.4	0.25	0.018	0.840	<=0.004	<=0.05	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	<=1.0	<=1.0	
06/02/97	8.0	0.45µm	U	19.5	31.0	1910	124	1540	30.6	0.17	0.039	2.81	0.21	0.028	0.035			#N/A	2710	755	#N/A	8200	2730	<=30	1548	0.14	<=0.1	2.63
06/02/97		0.45µm	settle/D			2050	131	1640	32.5	0.18	0.040	2.95	0.21	<=0.004	0.046			#N/A			#N/A							
06/02/97		0.45µm	D			2070	133	1670	32.4	0.18	0.039	2.99	0.21	<=0.004	0.046			#N/A			#N/A							
10/07/97	7.5	0.45µm	D	18.1	38.0	1670	143	1360	47.0	<=0.1	0.05	2.67	<=0.1	#N/A	<=0.04	<=0.04	#N/A	111	1867	614	10	8239	2480	<=30	1334	<=0.2	<=0.2	1.7
23/09/97	7.6	0.45µm	U	18.1	37.1	1610	117	1320	34.0	<=0.1	<=0.02	2.82	<=0.1	<=0.04	<=0.04	<=0.04	<=0.5	104	2060	644	10	7420	2560	<=30	1550	<=0.1	0.18	1.95
07/11/97	7.7	0.45µm	U	18.9	35.9	1560	114	1280	35.0	<=0.1	0.04	3.20	0.20	<=0.01	0.024	<=0.004	<=0.05	110	2572	680	10	8129	2660	<30	1350	<0.1	<0.1	2.78

Appendix Table C1 continued Brogborough leachate analyses

Date	pH	filter size	Digest (D) or or not (U) for metals	Cond	Temp	Na	Mg	K	Ca	Cr	Mn	Fe	Ni	Cu	Zn	Cd	Pb	BOD	COD	TOC	TVA	Alkal $CaCO_3$	Cl	SO_4	NH_3 As N	NO_3 As N	NO_2 As N	SRP As P
				mS/cm	°C	<------									Concentration =		mg/l											------>
Cell No. 6 (Industrial Waste)																												
25.01/94	7.6	.	.	15.7	25.3	1370	105	912	81	<=0.1	0.13	9.63	0.2	<=0.04	0.52	<=0.04	<=0.5	202	2300	747	35	8060	1680	5.5	1040	<=0.50	<=0.50	3.8
08.02/94	7.3	.	.	15.3	29.1	1390	108	944	84	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	167	2430	837	#N/A	6930	1700	35	940	0.2	<=0.10	#N/A
08.03/94	7.2	.	.	12.8	30.5	1230	94	798	71	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	136	2390	710	#N/A	6150	1600	125	1010	<=0.10	<=0.10	#N/A
06.04/94	7.5	.	.	11.9	29.2	1380	108	889	78	<=0.1	0.20	#N/A	#N/A	<=0.04	1.05	<=0.04	<=0.5	93	1950	622	5	6390	1540	<=10	1010	<=0.10	<=0.10	3.1
04.05/94	7.3	.	.	15.1	29.9	1380	106	913	77	<=0.1	0.11	3.98	0.2	<=0.04	0.48	<=0.04	<=0.5	167	2420	772	10	6550	1640	10.5	1030	0.27	<=0.10	4.3
04/10/94	7.5	UF a	D	15.3	25.0	1230	90	800	59	0.20	0.11	6.13	0.2	<=0.04	0.22	<=0.04	<=0.5	108	2900	742	#N/A	6280	1610	<=10	1010	<=0.05	0.078	4.00
04/10/94	#N/A	UF b	D	#N/A	#N/A	1340	97	870	64	<=0.1	0.12	10.8	<=0.1	<=0.04	0.35	<=0.04	<=0.5	111	2550	764	#N/A	6390	1620	<=10	1070	<=0.05	0.056	3.85
04/10/94	#N/A	1.2µm a	D	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	10	#N/A	#N/A	#N/A	#N/A	<=0.05	#N/A	#N/A
04/10/94	#N/A	1.2µm b	D	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	<=0.05	#N/A	#N/A
04/10/94	#N/A	1.2µm a	U	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04/10/94	#N/A	1.2µm b	U	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04/10/94	#N/A	0.45µm	D	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	8	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
04/10/94	#N/A	0.45µm	U	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01/03/95	7.3	UF	D	13.6	27.6	1200	87.3	847	52.2	0.18	0.10	7.09	0.12	<=0.02	0.41	<=0.02	<=0.3	168	2240	756	#N/A	6840	1600	<=10	1000	<=0.10	<=0.10	4.34
01.03/95	#N/A	1.2µm	D	#N/A	#N/A	1170	84.6	821	50.0	0.14	0.08	4.46	0.09	<=0.02	0.17	<=0.02	<=0.3	#N/A	2610	#N/A	10	7710	1620	<=10	1050	<=0.10	<=0.10	4.26
01/03/95	#N/A	1.2µm	U	#N/A	#N/A	1220	88.9	863	52.2	0.15	0.08	4.32	0.10	<=0.02	0.16	<=0.02	<=0.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01.03/95	#N/A	0.45µm	D	#N/A	#N/A	1160	84.2	818	50.6	0.15	0.08	3.55	0.10	<=0.02	0.04	<=0.02	<=0.3	#N/A	#N/A	#N/A	8	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01.03/95	#N/A	0.45µm	U	#N/A	#N/A	1250	89.5	881	54	0.12	0.08	3.17	0.07	<=0.02	<=0.02	<=0.02	<=0.3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
06.07/95	7.4	0.45µm	D	#N/A	33.7	1570	107	1090	59	0.3	0.10	4.15	0.3	<=0.04	0.58	<=0.04	<=0.5	154	2830	918	#N/A	7380	1840	<=10	1330	<=0.10	<=0.10	4.8
08/11/95	7.6	1.2µm	D	11	28.2	1530	96	1180	49	0.3	0.05	3.15	<=0.1	<=0.04	0.23	<=0.04	<=0.5	140	3480	1170	8	6960	1860	13	1380	<=0.10	<=0.10	5.4
29.02/96	7.4	UF	D	18	32.4	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	148	#N/A	838	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
29.02/96	#N/A	1.2µm	D	#N/A	#N/A	1190	81	974	50	0.2	0.08	1.84	<=0.1	<=0.04	0.46	<=0.04	<=0.5	#N/A	2720	#N/A	8	6010	1690	140	2500	2.49	0.13	3.9
29.02/96	#N/A	0.45µm	D	#N/A	#N/A	1100	76	917	47	0.2	0.07	1.32	<=0.1	<=0.04	0.08	<=0.04	<=0.5	#N/A	2860	#N/A	8	6440	1660	140	2430	<=0.10	0.10	3.8
25.04/96	7.6	1.2µm	D	15.0	35.2	1282	82.3	1037	45.4	0.2	0.06	2.74	<=0.1	<=0.04	0.21	<=0.04	<=0.5	140	2934	907	28	6620	1730	<=10	1265	<=0.10	<=0.10	4.9
20.06/96	7.5	1.2µm	D	#N/A	34.5	1520	93.0	1280	42	0.3	0.07	3.72	<=0.1	0.02	0.45	<=0.04	<=0.5	102	3321	1036	12	7602	1960	<=10	1349	0.28	<=0.10	5.6
20.06/96	7.5	0.45µm	D	#N/A	34.5	1450	89.1	1220	39	0.4	0.08	3.77	<=0.1	<=0.01	0.21	<=0.04	<=0.5	#N/A	#N/A	#N/A	10	7478	1960	<=10	1364	0.19	<=0.10	5.7
11/12/96	7.5	0.45µm	U	15.83	29.1	1510	86.0	1010	34.2	0.23	0.155	6.59	0.18	<=0.004	0.086	<=0.004	<=0.05	103	2593	865	4	6610	1740	<=30	1312	<=1.0	<=1.0	5.73
11/12/96	7.5	0.45µm	D/UP	15.83	29.1	1420	77.3	960	33.6	0.26	0.141	8.21	0.21	0.040	0.219	0.005	<=0.05	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
06.02/97	#N/A	0.45µm	U	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Appendix Table C2 Brogborough volatile fatty acid results

Cell 1

All values expressed as mg/l C

Date	filter	Ethanoic	Propanoic	i-Butanoic	n-Butanoic	i-Pentanoic	n-Pentanoic	i-Hexanoic	n-Hexanoic	Total Volatile Acids
25/01/94		6000	2286	872	8180	823	2117	<300	4653	24931
06/04/94		6260	1947	561	7760	509	1808	26	4371	23241
04/05/94		6064	1982	595	7460	536	1855	27	4433	22952
04/10/94	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01/03/95	0.45	744	252	105	401	69	182	6	345	2104
01/03/95	1.2	736	258	106	427	71	189	4	367	2158
09/11/95	1.2	672	139	118	113	48	82	2	38	1213
29/02/96	0.45	1272	243	147	429	71	170	2	242	2576
29/02/96	1.2	1188	233	141	399	68	159	2	235	2426
25/04/96	1.2	736	157	106	134	47	84	2	55	1320
20/06/96	0.45	604	107	70	55	27	30	1	7	903
20/06/96	1.2	624	108	70	53	28	31	<2	8	923
11/12/96	0.45	99	18	14	14	4	10	<2	4	162
10/07/97	0.45	76	5	<2	<2	<2	<2	<2	<2	80
23/09/97	0.45	67	2	<2	<2	<2	2	<2	<2	71
07/11/97	0.45	53	1	<2	<2	<2	2	<2	<2	56

Cell 2

All values expressed as mg/l C

Date	filter	Ethanoic	Propanoic	i-Butanoic	n-Butanoic	i-Pentanoic	n-Pentanoic	i-Hexanoic	n-Hexanoic	Total
25/01/94		816	282	98	774	106	212	<60	596	2884
06/04/94		721	273	160	669	104	223	7	598	2756
04/05/94		569	271	131	659	90	209	6	551	2486
04/10/94	0.45 a	1176	335	115	1058	126	280	7	782	3878
04/10/94	0.45 b	1012	336	118	1020	120	273	7	769	3656
04/10/94	1.2 a	1164	348	118	1014	125	268	7	807	3850
04/10/94	1.2 b	1004	341	115	998	122	272	7	788	3647
01/03/95	0.45	432	96	53	137	38	67	3	154	981
01/03/95	1.2	464	103	54	140	39	71	3	166	1041
09/11/95	1.2	444	133	59	397	53	126	3	344	1559
29/02/96	0.45	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
29/02/96	1.2	198	54	27	135	22	44	2	125	606
25/04/96	1.2	544	139	61	356	55	115	3	308	1581
20/06/96	0.45	492	129	61	323	55	112	3	316	1492
20/06/96	1.2	504	139	65	341	57	119	3	323	1552
20/06/96	1.2 Dup	520	130	56	290	53	102	2	291	1444
11/12/96	0.45	4	<2	<2	<2	<2	<3	<2	<3	4

Cell 3

All values expressed as mg/l C

Date	filter	Ethanoic	Propanoic	i-Butanoic	n-Butanoic	i-Pentanoic	n-Pentanoic	i-Hexanoic	n-Hexanoic	Total
25/01/94		1900	754	245	2181	265	706	<150	1675	7726
06/04/94		762	764	122	146	113	172	9	71	2158
04/05/94		267	221	59	78	44	86	3	102	861
04/10/94	1.2 a	88	45	17	16	14	22	<2	22	225
04/10/94	1.2 b	84	42	17	14	14	21	<2	22	214
01/03/95	0.45	48	10	2	7	2	3	<2	3	75
01/03/95	1.2	48	10	2	8	2	4	<2	4	77
09/11/95	1.2	18	3	<2	2	<2	<2	<2	1	24
29/02/96	0.45	10	<5	<2	<2	<2	<2	<3	<2	10
29/02/96	1.2	9	<5	<2	<2	<2	<2	<3	<2	9
25/04/96	1.2	23	<2	<2	<2	<2	<2	<2	<2	23
20/06/96	0.45	10	<2	<2	<2	<2	<2	<2	<2	10
20/06/96	1.2	14	1	<2	<2	<2	<2	<2	<2	16
11/12/96	0.45	5	<2	<2	<2	<2	<3	<2	<3	5
10/07/97	0.45	6	<2	<2	<2	<2	<2	<2	<2	6
23/09/97	0.45	6	<2	<2	<2	<2	<2	<2	<2	6
07/11/97	0.45	3	<2	<2	<2	<2	<2	<2	<2	3

Appendix Table C2 continued Brogborough volatile fatty acid results

Cell 4

All values expressed as mg/l C

Date	filter	Ethanoic	Propanoic	i-Butanoic	n-Butanoic	i-Pentanoic	n-Pentanoic	i-Hexanoic	n-Hexanoic	Total
25/01/94		388	136	115	300	65	135	<30	279	1418
06/04/94		332	79	44	<2	13	<2	2	<2	469
04/05/94		160	32	2	<3	<3	<3	<3	<3	194
04/10/94	0.45 a	181	36	3	1	3	<2	<2	<3	224
04/10/94	0.45 b	199	42	3	1	3	<2	<2	<3	248
04/10/94	1.2 a	227	43	3	2	4	<2	<2	<3	278
04/10/94	1.2 b	193	38	3	1	3	<2	1	<3	240
01/03/95	0.45	127	18	13	7	4	5	<2	2	176
01/03/95	1.2	124	19	13	8	4	5	<2	2	174
09/11/95	1.2	17	2	<2	1	<2	<2	<2	<2	20
29/02/96	0.45	28	3	<2	<2	<2	<2	<3	<2	31
29/02/96	1.2	23	<5	<2	<2	<2	<2	<3	<2	23
25/04/96	1.2	45	7	<2	4	<2	<2	<2	<2	56
20/06/96	0.45	37	5	<2	4	<2	<2	<2	<2	46
20/06/96	1.2	35	4	<2	3	<2	<2	<2	<2	42
11/12/96	0.45	16	<2	<2	<2	<2	<3	<2	<3	16
10/07/97	0.45	9	1	<2	<2	<2	<2	<2	<2	10
23/09/97	0.45	10	<2	<2	<2	<2	<2	<2	<2	10
07/11/97	0.45	8	<2	<2	<2	<2	1	<2	<2	10

Cell 5

All values expressed as mg/l C

Date	filter	Ethanoic	Propanoic	i-Butanoic	n-Butanoic	i-Pentanoic	n-Pentanoic	i-Hexanoic	n-Hexanoic	Total
25/01/94		71	4	<5	<5	<5	<5	<5	<5	75
06/04/94		46	1	<2	<2	<2	<2	<2	<2	47
04/05/94		23	<3	<3	<3	<3	<3	<3	<3	23
04/10/94	0.45 a	36	2	<2	<2	<2	<2	<2	<3	38
04/10/94	1.2 a	36	2	<2	1	<2	<2	<2	<3	39
04/10/94	1.2 b	42	2	<2	1	<2	<2	<2	<3	46
01/03/95	0.45	29	2	<2	<2	<2	<2	<2	<2	31
01/03/95	1.2	31	2	<2	<2	<2	<2	<2	<2	33
09/11/95	1.2	56	4	<2	2	<2	<2	<2	<2	62
29/02/96	0.45	17	<5	<2	<2	<2	<2	<3	<2	17
29/02/96	1.2	18	<5	<2	<2	<2	<2	<3	<2	18
25/04/96	1.2	48	3	<2	2	<2	<2	<2	<2	53
20/06/96	0.45	37	3	<2	2	<2	<2	<2	<2	42
20/06/96	1.2	35	2	<2	1	<2	<2	<2	<2	39
11/12/96	0.45	15	<2	<2	<2	<2	<3	<2	<3	15
10/07/97	0.45	37	1	<2	<2	<2	<3	<2	<3	38
23/09/97	0.45	25	<2	<2	<2	<2	2	<2	<3	27
07/11/97	0.45	24	<2	<2	<2	<2	2	<2	<3	26

Cell 6

All values expressed as mg/l C

Date	filter	Ethanoic	Propanoic	i-Butanoic	n-Butanoic	i-Pentanoic	n-Pentanoic	i-Hexanoic	n-Hexanoic	Total
25/01/94		24	2	3	3	<3	<3	<3	3	35
06/04/94		5	<2	<2	<2	<2	<2	<2	<2	5
04/05/94		10	<3	<3	<3	<3	<3	<3	<3	10
04/10/94	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
01/03/95	0.45	8	<2	<2	<2	<2	<2	<2	<2	8
01/03/95	1.2	10	<2	<2	<2	<2	<2	<2	<2	10
09/11/95	1.2	8	<2	<2	<2	<2	<2	<2	<2	8
29/02/96	0.45	8	<5	<2	<2	<2	<2	<3	<2	8
29/02/96	1.2	8	<5	<2	<2	<2	<2	<3	<2	8
25/04/96	1.2	28	<2	<2	<2	<2	<2	<2	<2	28
20/06/96	0.45	10	<2	<2	<2	<2	<2	<2	<2	10
20/06/96	1.2	12	<2	<2	<2	<2	<2	<2	<2	12
11/12/96	0.45	4	<2	<2	<2	<2	<3	<2	<3	4

Appendix Table C3 Leachate levels data (boreholes C, Cells 1 - 6)

	depth to leachate (metres below top of casing)						
Date	Cell1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Comments
22/08/91	17.5	17.8	16.7	#N/A	11.3	17.1	Cell 4 dry
19/09/91	17.4	15.5	16.3	#N/A	10.8	16.2	Cell 4 dry
24/10/91	17.6	17.7	16.7	#N/A	11.1	16.7	Cell 4 dry
21/11/91	17.3	15.7	16.2	17.9	10.3	#N/A	
09/01/92	16.8	15.2	15.9	15.3	11.1	#N/A	
30/01/92	#N/A	#N/A	#N/A	#N/A	9.8	#N/A	*
20/02/92	16.9	15.5	16.5	15.1	7.8	15.1	*
18/03/92	17.7	16.2	16.9	15.8	11.0	16.8	*
01/05/92	16.4	15.1	15.6	#N/A	#N/A	15.8	air 1
24/06/92	16.2	15.1	15.5	14.4	10.0	15.7	
28/07/92	16.1	15.0	15.1	14.0	9.8	15.6	water 1
19/08/92	15.9	14.8	14.9	13.7	9.7	15.6	
01/10/92	15.7	14.7	15.8	13.6	#N/A	#N/A	
29/10/92	15.6	14.7	14.7	13.2	#N/A	15.5	
19/11/92	15.5	14.7	14.7	13.2	9.4	15.5	
							air 2 & 3, water 2
24/01/94	12.6	12.3	8.8	11.5	8.0	11.7	
25/01/94	14.0	14.0	14.5	12.1	8.7	15.3	
07/02/94	13.0	13.5	12.9	12.0	8.5	15.3	
08/02/94	12.3	10.3	14.5	12.2	8.5	15.6	
07/03/94	12.9	13.5	8.5	11.9	8.4	15.2	water 3
08/03/94	13.7	14.1	9.5	12.3	8.5	15.2	
05/04/94	12.8	13.5	9.3	11.9	8.4	15.2	
06/04/94	13.6	13.8	11.8	12.3	8.8	15.2	
03/05/94	12.6	13.4	9.9	11.8	8.3	15.0	
04/05/94	11.3	11.5	13.4	11.9	7.8	15.3	**
03/10/94	12.0	13.2	#N/A	#N/A	#N/A	#N/A	
04/10/94	12.0	11.0	12.1	11.6	7.9	#N/A	
01/03/95	10.7	12.0	4.5	11.0	7.2	14.3	
02/03/95	11.0	12.4	8.1	10.8	7.3	14.2	
05/07/95	10.3	11.8	7.9	10.7	7.7	14.7	
06/07/95	10.7	12.3	7.7	10.6	7.3	14.1	
08/11/95	10.0	11.5	7.4	10.0	7.4	13.8	
09/11/95	10.3	10.6	7.5	9.9	7.4	12.6	
28/02/96	9.7	10.8	7.1	9.0	7.2	12.7	
29/02/96	10.1	12.2	7.5	9.3	#N/A	#N/A	
24/04/96	9.6	11.2	7.0	8.7	7.0	12.3	
25/04/96	10.1	11.9	7.0	8.7	6.5	12.3	
19/06/96							not received
20/06/96	9.9	11.6	7.0	8.3	7.0	11.6	
10/12/96	8.9	11.1	6.4	7.8	7.0	11.0	
11/12/96	8.7	11.1	6.2	7.6	6.9	13.0	
05/02/97							not received
06/02/97	9.0	11.1	6.2	7.7	7.0	11.1	
09/07/97	8.2	#N/A	5.6	6.7	6.7	10.3	
10/07/97	10.0	#N/A	5.5	6.6	6.5	9.4	
22/09/97	8.2	#N/A	5.4	6.3	6.3	10.3	
23/09/97	8.1	#N/A	5.6	6.6	6.4	10.2	
06/11/97	7.3	#N/A	5.1	6.3	6.2	#N/A	
07/11/97	7.4	#N/A	5.1	6.5	6.5	#N/A	

NOTE:
air 1 - CELL 4 injected with 746m^3 of air over 5 hours on 28 April 1992
air 2 - CELL 4 aborted air injection on 23 Feb 1993
air 3 - CELL 4 injected with 11,101m^3 of air, 24 hours between 2-6 August 1993
water 1 - CELL 3 injected with 98.5m^3 of water, 2-3 July 1992
water 2 - CELL 3 injected with 21.3 m^3 of leachate, 20-24 April 1993
water 3 - CELL 3 injected with 231.2 m^3 of water, 21-25 Feb 1994
* CELL 5 - Possible false reading due to foam ontop of water column
** CELLs 1,2 & 5 - Possible false reading due to foam on top of water column

APPENDIX D ION BALANCE CALCULATION

An ion balance calculation compares the sum of the main cations and anions as milliequivalents/litre (meq l^{-1}): the calculations are presented below. The ion balance calculation for leachates and leachate contaminated groundwaters is more complex than uncontaminated groundwater because:

- the contribution of carboxylic acids to the alkalinity measurement may be significant. This is the availability of ethanoic, propanoic and n-butanoic acids to contribute to the alkalinity measurement between the pH of the sample and pH 4.5 (end point of the alkalinity measurement);

- the dissociation of the acids is pH controlled and has the effect of shifting the end-point of the titration. This must also be calculated;

- the contribution of ammoniacal nitrogen to the alkalinity measurement may be significant and this should be calculated.

Sources of error should be sought ***where an ionic imbalance of greater than ±15% is obtained*** for a leachate sample.

The reader is advised to consult a competent chemist regarding ion balance calculations. However, a simple BASIC program which computes an ionic balance for leachates and contaminated groundwaters, which accounts for the points above, is presented in Table D1.

Appendix Table D1 Ion balance program for leachates

```
5       ! IONIC BALANCE CALCULATIONS PROGRAM
        ! S Blake & D Craft 19 Oct 1988
        !
10      PRINT "Calculation of ionic balance"
        PRINT "-----------------------------"
        PRINT "Please note that the following has been assumed:"
        PRINT " (i) Fe present as FeII"
        PRINT " (ii) Three major volatile acids accounted for separately."
        PRINT "(iii) pH affects amount of volatile fatty acid dissociation"
        PRINT " - calculations are made accordingly"
        INPUT "pH ";PH
        INPUT "Acetic acid mg C l-1 ";AC
        INPUT "Proprionic acid mg C l-1 ";PR
        INPUT "n-Butyric acid mg C l-1 ";BU

        ! Calculation of concentration of fatty acids available to contribute
        ! to alkalinity measurement between pH of sample and pH 4.5 (end-point
        ! for alkalinity measurement)
        ! NB Fatty acid (FA) concn. in mg C l-1 - converted to mg FA l-1

20      CAC=AC*2.50/(1+(10**-PH)/(1.7539*10**-5))-AC*2.50/(1+(10**-4.5)/(1.7539*10**-5))
        CPR=PR*2.06/(1+(10**-PH)/(1.3366*10**-5))-PR*2.06/(1+(10**-4.5)/(1.3366*10**-5))
        CBU=BU*1.83/(1+(10**-PH)/(0.8913*10**-5))-BU*1.83/(1+(10**-4.5)/(0.8913*10**-5))

        ALKAC=CAC*50/60                    ! RCOOH = CaCO3
        ALKPR=CPR*50/74                    !
        ALKBU=CBU*50/88                    ! RCOO- = CO32- / 2
        ALKFA=ALKBU+ALKPR+ALKAC            !

        PRINT "Fatty Acid Alkalinity = ";ALKFA;" mg/l CaCO3"
        PRINT " Ac = ";ALKAC;" Pr = ";ALKPR;" Bu = ";ALKBU;
        PRINT
        INPUT "mg Ca l-1 ";CA
        INPUT "mg Mg l-1 ";MG
        INPUT "mg Na l-1 ";NA
        INPUT "mg K l-1 ";K
        INPUT "mg Fe l-1 ";FE
        INPUT "mg NH3-N l-1";NH3
        ! Calculation of concentration of ammonia available to contribute
        ! to alkalinity measurement between pH of sample and pH 4.5 (end-point
        ! for alkalinity measurement)
        ! NB Ammonia concn. in mg N l-1 - converted to mg NH3 l-1
        ! kw/kb (NH3) = 5.637*10**-10
        ! kb (NH3 aq) = 1.744*10**-5 @25C

        CNH3=NH3*(17/14)*(10**-4.5/(5.637*10**-10+10**-4.5))-NH3*(17/14)*(10**-PH/(5.637*10**-10+10**-PH))

25      IF CNH3<0 THEN LET CNH3=0 ELSE GOTO 26 ! i.e. if pH < 4.5
26      ALKNH3=CNH3*50/17

        PRINT "Ammoniacal Alkalinity = ";ALKNH3;" mg l-1 CaCO3"
        PRINT

        INPUT "mg CaCO3 l-1";TOTALK
        INPUT "mg Cll-1 ";CL
        INPUT "mg SO4 l-1 ";SO4
        INPUT "mg NO3-N l-1";NO3
        INPUT "mg Pl-1 ";P
```

```
        ! Ionic contribution of Ac, Pr, Bu and NH4+ at pH of sample

        PHCAC=AC*2.5/(1+(10**-PH)/(1.7539*10**-5))
        PHCPR=PR*2.06/(1+(10**-PH)/(1.3366*10**-5))
        PHCBU=BU*1.83/(1+(10**-PH)/(0.8913*10**-5))
        PHNH3=NH3*(17/14)*(10**-PH/(1.774*10**-5+10**-PH))
        CTOT=(CA*2/40.07)+(MG*2/24.32)+(NA/22.997)+(K/39.096)+(FE*2/55.84)+&
        (PHNH3/17)

        ! Check to find if measured alkalinity less/greater than sum of
        ! fatty acid & ammoniacal 'alkalinity'.....

27      IF TOTALK<(ALKNH3+ALKFA) THEN LET TOTALK=ALKNH3+ALKFA ELSE GOTO 30

30      ATOT=((TOTALK-ALKNH3-ALKFA)*2/100.09)+(CL/35.457)+(SO4*2/96.064)+(NO3/14.008)+&
        +(P*3/30.97)+(PHCPR/74)+(PHCAC/60)+(PHCBU/88)

        PRINT "Cations . . . . ";CTOT
        PRINT "Anions . . . . . ";ATOT
        PRINT "Difference (C-A) ";CTOT-ATOT
        PRINT ""

40      IF (CTOT<ATOT) THEN GOTO 100 ELSE GOTO 200

100     CDEF=(ATOT-CTOT)*100/ATOT
        PRINT "% Cation Deficiency [(A-C)/C]=";CDEF;"%"
        GOTO 500
200     ADEF=(CTOT-ATOT)*100/CTOT
        PRINT "% Anion Deficiency [(C-A)/A]=";ADEF;"%"
        GOTO 500
500     INPUT "Have you finished [N] ";ANS$
510     IF (ANS$="y" OR ANS$="Y") THEN GOTO 520 ELSE GOTO 10
520     END
```