The Effectiveness of Liners in Inhibiting the Migration of Landfill Gas

R&D Technical Report P256

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Research Contractor:

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This report presents the results obtained from monitoring the effectiveness of various natural and synthetic landfill liner materials in providing efficient passive barriers to landfill gas migration.

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EXECUTIVE SUMMARY

There is considerable debate about the effectiveness of various natural and synthetic liner materials in providing efficient passive barriers to landfill gas migration. This paper describes the construction and results of a four-year field scale project, funded by the Department of the Environment (and transferred to the Environment Agency), to evaluate the relative performances of a natural clay material and a 2mm thick high-density polyethylene (HDPE) membrane in inhibiting such migration.

The experimental HDPE liner covers an area of about $3500m^2$; it forms a strip 50m wide, set in the middle of a 120m long clay sidewall of a landfill, and extends from top to bottom down the slope of the boundary embankment.

The membrane was anchored into the underlying clay, with 12 gas samplers installed immediately beneath the liner. Other gas samplers were installed in the clay sidewall on either side, and thermocouples were set at various depths to determine any temperature gradient away from the interface with the waste.

The landfill cell had a volume of $280{,}000m^3$. This was filled within a year by daily input of household waste, giving a maximum depth of waste of about 16m. It was finally capped with 1m of clay, to a domed profile, by September/October 1992.

This paper presents the results obtained from monitoring at two weekly intervals over three years, followed by monthly intervals in the last year to March 1996.

Results have shown the progressive build-up of gas within the waste and the concurrent measurements of gas presence in some of the samplers beneath the HDPE liner. The majority of the samplers demonstrated negligible concentrations of methane but two of them persistently showed values in the 20% range; however, these were far below the concentrations in the waste and only at pressures too low to be measured in the field.

Gas monitoring for movement in the clay showed that, in general, it might be a good barrier against water flow but it was a poor barrier to the movement of gas.

Two years after the installation, gas pressures in the waste were relieved by pumping from a well-field in the landfill. Sampling was extended to observations within the waste and in the surrounding ground to examine the reduction in gas concentrations at the boundary, both behind the clay embankment and the liner. These confirmed the overall effectiveness of the HDPE barrier and the relatively poor performance of the clay.

KEY WORDS

Landfill gas; liners, methane; waste; HDPE barrier; gas migration.

ACKNOWLEDGEMENTS

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1 INTRODUCTION

The incidence of gas migration into land adjoining waste disposal sites has increased in recent years as a result of the tendency towards the creation of large, deep landfills, which promote generation of methane. The typically higher daily waste inputs to these sites, coupled with progressive infilling, capping and restoration of finished phases, helps to control moisture input and restrict leachate formation. Such control inhibits rapid methane generation, but any gas that is generated is retained beneath the cap and, as pressure increases, it flows along paths offering the least resistance, often laterally into adjoining formations.

Guidance documents such as Waste Management Paper No 27 (Rev. 1991) on Landfill Gas, indicate that multi-barrier gas control systems should be applied wherever possible. Chapter 8 of the Paper refers to the lack of quantified data on the effectiveness of various single liners in preventing gas migration. As one step towards improving the guidance currently available, and in order to generate further quantified data, the Department of the Environment elected to fund a field-scale research project into the ability of liners to inhibit landfill gas migration. This work was commissioned by the Wastes Technical Division of the Department of the Environment under Contract no.PECD7/10/283. The project was transferred into the Environment Agency's R&D Programme in 1996 as R&D Project P1-159. The project was designed and managed by the National Environmental Technology Centre over the period from October 1991 to March 1996.

2 OBJECTIVES

The objectives of the project were:

- to determine the effectiveness, under operational conditions, of a layer of reworked clay at least 1m thick, as a barrier to the migration of gas from landfills;
- to compare the results with those obtained from a 2mm barrier formed from high density polyethylene sheet welded into a continuous layer and functioning under identical operational conditions;
- to determine the changes in gas migration brought about by a gas extraction system;
- to investigate the relationship between changing meteorology and on and off-site landfill gas migration by field measurement of gas pressure and quality.

3 PROJECT MANAGEMENT

3.1 Programme of Work

The programme of work was:

- to select an active landfill in the course of development that was likely to generate much landfill gas and that also utilised local clay as a barrier material;
- to oversee the laying of 4000 sq. metres of HDPE liner; welded in-situ and placed by specialist sub-contractors down slope against a 50m length of the landfill boundary embankment;
- to install gas monitoring equipment beneath the membrane and within the clay, also to record the build-up of gas within the landfilled waste;
- to monitor for gas migration beyond the liners;
- to measure temperature variations at the waste/liner interface;
- to prepare a final report of the study and submit it to the Department of the Environment.

3.2 Selection of Site

Following a lengthy search for a suitable site, a landfill offered by Greenways (Appleford Sidings) was judged to be technically suitable and, in practical terms, conveniently close to AEA Technology offices for the prolonged monitoring envisaged.

The site contained a number of adjoining landfill areas, several of which were completed, but the then current landfill at the western extremity of the site, was about to be extended to take in a former gravel pit adjacent to the property boundary near the village of Sutton Courtenay. The gravel pit was square shaped; it abutted farmland to the north and a recreation field to the west; the other sides would be in continuity with the main landfill to the south and east (Figure 1). It provided an opportunity to utilise a new cell on the boundary of an operational landfill where gas production rates were moderate. The location, adjacent to farmland, was favourable for long-term monitoring since further expansion of landfill activities was not anticipated at the edge of the site, close to a village.

The new cell would be of adequate depth (16m) for the purposes of the experiment, and the start of its construction could be conveniently accommodated to coincide with the requirements of the research contract. Most importantly, its dimensions and the projected rate of household waste input would ensure that the cell would be filled and capped within a year. This would therefore leave a further three years for the collection of monitoring results, within a total four year contract period.

3.3 Geology of Site

The surface deposits of the area are composed of ~6m of alluvium, containing sand and gravels, underlain by the Lower Gault clay, reported (1) to be between 29m and 43m thick. Below this is the Lower Greensand. The gravel pit extended down to the clay and had been

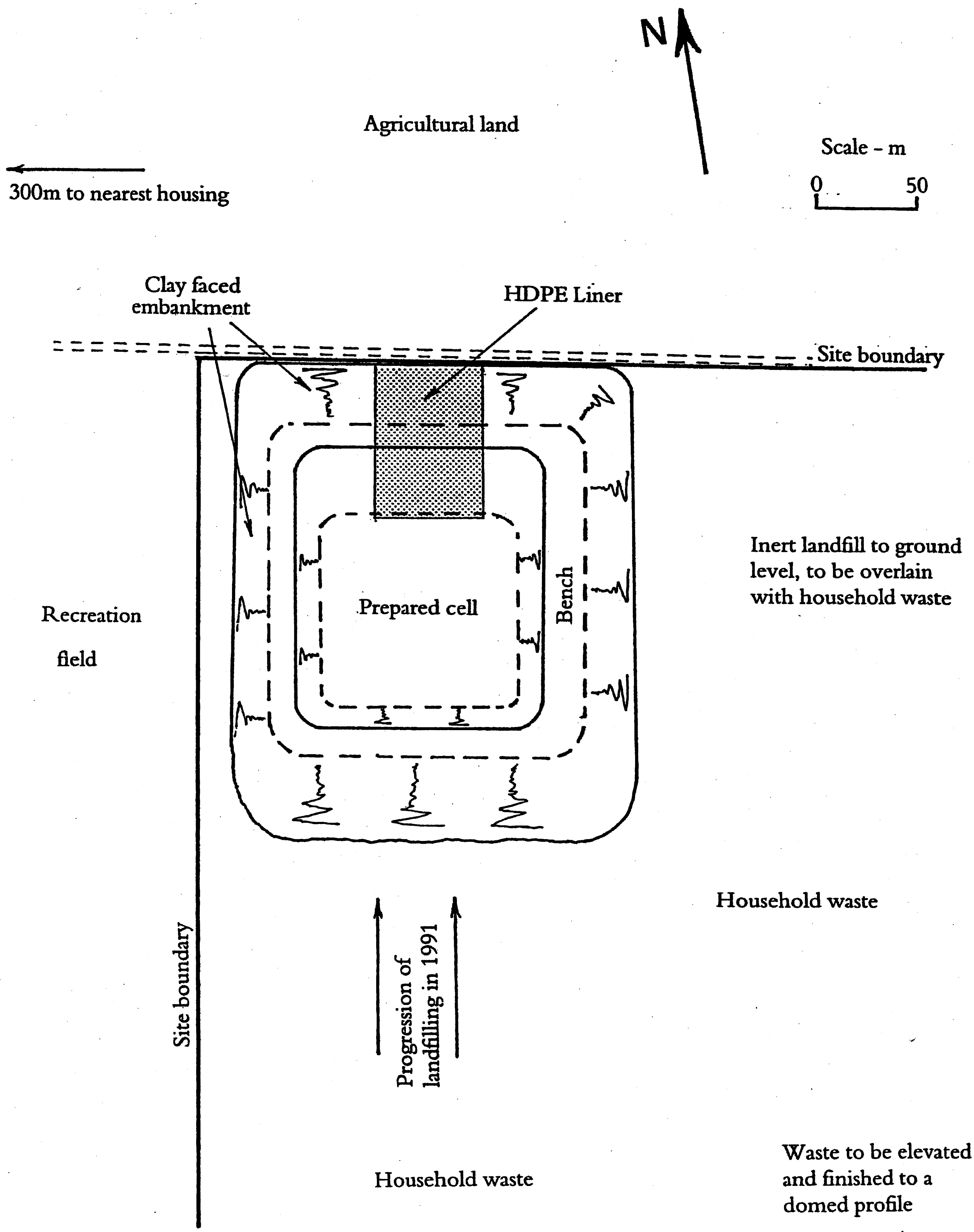


Figure 1 **Site plan in 1991 - showing cell prepared for waste disposal, clay lined perimeter and position of synthetic liner.**

left with a surrounding embankment, faced with emplaced clay which abutted and retained the gravels.

The characteristics of the clay base of the gravel pit were determined by a prior borehole investigation undertaken for Greenways Landfill (2). This showed that the grey/black, sandy, silty clay (Lower Gault) was relatively homogeneous to a depth of 8m but that below this depth the silt content increased, the clay content decreased and the material became more compacted.

The grain size distribution in the upper 8m indicated 45-50% clay, 35-50% silt and about 5% fine sand. The clay mineral component of the Lower Gault is predominantly Smectite (3).

The natural moisture content of the upper 8m was 25% and its plasticity index 48% (2), indicating a plastic 'C' type soil (BS Soil Classification). This meets the NRA criteria for lining material (plasticity index less than 65% and its clay content greater than 10%). Triaxial permeability tests (2) indicated a hydraulic conductivity of 10^{-11} m/s, dropping to 10^{-10} m/s below 8m depth, and that the optimum moisture content for maximum compaction was 15%.

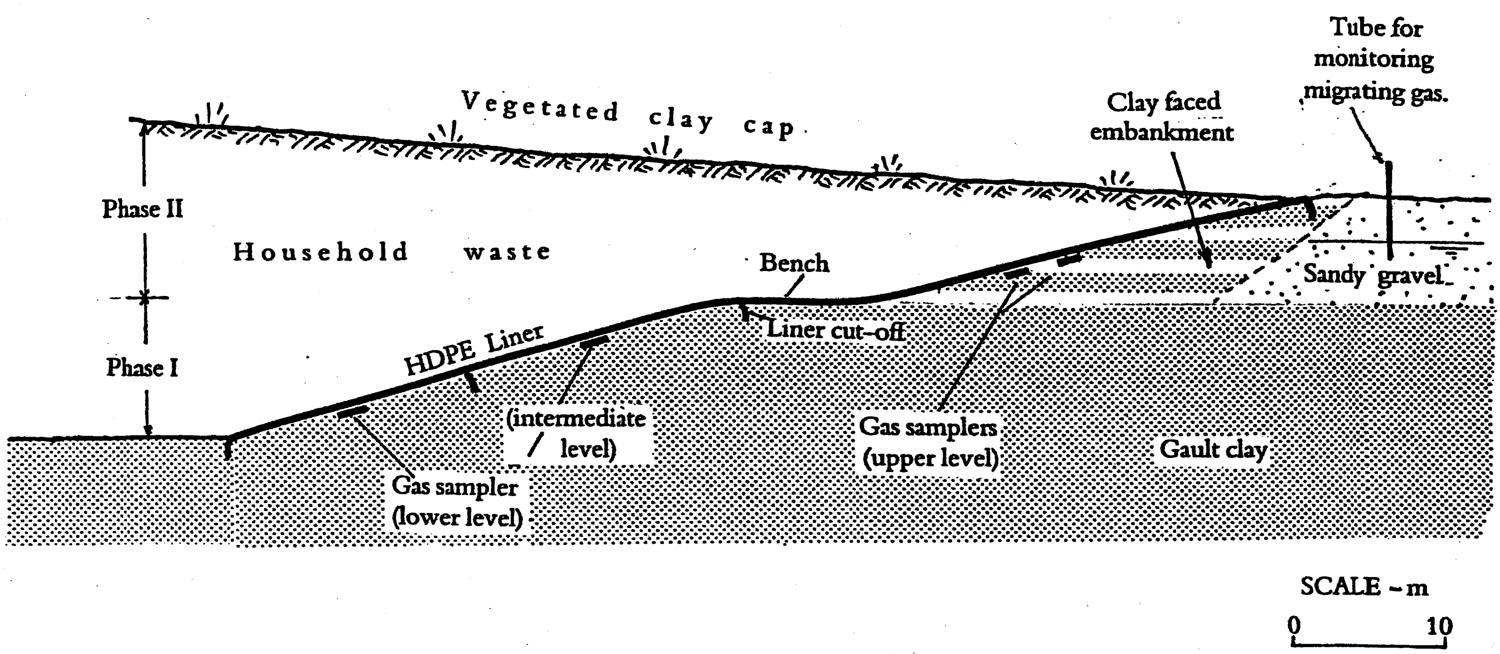
These results confirmed the suitability of the Gault as a landfill lining material for the purposes of leachate containment.

The embankment enclosing the cell on its north and west sides (Figure 1) and which retains the upper 6m waste, was formed in 1988 by bulldozing clay from the base of the excavation towards the exposed face of the surrounding gravels. The build-up of clay was continued until water drainage, from gravels beneath the adjoining field and into the excavation, was halted. No other construction details for the embankment are known, except that the clay cross section is roughly triangular and tapers off at its top.

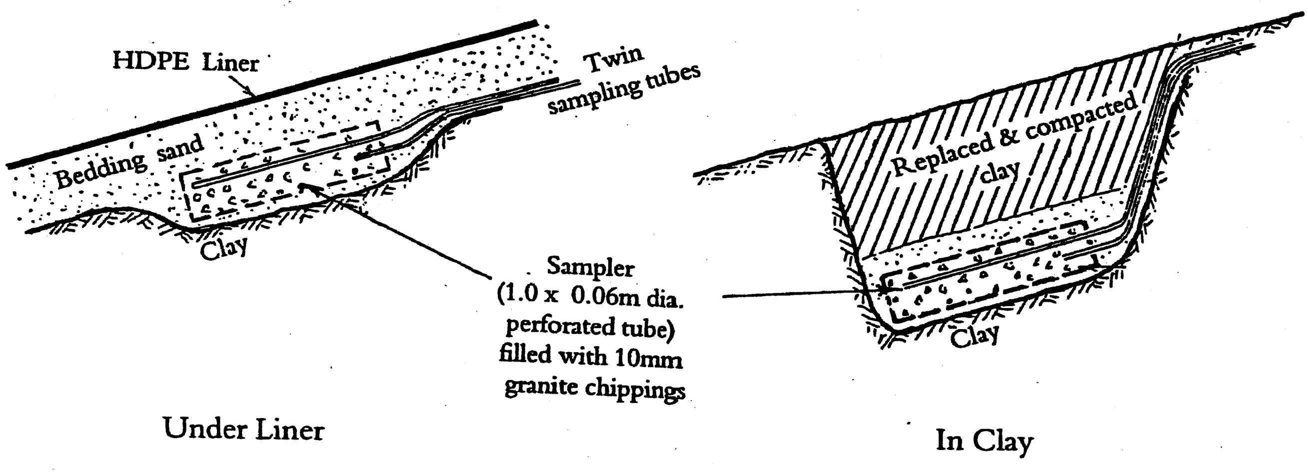
3.4 Description of Site

For waste disposal purposes, the pit was dewatered and then deepened by excavating 10m into the Gault, creating a hole 90m square at its base with sidewalls sloping up at a gradient of 1:1. It was oriented to leave a perimeter bench 20m wide along the toe of the surrounding embankment. Such a profile, with a bench between the embankment and the lower exposed clay slope, was adopted by the site operator to ensure the stability of the sidewalls while the excavation remained open.

The embankment on the north side of the pit was selected for the experiment since it had good access from a boundary road and was sufficiently long and straight to accommodate a 50m wide HDPE liner while still leaving room for experiments on the clay embankment at either side. It was 300m away from the nearest house at Sutton Courtenay. No difficulties were anticipated in installing the experimental facilities against the 6m high clay-faced gravel embankment with its slope of 1 in 4.5 but the projected 1:1 slope of the lower 9m into the Gault was judged to be too steep. It was accordingly reduced to a 1:3.5 slope at which the installers of the liner could weld horizontal joints and at which gas samplers could be properly positioned by hand. To compensate for any consequent loss of waste disposal volume that this entailed, it was decided that the width of the bench along this side could be reduced from 20m to 10m, without endangering the stability of the slope.



Cross Section Through Experimental Liner Installation



Gas Sampler Detail

Not to scale

Figure 2 Cross-section through liner installation and gas sampler details.

The total volume of the new cell was estimated to be 280,000m^3 of which 190,000m^3 lay within the lower 9m of the Gault.

3.5 Layout of the HDPE Liner

The procedure for installing the HDPE liner was adjusted to meet the needs for installing gas samplers under it at three separate horizons, i.e. at upper, intermediate and lower levels. In order to inhibit gas flow between these horizons and so ensure representative localised sampling from under the liner, it needed to be anchored into the underlying clay. This was done by arranging for the edges of the membrane to overhang into two horizontal trenches across the slope; it was secured in place at a depth of 0.6m by the clay being replaced and compacted. In this way the lower sampling zone would be isolated from the intermediate and the intermediate from the upper zone. To achieve this, liner laying in the lower zone had to be completed and anchored into trenches at both top and bottom before the intermediate zone could be attempted (Figure 2).

The width of the liner was 50m, composed from five adjacent strips welded together and yielding a nett experimental width of about 48 metres, taking into account the widths of the outer edges that were folded over and anchored into the underlying clay.

The effective length of the liner downslope was about 72m plus the extra lengths of membrane used to anchor the ends at the toe, the crest, and at two intermediate horizontal anchor trenches down the slope. The profile (Figure 2) comprised: the upper embankment slope (gradient 1:4.5 and length 29m) down to and then across the horizontal 10m bench; followed by a lower slope (gradient 1:3.5 and length 33m) down to the base of the lower excavation.

3.6 Site Preparation and Liner Installation

The liner was laid in two phases, in order to minimise the length of time that it remained uncovered during installation. This was necessary to reduce the possibility of sand cover material being eroded by rain and to minimise the possibility of damage by vandalism.

Accordingly, the first phase, covering the lower and intermediate gas sampling zones was laid up to the 10m bench level; this was completed by the beginning of October 1991. The second phase was installed in April 1992, at the time when the level of waste had risen almost to the top of the first phase.

The slopes were formed to the planned profiles yielding a smooth clay surface that was flaky when dry and slippery when wet, but this was deemed unsuitable as a bedding for the liner. Instead, the experience of the manufacturer and installer (SLT Linings) required it to be laid on a 0.1m bed of sandy material. In this case, sand/silt rejects from on-site gravel operations were deposited to the required thickness. This operation had to be synchronised with the implantation of the gas samplers and completed immediately before the liner was laid. In fine weather such preparation was straightforward, but after rain the clay slopes became so slippery that tracked vehicles, used for distributing the bedding sand, lost their grip and occasionally slid down the 1 in 3.5 slope. Under these conditions the repair of the damaged clay slope and the re-profiling of the slumped wet sand was most difficult.

The liner arrived on site in two 2000m^2, 10m wide rolls; the membrane therefore had to be assembled from 10m wide strips, cut to lengths corresponding to the section to be covered. The cutting procedure involved depositing one of the rolls along a nearby horizontal flat area covered with a prepared bed of sand. It was partially unwound and appropriate lengths cut off varying from about 18m (Phase 1) to 40m (Phase 2). Each was then re-rolled and transported by a sling to the trench above the section to be covered and positioned on the downside lip with its free end left hanging in the trench. The roll was then released and allowed to unwind by rolling down the slope. Five such lengths were released over the lower section, with their lower ends finishing in the toe anchor trench at the base of the landfill; each liner strip was then welded to its neighbour. The trenches at top and bottom were subsequently backfilled with clay and consolidated. For the lower section this consolidation was helped by rain wetting and softening the clay infill.

For the intermediate section, the top anchor trench was much more conveniently positioned along the 10m wide bench. The five lengths of liner, when released, overlapped the top of the lower section liner, by then, firmly secured into its trench.

With the strips of liner in position, their longitudinal edges were overlapped and joined by an automatic welding machine that produced a 40mm flat overlap extrusion weld. For the horizontal seams, where the intermediate lengths overlapped the tops of the lower lengths, the joints were sealed by a hand-operated welder creating a surface (fillet) weld.

The whole area was then inspected and several punctures discovered. Most of these appeared to have been caused either when the main roll was being unloaded or when the cut and rolled lengths were being transferred by machine into final position for unrolling down the slope. All such punctures were repaired by cutting suitably sized patches from HDPE offcuts and sealing them in position by hand welding.

All the welds were then tested to ensure that there were no leaks. An ultra-sonic testing device was used for the machine welds and a spark conduction test for the hand welds, the latter having had a wire conductor embedded at the interface of the two HDPE liner layers. Phase 1 of the installation took 10 working days to complete owing to the delays incurred by rainstorms and the repetition of preparatory work that had been washed out.

Once this was completed, used car tyres were placed at close intervals over the liner and positioned by hand by workers shod with soft footwear to avoid damaging the liner. The tyres served the dual purpose of weighting down the liner in the event of sudden high winds (which might otherwise have lifted and damaged the membrane) and providing a key for the deposition of a sand/silt cover.

Sand was hauled in by truck and deposited by the base of the liner, from where it was pushed up the slope by a bulldozer – progressively covering the tyres and so providing a base on which the machine could track without damaging the liner some 0.6m beneath.

Rapid progress was made in the early stages of Phase 1, with 25% of the area being covered with sand within the first day. However, this rate was not maintained owing to heavy rain and, later, to a temporary interruption in the supply of tyres.

Within a few days of sand being laid, waste was deposited at the base of the liner in such a way that there was a minimum 1m of protective waste and sand (with tyres) between the compacting machine and the membrane.

Phase 2 was started six months later by which time the steady deposition of waste had brought it up to a level close to the top of the first phase of the liner installation. Procedures for construction of the second phase were similar to those for its predecessor, but simplified by having fine Spring weather and no need to construct a further intermediate anchor trench half way up the slope.

3.7 The Gas Samplers

Each gas sampler comprised a 1m length of perforated, corrugated, polypropylene pipe of 6cm diameter, filled with 10mm granite chippings and closed at each end with polypropylene mesh (Figure 2). The void volume was about 1.25l. Two gas collecting tubes were inserted into the chippings, the lengths of which were sufficient to extend up the slopes, to one of six manholes at the crest of the embankment. For the lowest samplers this length was at least 65m.

The placing of the samplers in the bedding layer of sand had to be so times that they were in position just before the membrane was laid. To have installed them earlier would have risked their being washed out and exposed in the event of sudden rainfall. Each sampler was placed in a very shallow depression in the clay of about 0.1m, surrounded with coarse sand, and then covered with the sandy silt to the level of the surrounding bedding profile.

The collecting tubes were also buried in the sandy silt layer as they were inserted up the slope. However, where they approached the upper edge of each section they were buried deeper into the clay (to 0.5m), in order to pass beneath the cut-off flaps of the liner anchored into the clay. In this way it was hoped that the integrity of each gas zone beneath the liner would be retained, while allowing gas sampler tubes to traverse zones between collection points and sampling manholes.

The collecting tubes were of double-walled plastic with an inner nylon tube (ID 1.6mm, OD 3.6mm) encased in a polyethylene sheath of 1mm thickness, so giving an overall OD of 5.6mm.

Two tubes were used rather than one to reduce the likelihood of blockage during gas sampling. It enabled checks to be made for continuity of gas flow between the sampler and its manhole by applying pressure to one tube and suction to the other. In the event of gas flow being blocked it was possible to determine whether flooding was the cause of a blockage.

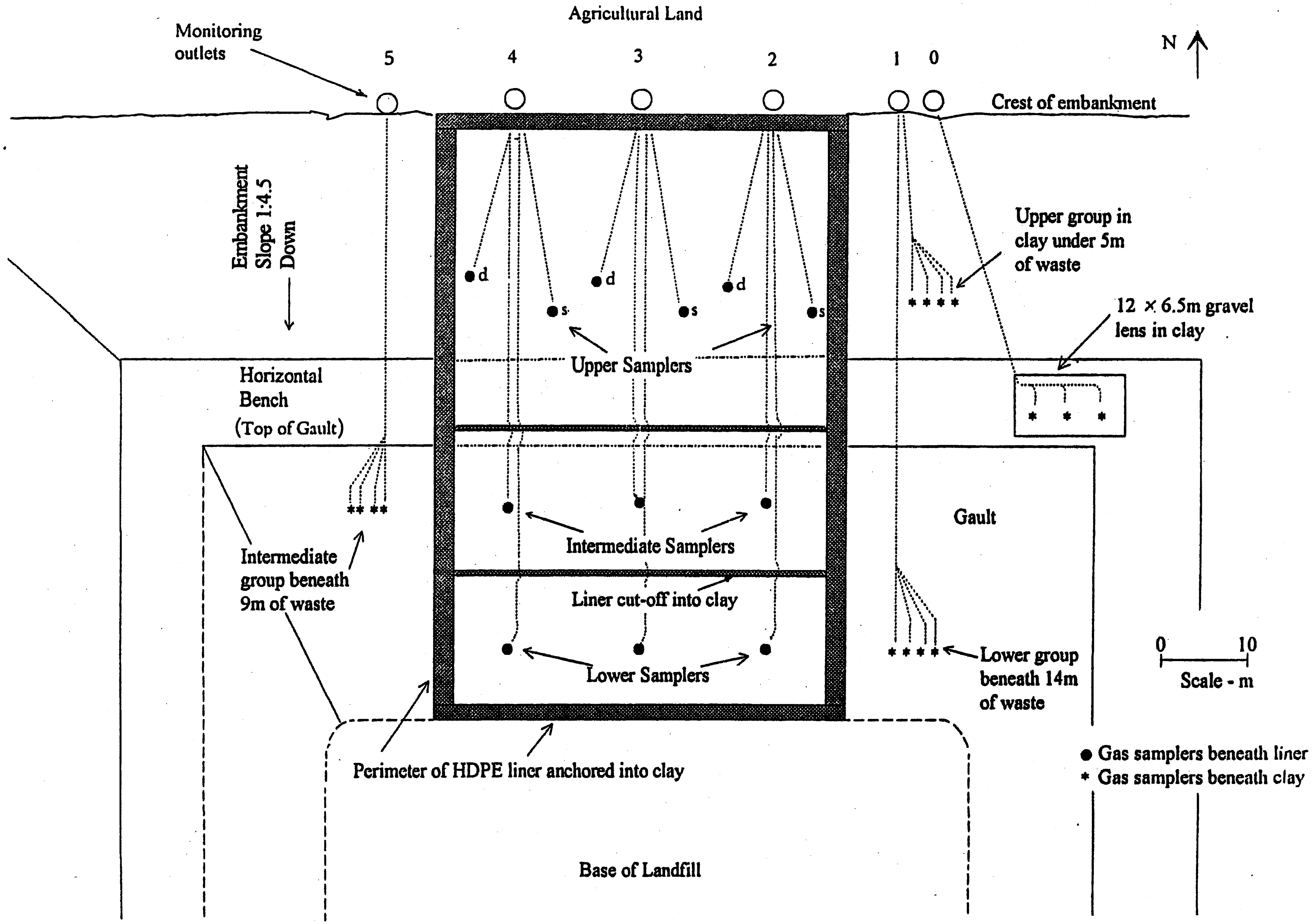


Figure 3 **Plan of HDPE liner and gas samplers beneath liner and clay.**

3.8 Layout of Gas Samplers Beneath the Liner

The configuration of the 12 gas samplers beneath the HDPE liner is shown in plan (Figure 3) with three in each of the lower and intermediate levels and six in the upper level. For ease of arranging the layout of sample collection tubes, they were oriented in groups along three axes – one down the centre line of the liner and the other two 16m on either side, i.e. about 8m in from the edge of the liner. The sampling tubes from four samplers in each group are fed to a separate manhole at the top of each axis.

In order to avoid damage to the sample collecting tubes during construction, extensions from the lower and intermediate samplers were coiled into temporary manholes (oil drums) buried on the bench at the top of Phase 1. They were later unwound and laid in trenches up the slope to their permanent manholes immediately before the Phase 2 liner was laid.

The three samplers in the lower zone are positioned half way down the section where the superimposed waste is about 14m deep. Three others in the intermediate zone lie beneath 9m of waste. The six samplers in the upper zone, beneath 4-5m of waste, are positioned about two thirds of the way down the section and offset, as shown in Figure 3.

3.9 Layout of Gas Samplers in the Clay

The sampling of gas in the clay was designed to be complementary to that beneath the liner, but less extensive, with groups of four samplers concentrated into three small areas. These were positioned at distances of 65m, 50m and 20m downslope, at levels matching those of other samplers in the three zones beneath the liner (Figure 3). The 65m and 50m group were thus positioned on that part of the slope formed from the undisturbed Gault. The 20m group was, by contrast, positioned on the face of the embankment in recompacted Gault clay.

Each group includes four gas samplers: one at the interface of the clay with the waste, and the other three at depths of 0.5m, 1.0m and 1.5m into the clay. In order to achieve this, the samplers were staggered in plan, each one being placed in the base of its own short slit trench of the appropriate depth. The trench width was equal to the width of the bucket of the excavator.

Each sampler was laid in a shallow bed of sandy gravel and then covered with clay, which was deposited and compacted in thin layers up to the level of the surrounding clay surfaces. The clay was compacted with a hand operated vibrating tamper. Near to the final (upper) level, compaction was augmented by the track of the excavator being run backwards and forwards along the line of the trench.

The samplers at the top of the clay, nominally at the interface with the waste, were in fact laid in the base of a second 0.5m deep trench, but filled only with gravel. In this way it was considered that the sampler would be afforded more protection against damage by the compactors over the waste.

The output tubes from all the samplers were brought together and placed in the base of a trench to a manhole at the top of the slope.

3.10 Gas Samplers in Gravel Lens within Clay

To augment the measurements of gas quality over the small experimental areas in the clay, a larger scale test was set up on the flat area of the bench (Figure 3). The object of this was to determine gas concentrations in a lens of sandy gravel encapsulated in clay, where the clay cover was consolidated under typical operational conditions.

An area of 12m long and 6.5m wide was excavated in the undisturbed Gault to a minimum depth of 1.25m increasing to 1.5m at one end. Gravel was laid on this to a level surface 0.75m below the rim of the surrounding clay. Three gas samplers were laid in this, each bedded in coarse sand and with the sampler tubes laid to exit at one end into a trench leading to a separate manhole at the top of the embankment.

A layer of Terram (10m x 5m) was placed on top of the gravel and the clay then replaced in thin layers, each layer being consolidated by at least three passes of a 15t excavator moving backwards and forwards across the whole surface. The process was repeated to provide a total 0.75m of consolidated clay cover up to the level of the surrounding clay. Waste was immediately deposited over the area.

In order to provide a comparison between gas concentrations in the gravel and the waste, a sampler was also placed in the waste at a height of about 1m above the experimental site. This was done two weeks later when the level of the landfill had risen locally by about 5m. A hole was dug in the superimposed waste to the limit of the machine's boom (4.5m) and gas sampler lowered into the bottom. It was surveyed for position and level and immediately buried, with the waste being replaced.

3.11 Thermocouple Installations

Because temperature changes can induce the drying out of clay and cause it to shrink, the opportunity was taken to examine any variations in temperature with depth in the base of the landfill. Thermocouples were thus installed at various depths in the clay.

At the site of each group of gas samplers, a separate trench 1.5m deep was dug to create a vertical face of fresh undisturbed clay. Thermocouples, each 0.5m long (4mm diameter), were inserted snugly into close-fitting holes driven into the clay face at depths of 0.5m, 1.0m and 1.5m below the surface. In two of the groups an additional thermocouple was inserted in a protective steel pipe and placed on top of the clay in contact with overlying waste. Because of the fragility of the leads, these were placed inside plastic hoses secured to the wall of the trench, to protect them while it was being backfilled with clay. Subsequently all the hoses were brought together and the leads fed into a single larger hose laid in the trench, together with gas sampling tubes that conducted them up to the monitoring manhole.

4 GAS MONITORING PROGRAMME

The gas monitoring schedule was increased in the following stages as the project developed.

Initial sampling for gas at the intermediate and low levels from samplers beneath the liner and in the undisturbed clay; starting two months after the Phase 1 installation.

At the completion of both phases of the installation, six months later, monitoring was expanded to include similar samplers at the upper level beneath the liner and in the clay embankment. It also included gas sampling from the gravel/sand lens encased in the clay bench as well as in the 6m of superimposed waste.

At 17 months, with increasing gas generation, sampling tubes were drilled into the embankment behind the clay. These were monitored to detect any residual gas that may have migrated behind the liner or through the clay on either side of it.

After a further 15 months (32 months after monitoring started) the landfill operator installed gas extraction wells in the waste, monitoring was then further extended to measure gas pressure and quality in those wells close to the experimental area. Also to measure leachate levels accumulating in the waste.

4.1 Gas Monitoring Procedure

An Analox 1200 portable, infra-red gas analyser was used to monitor the gases present in the samplers. This withdraws the gas continuously and simultaneously produces readings of the varying percentages of methane, carbon dioxide and oxygen present. Pressure readings were also taken concurrently by an on-line micromanometer that showed any initial pressure and the suction induced in the sampling lines as the analyser pump was withdrawing gas. Each sampler was provided with two tubes either of which could be used. Early tests were made to determine the effect of leaving the tubes either permanently open or clamped shut but the results showed that it made negligible difference; the initial pressure or suction being so low as to be effectively ambient atmospheric pressure.

In the process of withdrawing gas and when pumping suctions remained low, typically a rise in methane and carbon dioxide concentrations was accompanies by a decline in oxygen concentration that would approach zero. Measurements tended to be recorded at the point when oxygen levels were at their minimum since this indicator was slower to respond than those for the two other gases. Sometimes the oxygen would reach a minimum and then start to rise again, signifying that air was being drawn in through the vent tube and was circulating through the sampler.

4.2 Monitoring Beneath HDPE Liner & within Clay Liner

Unfortunately, it was more common, particularly for sampling at deeper horizons, for the suction in the tube to rise immediately to the maximum recordable (-20"water gauge) and then for the pump to labour under negligible gas withdrawal until it finally cut out. When this occurred it was always the result of water entering the sampler and its lines. For shallower

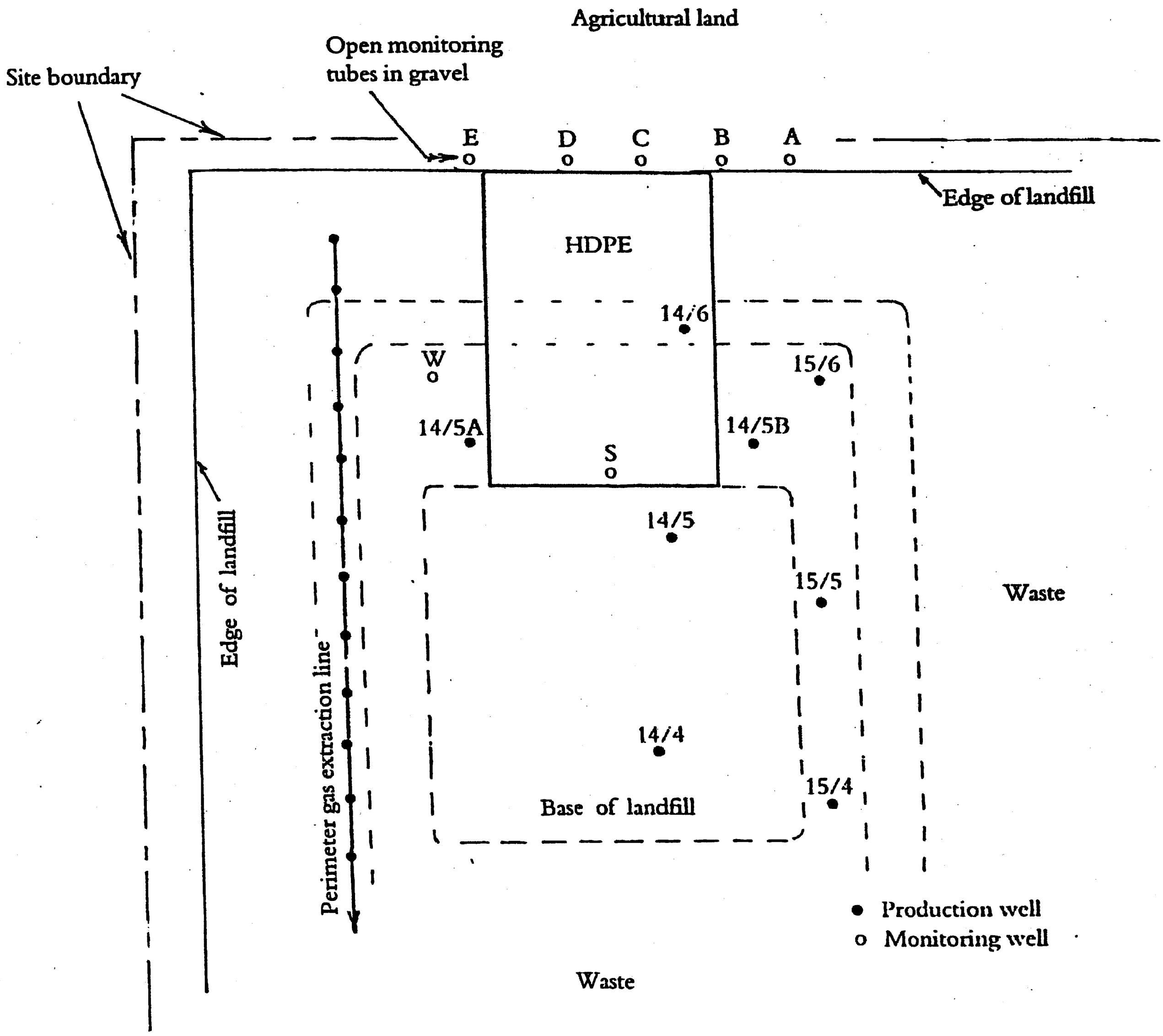


Figure 4 Monitoring points in waste and adjacent gravels.

samplers with a record of reliable readings, results would sometimes be impeded by a rise in groundwater levels resulting in water being withdrawn up to the inlet of the analyser. In these cases a water trap was put into the line and, if it could all be evacuated, residual gas readings were taken. These were considered unreliable since they were generally quite different from the gas proportions normally measured. For some samplers however, particularly those under the liner, resistance was found to be high but the pump continued to labour without cutting out.

In a few cases, where the portable analyser pump had cut out under suction, nitrogen was occasionally introduced under pressure into one of the tubes. This generally cleared the system, with copious quantities of water being ejected; but repeated efforts to sample for gas, on the following day, resulted in the sampler either being refilled with water or found to be still full of residual nitrogen.

4.3 Monitoring for Migrating Gas in the Embankment

After 32 months from the start of monitoring, five shallow boreholes were drilled into the soil behind the crest of the boundary embankment and small diameter (33mm OD) slotted tubes were inserted. The objective was to detect and sample any migrating gas. They were made of thick walled plastic (ID 24mm), 4m-5m long; and were sunk sufficiently deep to intersect the groundwater that extends beneath the adjoining field.

The positions of these monitoring tubes are shown in Figure 4. Two of them were placed behind the length covered by the liner and the remaining three on either side of it (one to the west, two to the east). They were left permanently open to the atmosphere.

For monitoring purposes, gas was withdrawn from the base of the tubes, by lowering down a length of flexible sampling tubing (ID 1.6mm) to just above the water table; its upper end being connected to the inlet of the Analox. Measurements of gaseous composition quickly reached equilibrium with readings of oxygen levels down to the 1% range and the methane and carbon dioxide levels remaining stable. Since the tubes were slotted for the entire length below ground, but not above, the results were considered representative of the migrating gas beyond the site boundary in the unsaturated sandy gravels.

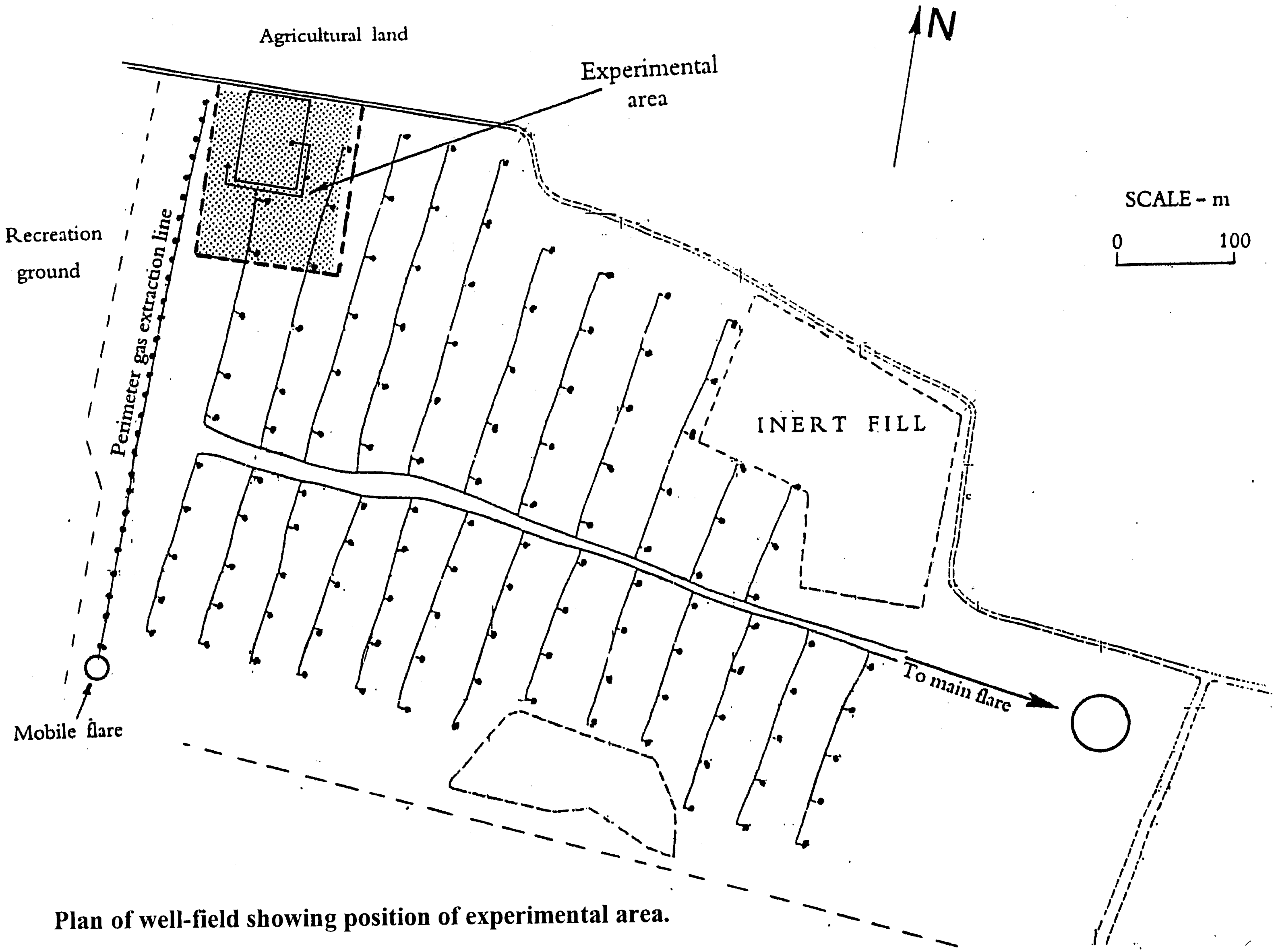


Figure 5 **Plan of well-field showing position of experimental area.**

5 GAS EXTRACTION FROM THE LANDFILL

5.1 Well-Field Installation

To relieve the pressure of gas guild up in the landfills, Greenways installed a well-field to extract and flare-off the methane. The wells were spaced on a grid of 50m connected as north-south laterals that fed into an east-west trunk main along the centre line of the landfills (Figure 5). The field eventually comprised 120 wells, the output of which was directed to a $2000m^3/h$ main flare.

The well heads were equipped with connectors to enable the measurement of gas pressure and sampling for on-line analysis. They were also provided with removable screw tops for measuring the depth down to leachate.

In the summer of 1994, the well-field was extended to include the area of the experiment that lies at the extreme north-west limit of the complex. When this occurred, the opportunity was taken to vary the research contract and so enable three extra wells to be installed for experimental purposes. One of these, on the east-wide of the liner, was connected to the extraction system while the other two were installed purely for static monitoring of gas within the waste; one above the toe of the liner and the other on the west side. Since these were all slotted throughout the entire depth of waste, monitoring results were judged to offer an aggregate of gas quality and pressure from the body of waste overlying the liner.

In addition to the well-field, Greenway6s installed a separate line of perimeter wells along the western edge of the landfill in order to intercept any migration of gas into the ground beneath the adjoining playing field. The wells were spaced at 12.5m intervals along a line 35m in from the edge of the landfill and 31m to the west of the liner. At the north end, near the experimental area, the wells penetrated through 6m of waste down to the clay bench on the west side of the original excavation. They were finished 0.6m above ground level and connected in line by transmission pipes slung between well tops. The line extended 500m to the south-west corner of the site where it fed into a mobile flare of $250m^3$ capacity.

5.2 Well-Field Operation

The extraction of landfill gas started in Summer 1994 (i.e. at about month 32) when positive pressures (0.07"H_2O) were registered in the waste and the local CH_4:CO_2 ration as 45.55. Since the site was at the extreme end of the well-field, it was not until September, that suction was achieved, reaching –0.35"H_2O in October at the toe of the liner. However, by mid-October, the main flare of $2000m^3$ capacity had to be taken out of service because the foundation had tilted caused by differential settlement in the underlying waste (4).

Henceforth, a temporary flare of $500m^3$ capacity was installed and continued to function through to July 1996. This worked flat out, but lacked the operational controls of the larger flare that adjusted its burning rate according to the methane available and the oxygen content of the incoming gas. Thus, if excess air was drawn in through one of the wells the temporary flare would be automatically extinguished and pumping of the well-field would cease. It would then have to await the next daily inspection visit to be re-lit and the pumping resumed.

Records of the time that the flare operated, were thus limited to aggregated figures presented as a percentage of the total time that it was on-line per month.

6 RESULTS

6.1 Gas Sampling from Under the HDPE Liner

Monitoring was undertaken for a period of 50 months starting on 1 December 1991, two months after the liner was installed in Phase 1. The frequency of monitoring varied according to the rate of change in results; starting at weekly intervals but reducing generally to two-weekly and finally monthly intervals over the last year.

In the course of monitoring beneath and within liners, data was collected on the variation of landfill gas quality within the waste. These measurements came from samplers at the base of the waste just above the clay; from a sampler within the waste and latterly from slotted monitoring wells penetrating the depth of waste overlying the liner. The record of the build-up of landfill gas components over the 50-month period is shown in Figure 6.

Of the 12 gas samplers installed beneath the liner, the most successful were those six in the upper level. Those in the intermediate and lower horizons were more prone to flooding from groundwater, with the result that reliable readings of gas content became fewer and fewer as the experiment progressed.

6.1.1 Upper Level

Upper level records of the percentage methane, carbon dioxide and oxygen concentrations in the six upper level samplers are given in Table 1 (Appendix). The figures are listed in columns arranged to correspond to the relative positions of the samplers on site where the outputs were collected in pairs at three manholes. The plan of these sampler positions is shown in Figure 2.

The tabulated results also signify the conditions under which the measurements were recorded, namely:

- the suction applied in inches of water, if less than the maximum recordable by the micromanometer (-20"H_2O);
- with the maximum suction applied, whether the analyser pump continued to function (~);
- with the maximum suction applied, whether the analyser pump cut out (*);
- whether water presence was confirmed (*w*);
- whether continuity of flow was established through the sampler (*c*).

Of the six samplers, three remained virtually free from methane except for low concentrations, (normally less than 5%) that occurred occasionally after the 30th month. These were the western pair and the single blue sampler of the centre pair. Of the remaining three, the other centre sampler (double blue) showed a consistent presence of methane from the 16th month onwards. The development of methane leakage at this particular area of the liner is shown in Figure 7. It demonstrates the record of methane growth in the superimposed waste and

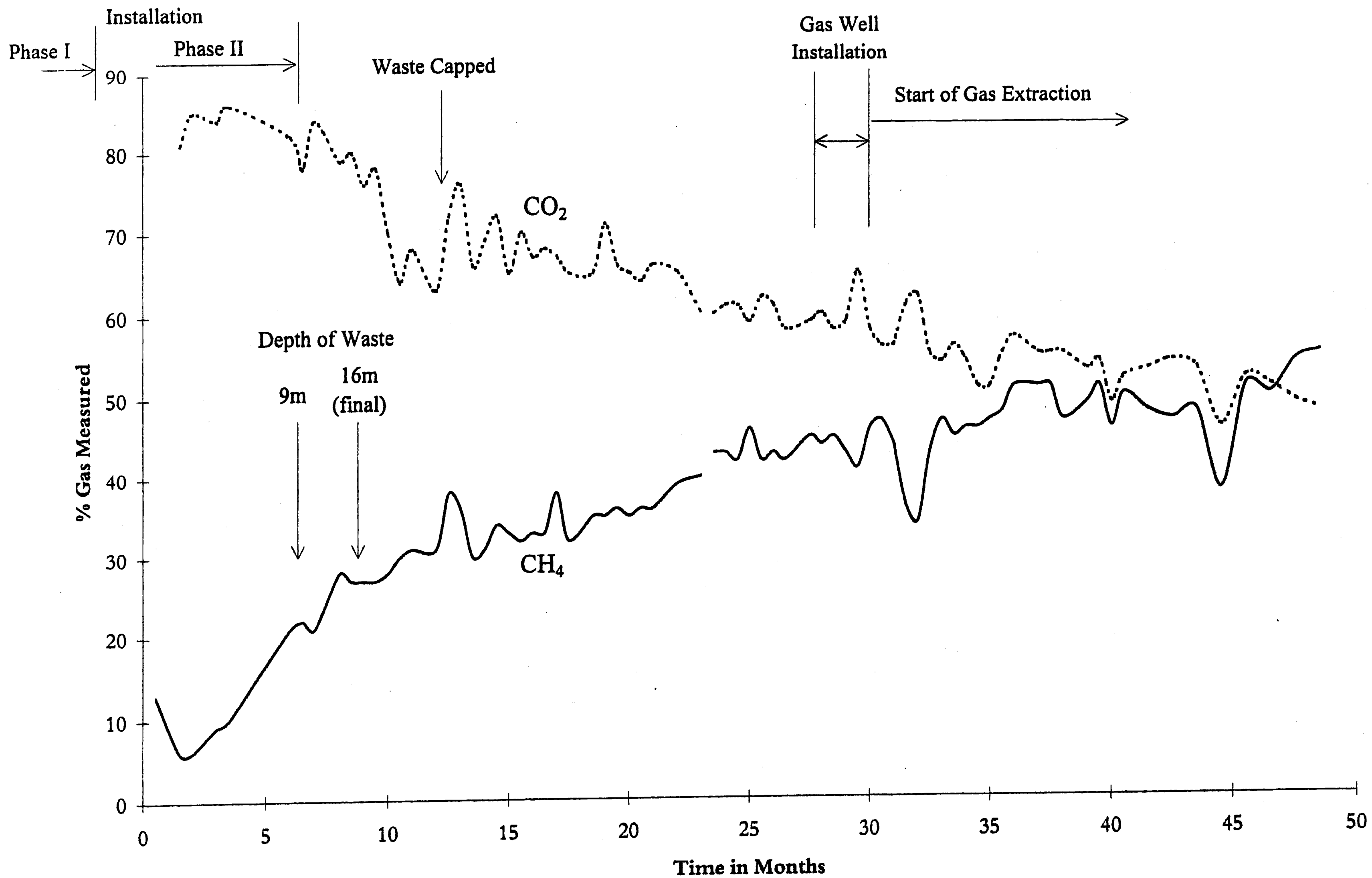


Figure 6 **Development of gas composition in landfill (as measured beneath 9m of waste-intermediate level)**

provides a comparison with the build-up of methane percentage of gas in the sampler beneath the liner.

This shows that a peak of 45% methane was attained after 30 months and that subsequently it declined to a plateau of 28%-30% over the next 20 months.

The other two samplers, the eastern pair, yielded intermittent methane concentrations of 18-20% but not at the same time in both. When it was present in one, it tended to be absent from the other, however, it was absent from both of them concurrently for extended periods. Although these results were often influenced by the intermittent presence of water in the sampler, there were occasions when continuity of flow was established through the suction and vent tubes to the sampler, so confirming that the absence of methane was genuine and not merely apparent because of a blockage.

It was noted that the persistent methane leakage at the centre (double blue) sampler did not infiltrate the samplers on either side, which consistently showed negligible concentrations of methane. This added support to the observation that there were probably no gaseous flows between samplers along the same horizon.

6.1.2 Intermediate level

Results of sampling at the intermediate level (Table 2 Appendix) show that of the three samplers, only the centre one, has persistently indicated the presence of methane. The eastern sampler showed methane briefly from the fourth to the ninth month after waste was deposited but has remained free ever since. The table shows that these samplers have experienced much flooding or blockage that has impeded sampling and given rise to high suction and negligible gas flow often causing the pump to cut out. These suspect readings all exhibit unrealistically high oxygen concentrations. Nevertheless continuity of flow through the samplers has been achieved sufficiently often to confirm the absence of methane to be genuine in the two outer samplers. It also reaffirms the more or less continuous presence of methane in the centre sampler although the percentage concentration of methane detected was much lower than that measured concurrently in the landfill.

6.1.3 Lower Level

No methane has been detected in these samplers other than in transient low quantities (Table 3 Appendix). Sampler flooding has been an almost continuous problem as shown even from the early months of monitoring when liquid had to be ejected under pressure.

6.2 Gas Sampling within the Clay

6.2.1 In the embankment lining

The 12 samplers in the clay were arranged in three groups of four at the upper level in the embankment and at the intermediate and lower levels in the Gault. Each group was composed of a sampler at the clay/waste interface and three others at depths of 0.5m, 1.0m and 1.5m in the clay.

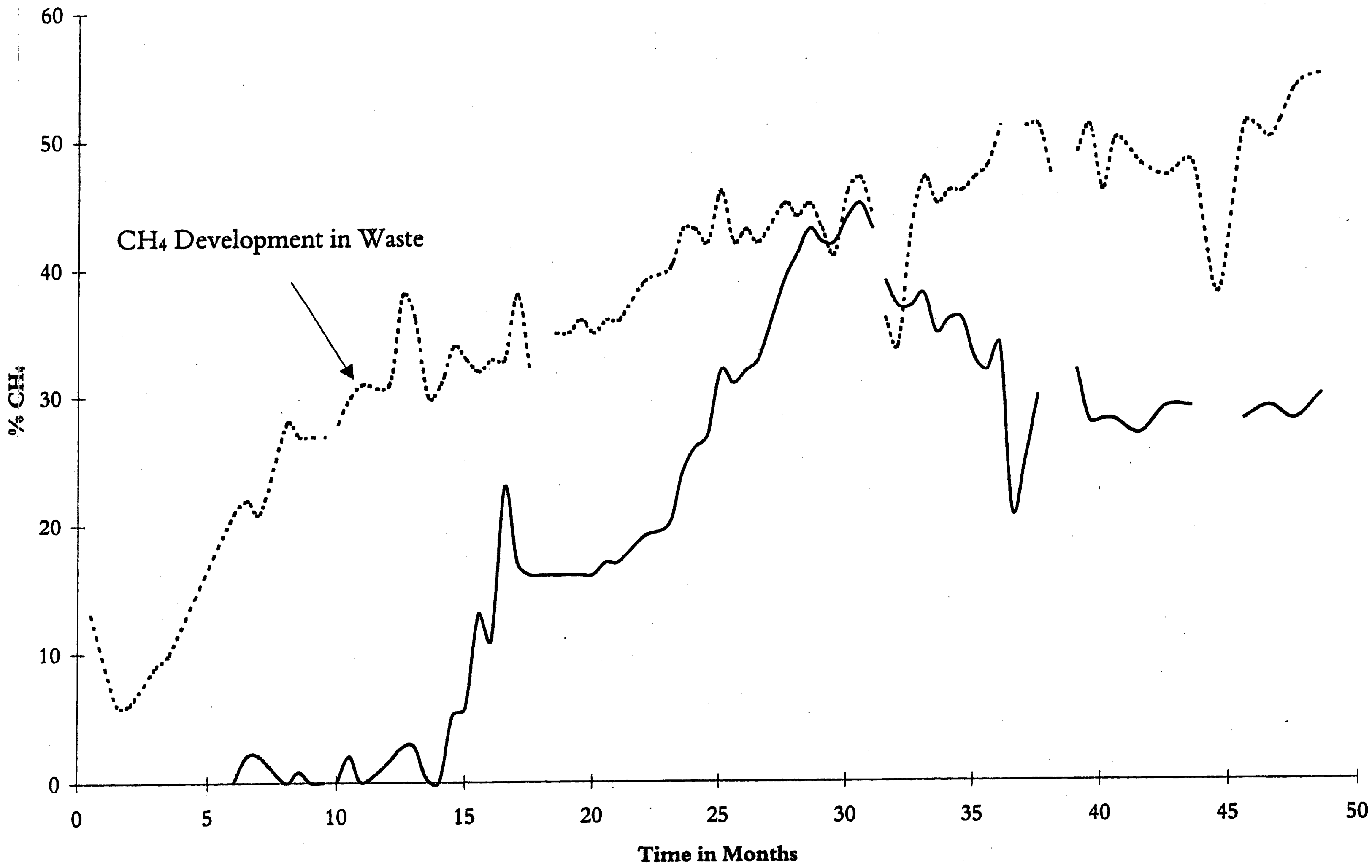


Figure 7 **Variation over time of methane leakage concentration through liner (upper level sampler).**

In the upper group, the results of which are shown in Table 4 (Appendix), three of the samplers functioned satisfactorily but the deepest one, at 1.5m has always been partially blocked and unresponsive to the application of nitrogen pressure. The other three have shown that carbon dioxide was first recorded after six months and methane after eight months. Henceforth, they have all recorded the initial increase of methane being matched by a corresponding decrease in the percentage of carbon dioxide. The two percentage figures normally aggregated to 90-100% since the percentage oxygen component remained low throughout.

The relative methane measurements present at increasing depths in the clay liner are shown in Figure 8. These refer to the upper group of samplers beneath 5m of waste, showing the percentage methane concentrations at the clay/waste interface and at depths within the clay of 0.5m and 1m.

They demonstrate that the clay provided only a weak barrier to the passage of methane and that the concentrations at 1m depth were only slightly, but consistently, less than those at 0.5m depth. The exception to this occurred in Autumn 1994 between months 32 and 35 when the methane and CO_2 percentages in the waste declined owning to the efficient operation of the gas extraction system, while the levels in the clay, although reduced, were still higher than those in the waste.

Sampling from the intermediate depth group was far less satisfactory because of water ingress under high pressure into the compacted clay surrounding the samplers. Results, given in Table 5 (Appendix), show that the interface sampler and that at 0.5m depth functioned for only one year and the 1m depth sampler lasted for two years. Only the deepest one at 1.5m has continued to function. While they were all working, these samplers also showed that the concentration of methane in the clay declined slowly with depth in the clay, but, by the time that concentrations of methane had risen to 50%, in the deepest sampler, there were none others left working with which results could be compared.

Sampling in the lower group (Table 6 Appendix) started very early in December 1991. After two months carbon dioxide was detected in the clay samplers but not at the interface. After six months high CO_2 levels were recorded at 1m depth in the clay with complementary percentages of methane. However at eight months, blockages built up to thwart effective sampling and three months later flooding became serious. Further unsuccessful attempts were made subsequently leading to sampling being finally abandoned after 23 months.

6.2.2 In the gravel lens

Sampling for gas in the gravel lens and within the superimposed waste started in July 1992 (the seventh month) when the methane:carbon dioxide proportions were 15:85. The results, in Table 7 (Appendix), show that the progressive growth in methane and decline in carbon dioxide in the waste has been closely mirrored by similar concentrations in the 78m^2 of gravel lens beneath 0.75m of compacted clay.

The records of methane measurements in the lens and in the waste above are plotted in Figure 9. Methane concentrations rose to a maximum of 53% after 47 months but at that time the concentration in the lens was measured at 74%; it subsequently declined. There is the

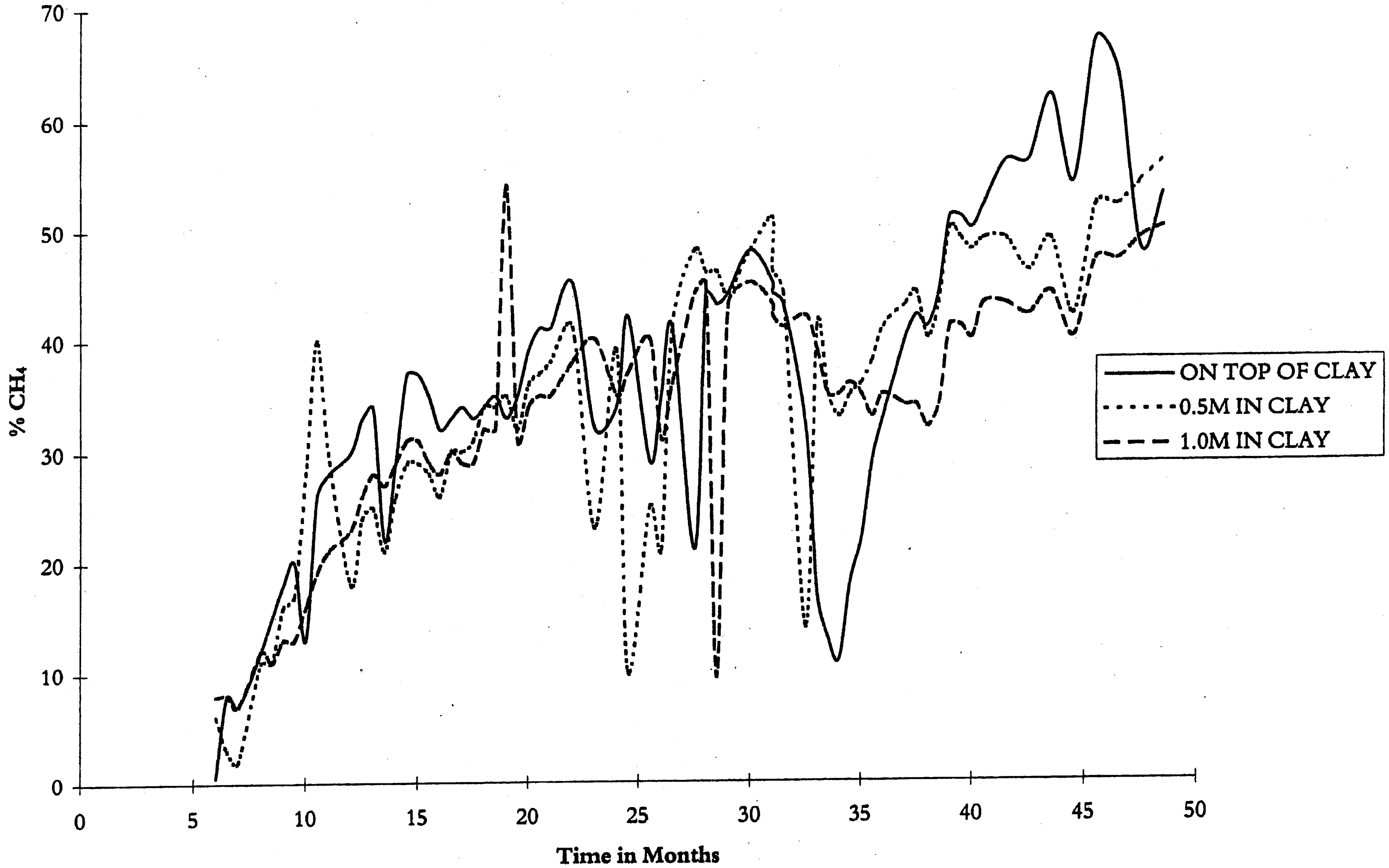


Figure 8 **Percentage methane recorded at base of waste and at 0.5m and 1.0m in clay.**

possibility that since sampling was reduced by this time to once per month, the high reading may have been the result of transient earlier high concentration in the waste that went unrecorded.

These results confirm that ~0.75m of compacted clay provides little or no barrier to gas flow without concurrent gas extraction from within the waste; it supports earlier findings with other clay samplers. However, the compacted clay successfully excluded water from the gravel despite perched water (as leachate) accumulating on the bench at the experimental area; it was only after 45 months that any leachate was encountered during gas sampling. It demonstrated the superior compaction that was achieved in the clay, compared with that surrounding the other individual gas samplers installed within the clay embankment.

6.3 Gas Sampling in the Boundary Gravels

The results from monitoring for migrating methane in the embankment gravels are given in Table 8 (Appendix) starting at the 23rd month of the main monitoring programme. Only at that time were all five monitoring tubes emplaced with A and B to the east, C and D behind the liner and E to the west.

Results show that the methane concentrations behind the liner were generally less than those behind the clay. Moreover, the pattern of variation with time showed a strong similarity with those behind the liner appearing to be a subdued replica of those behind the clay. This is seen from two sets of graphs in Figure 10 in which the upper curves show the record of methane concentrations behind the clay and the lower curves, those behind the liner.

It demonstrates clearly how the operation of the main flare on the well-field was so effective that the migration behind both liners was reduced to zero between months 31 to 35. Subsequently when it was replaced and a temporary substitute installed, the reduced suction enabled migration to resume, albeit at a lower level than before any flare was operational. The temporary flare has been unable to provide adequate suction at this extremity of the well-field.

Examination of the results in Table 8 (Appendix) also show that there have been large methane variations in the western tube E, behind the clay. It is suspected that this is attributable to the behaviour within the perimeter pipeline some 30m to the west of sampler tube E. The very high levels are thought to have occurred when there was little or no suction in the pipeline owing to the build-up of condensate at low points along it. This was periodically drained off to enable the system to renew its scavenging of gas from near the edge of the landfill. Unfortunately, it was not possible to assess the efficiency of this line until month 41 when a sampling point was constructed on top of the penultimate well near the liner. Subsequently, the well heads have been lowered to ground level, so reducing this propensity to trap condensate and cause blockages. However, later monitoring showed that pressures varied between –1.96" and +2.42" suggesting that the line was still blocking or that the mobile flare of $250m_3/h$ was not working at full power.

Table 8 (Appendix) also includes a column showing monitoring results of atmospheric pressure. The object was to see whether there was any observable correlation between these

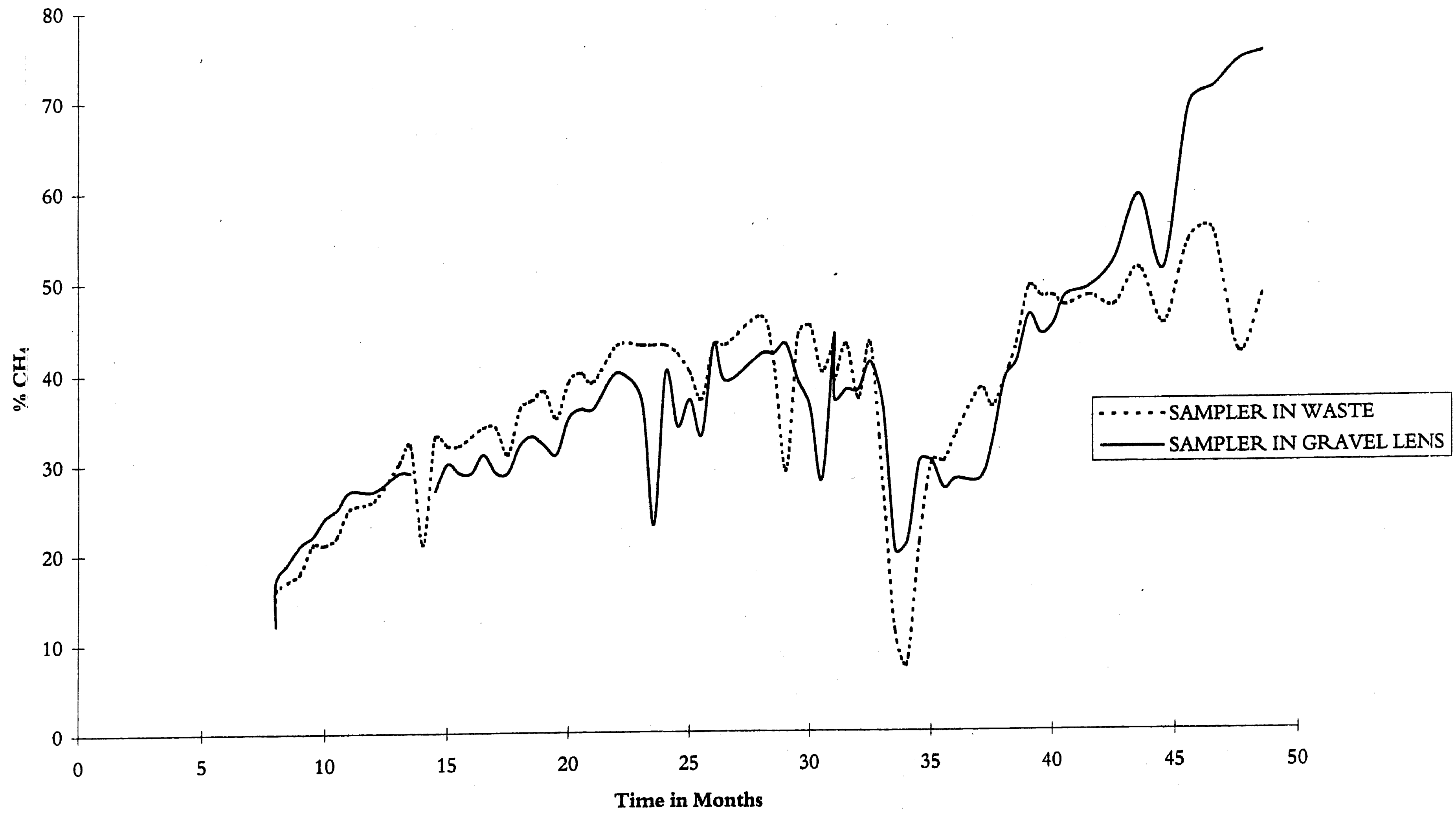


Figure 9 **Record of methane in gravel lens and in the superimposed waste.**

and the concentrations of migrating methane. The figures, taken at 2-weekly internals demonstrated no discernible influence. It is usually assumed that transient gas released from landfills respond to changes in atmospheric pressure and can be recognised only by continuous monitoring of both variables.

6.4 Gas Monitoring in the Waste

Monitoring in the waste was undertaken with the following objectives:

- to demonstrate the pressure variations across the waste towards the liner;
- to compare methane concentrations in the waste with those beyond the boundary;
- to observe the pressure relief afforded by the line of perimeter wells to gas concentrations and pressures in the landfill.

Unfortunately, the position and elevation of well-heads was to limit the effectiveness of these measurements. In order to conform to planning requirements, the well-heads had to be finished below ground level so that the metal protective emplacements should not protrude above ground. As a result, during wet periods, run-off from the vegetated clay surface would collect within the surrounds, flood the well-heads and deny access for monitoring purposes.

Monitoring therefore had to be discontinued at many wells during the winter months. There was also an unfortunate interruption to monitoring in the summer of 1995 when several well-heads and their protective covers were accidentally wrecked when the agricultural cap was being ploughed. They were subsequently reinstated.

As a result of these interruptions the results of monitoring in the waste are limited to just six wells (four production, two monitoring) as shown in Table 9 (Appendix). (Well positions are shown in Figure 4). In the absence of continuous records for al the neighbouring wells, the presentation of results is confined to the display of assumed contours of equal gas pressure and equal methane concentration in the waste. They refer to three monitoring occasions selected because of the pressures and suctions observed in the perimeter pipeline and to demonstrate conditions under both high and low gas pressures in the waste. These are shown in Figures 11a, b & c and assume that there is a linear variation of pressure and concentration change between monitored wells.

The first example taken at 41.5 months was when there was a slight positive pressure (0.28") in the perimeter pipeline and pressures in the waste were between 0.4" and 0.7". The pressure gradient was towards the north-west across the liner and methane concentrations at 60% at the centre of the landfill, declined to 50% across the lower part of the liner. The corresponding methane concentrations of migrating gas beyond the barriers, were between 0.2% and 10% behind the liner and 12-27% behind the clay.

In the second example at 46.5 months, there was a –0.05" suction in the pipeline and pressures in the waste from +0.06" to –0.01" with the pressure gradient again towards the north-west. The methane concentration gradient was similarly from 60% down to 40% over the liner, but the migrating concentrations were 0.9% to 3.4% behind the liner and 10% to 11% behind the clay.

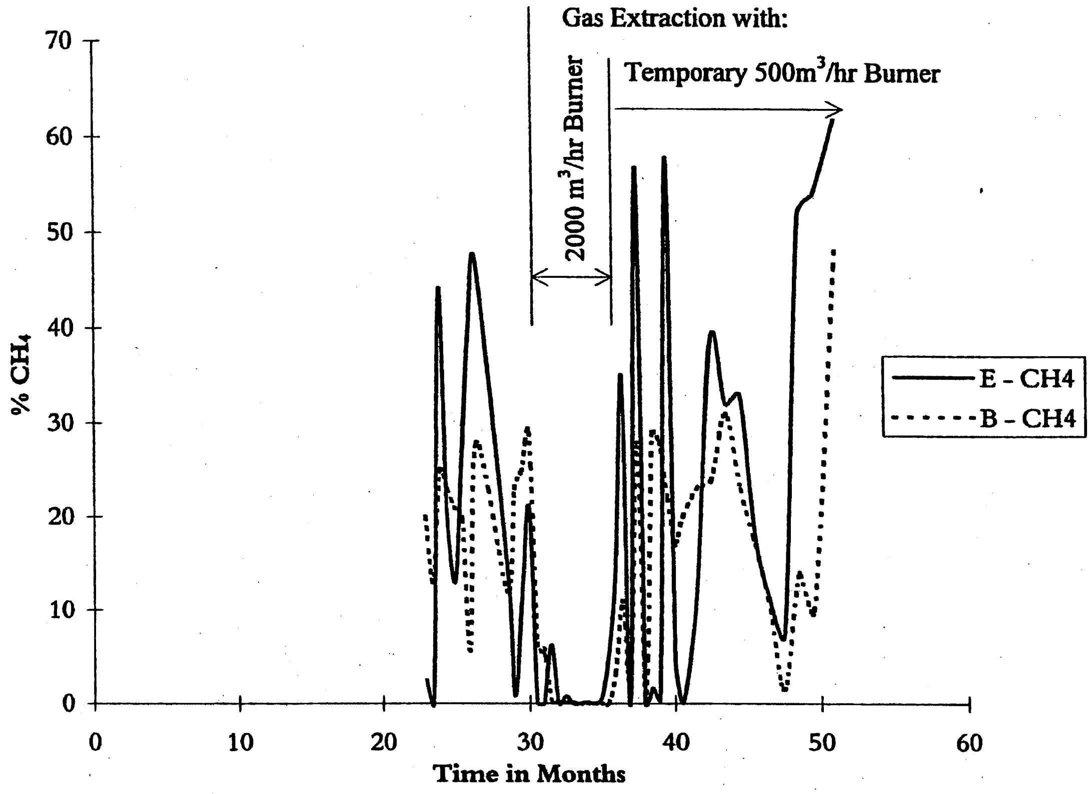


Figure 10a Migrating methane behind clay barrier (on either side of HDPE liner)

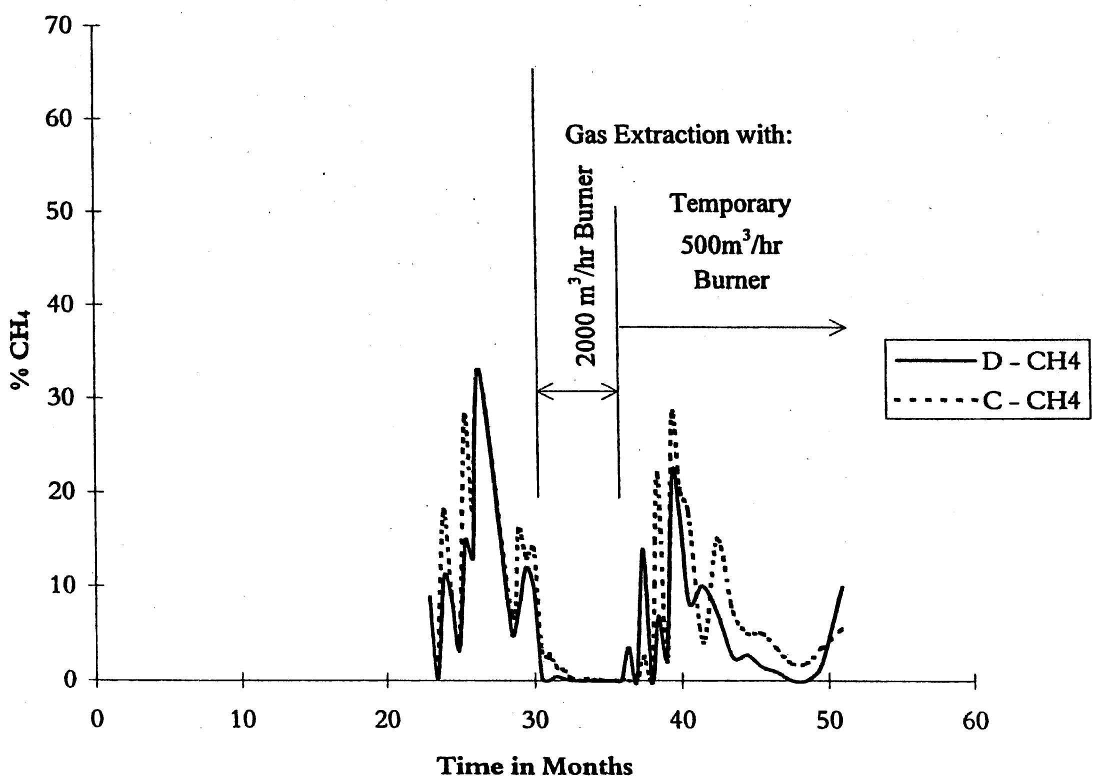


Figure 10b Migrating methane behind HDPE barrier.

In the final example at 51 months, there was a high pressure in the pipeline (+2.42") and the pressure gradient varied from +5.39" to + 1.95" but this time, the pressure gradient was more radial towards both the liner perimeter to the north and the pipeline to the west. There was negligible concentration gradient across the waste (from 64-61%) but the migrating methane concentrations were only 5.6% to 10% behind the liner and 49% to 62% behind the clay. In this case, it would appear that the main suction on the well-field was functioning only poorly and that the mobile flare on the pipeline was completely overwhelmed.

6.5 Temperature Measurements

Temperature results are presented in Table 10 (Appendix), showing recorded temperatures from three groups of sensors in the underlying clay beneath 5m, 9m and 16m of waste. Each group was intended to provide temperature gradients into the clay but only the lowest group gave a complete record, the others suffering from progressive equipment failure.

The results show that:

The temperature gradient in the clay beneath the waste typically dropped about one degree across 1.5m of clay – but only where it was superimposed by at least 9m of waste.

Measurements taken beneath 5m of waste were more erratic and at times showed a reverse gradient with temperatures rising slightly with depth into the clay. However, there was no evidence to suggest that temperatures beneath 5m of waste were influenced by seasonal ambient temperature variations.

During the first 18 months, the highest temperatures recorded in the clay were those beneath 5m of waste. Subsequently these declined, while those in the lower horizons increased until, after 4 years, they appeared to be stabilising. From then onwards, the temperatures, all measured at a depth of 0.5m into the clay liner, were typically 13, 16 and 18 degrees corresponding to depths of 5m, 9m and 16m respectively of superimposed waste;

One other sensor, placed immediately under the liner, beneath 5m of waste, gave temperature results similar to those measured on the clay at the same horizon but to the east of the liner.

6.6 Leachate Build-up within the Waste

Observations of leachate levels started in August 1994 (the 32nd month) after the gas wells were installed. Readings were taken in 10 wells to determine the pattern of accumulation across the area of the original excavation.

There are no arrangements for the extraction of leachate from this area of the landfill.

The layout of the observation wells is shown in Figure 4 and the results from six of them compiled in Table 11 (Appendix). Well 14/6 was situated above the liner where it crosses the horizontal bench. This has shown that leachate has accumulated and stabilised to a maximum depth of 1.5m at this point half-way up the slope. The only wells to penetrate towards the base of the landfill (at +36.0 mO.D.) are production wells 14/4 and 14/5 and the observation well S at the toe of the liner. Unfortunately, 14/5 suffered excessively from damage and surface flooding; this record of readings is therefore sparse and intermittent.

The observations well S remained dry for 33 months, up to September 1994, but in the following 15 months the level of leachate rose 1 metre. Meanwhile at the centre of the original hole at 14/4, the level of leachate had risen by February 1996 to +40.45, indicating a standing leachate depth of at least 4m. A plan of the leachate contours is shown in Figure 12 demonstrating how the surface profile of the saturated zone is influenced by the shape of the containment hole with its sloping sidewalls. It also shows that the level of the water table in the surrounding gravels is +49.5m O.D. ($\pm$ 0.5M seasonal variation). There is therefore a head difference of at least 9m between this the accumulated leachate level in the waste on the base of the cell.

This mean annual rate of increase in leachate levels over the base, is equivalent to say 400mm of infiltration assuming a porosity of 40%. However, the normal annual precipitation of 600mm for this area is expected to yield a nett infiltration of no more than 10%, or 40mm, taking into account evapotranspiration and run-off. It is therefore deduced that there must be an ingress of groundwater into the waste through the sides of the landfill.

7 DISCUSSION

7.1 Scope of Study

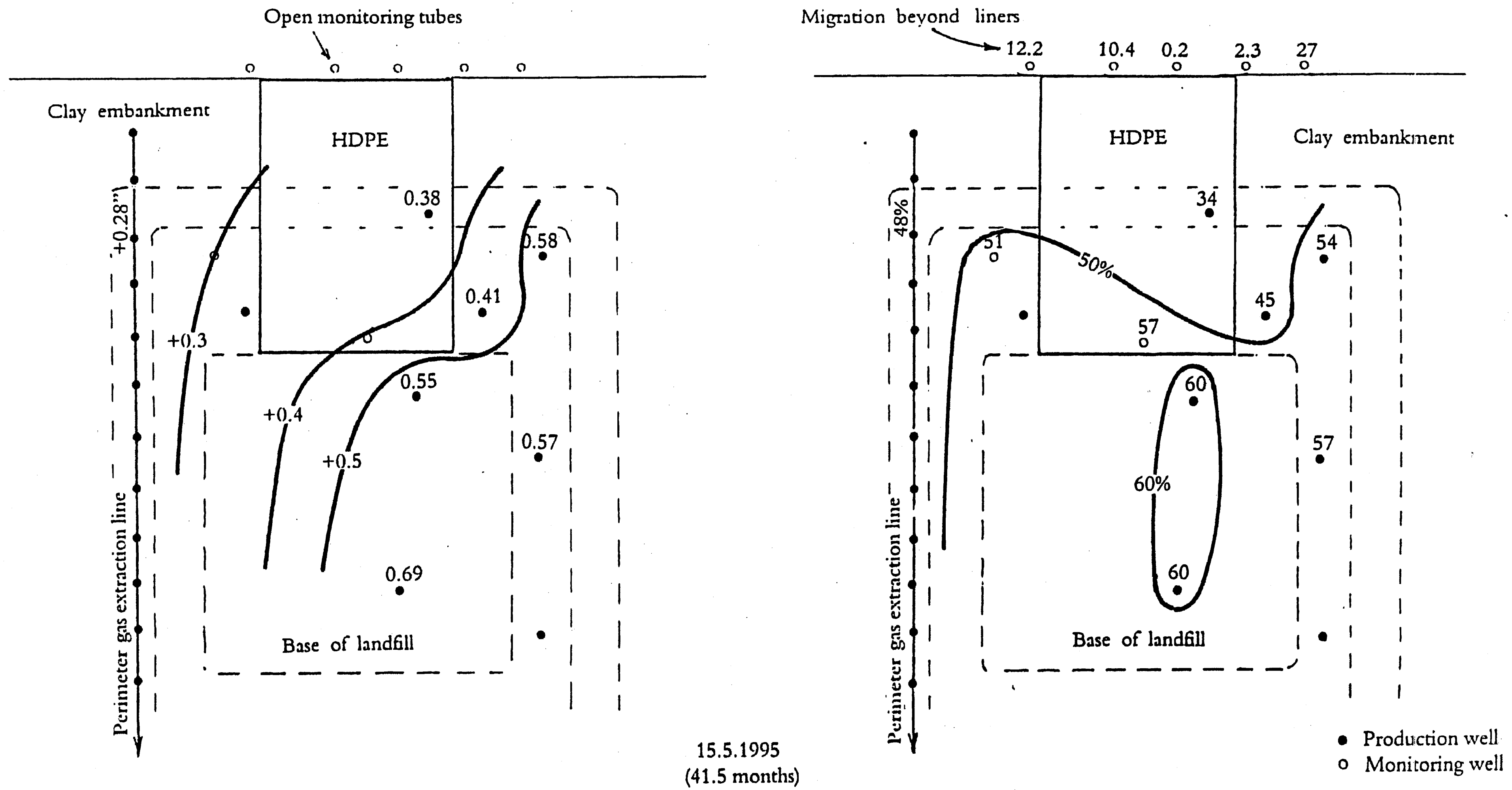
When the project started, it was envisaged that the study would be limited to sampling for gas beneath the liner, to confirm the integrity of the membrane as a barrier to gas flow. It would then be compared with the characteristics of the clay. In the event, observations were extended to include the monitoring for migration behind the liners and the collection of data about gas quality and pressure configurations in the waste overlying and surrounding the experimental area.

In this, the project was greatly assisted by the fortuitous breakdown of the main flare extracting gas from the landfill, and by its temporary replacement with a smaller flare of one quarter the capacity. As a result the liners and monitors were subjected to much greater pressures and concentrations than those anticipated when the well-field operated under normal suction conditions.

7.2 The Effectiveness of the Monitoring Installation

To monitor for the presence of landfill gas behind the HDPE liner, it was imperative that the edges of the liner be sealed into the underlying clay to avoid the seepage of gas round the edge. It was also desirable to ensure that the samplers installed underneath, were isolated from each other. This was made more difficult by the need to lay the liner on a bed of sand, permeable to gas, that could provide paths for the possible movement of gas between samplers. The construction of cut-off flaps extending into anchor trenches in the clay appeared to be successful in impeding flow across or around the edge of the liner. This was encouraging since at the time when the anchor trenches were being backfilled with clay, it was difficult to consolidate the material when it was lumpy and dry. It remains questionable whether there was any interconnection of gas flow between two samplers that leaked persistently at different levels in the centre of the liner. If such a connection existed, a single leak at the intermediate level could have indicated a spurious leak at the upper level. However, to do this, the gas would need to traverse a circuitous path up and across the bench and beneath the cut-off flaps, before reaching the 24m to the upper sampler. Such a scenario is thought to be unlikely, but the circumstances remain suspicious.

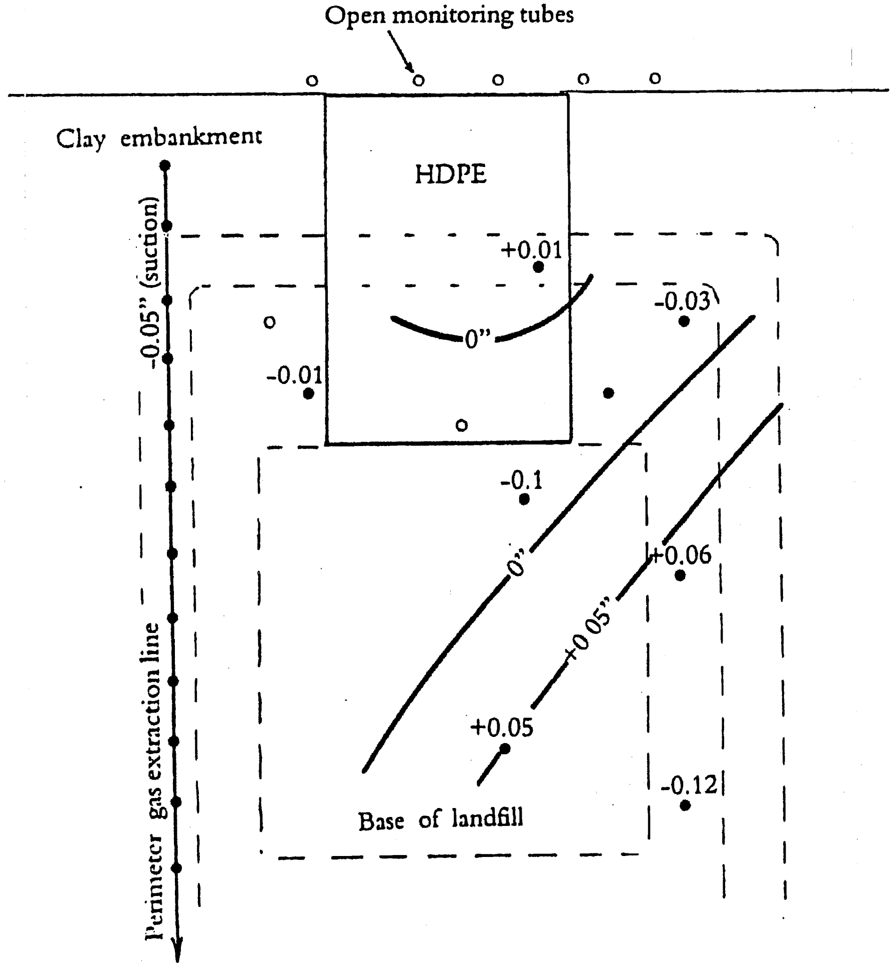
By contrast, the isolation between samplers positioned along the same horizon appears to have been achieved, even though there were no cut-offs to impede horizontal gas flow. In the installation of the liner, exceptional care was taken to ensure that it was laid to specifications, but the specialist installer had to content with delays incurred in placing the samplers and their tubes in position. With the lower, and parts of the intermediate layers, problems were exacerbated by heavy rain that caused prepared profiles and bedding to be washed out; they had to be replaced hurriedly to standards that were probably not so good as they were before. Nevertheless, it is unlikely that these difficulties would have contributed towards damaging the membrane and causing small leaks.



Gas pressure contours in waste (inches H_2O)

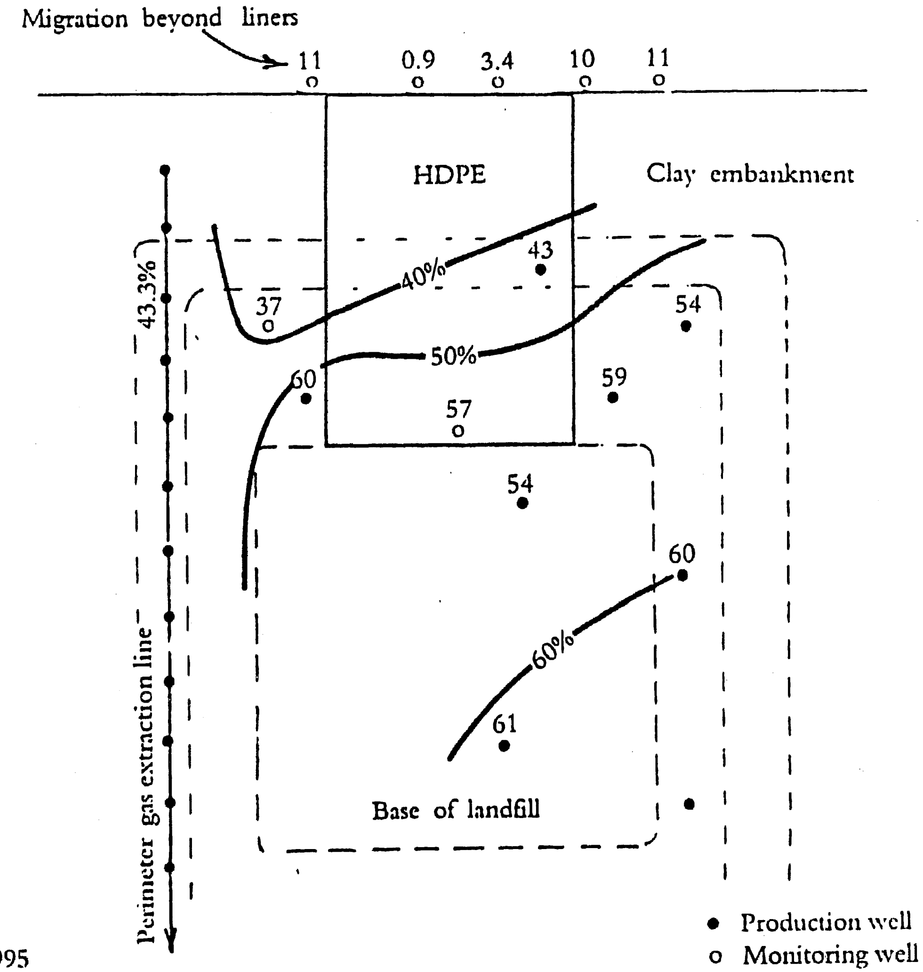
Percentage methane contours in landfill gas.

Figure 11a Contours of gas pressures in waste and methane concentration in waste and in adjacent gravels (at 41.5 months)



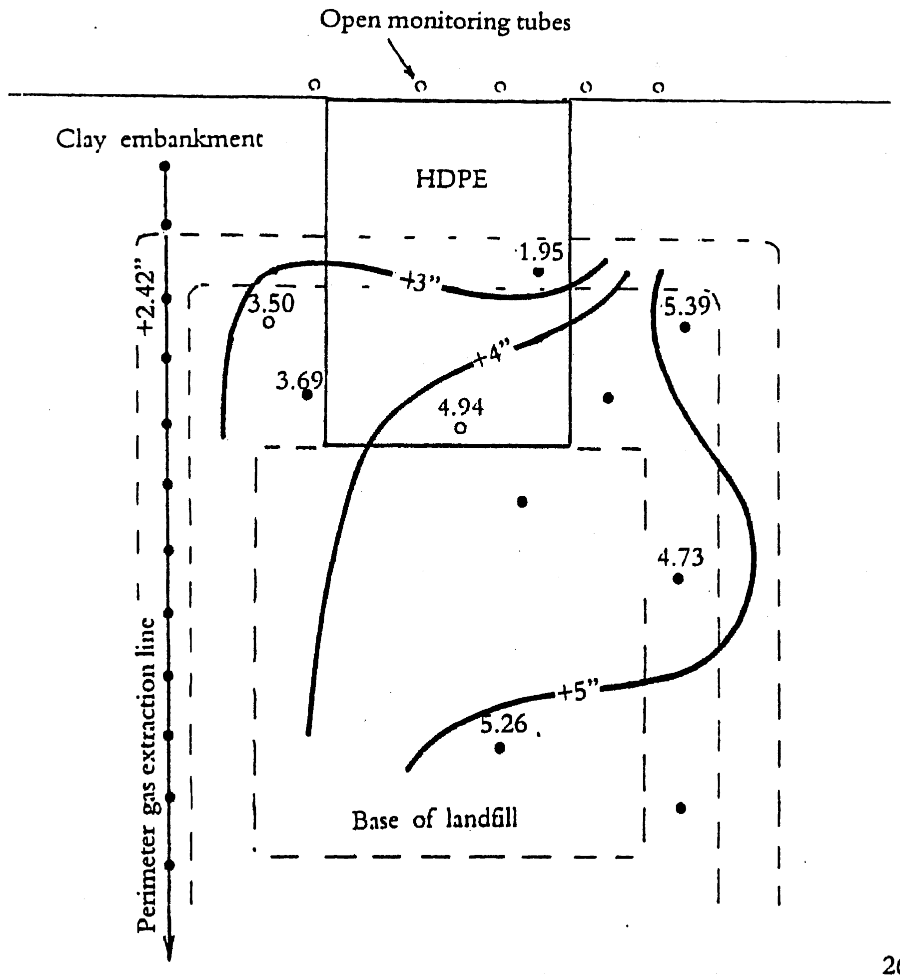
Gas pressure contours in waste. (inches H_2O)

17.10.1995
(46.5 months)



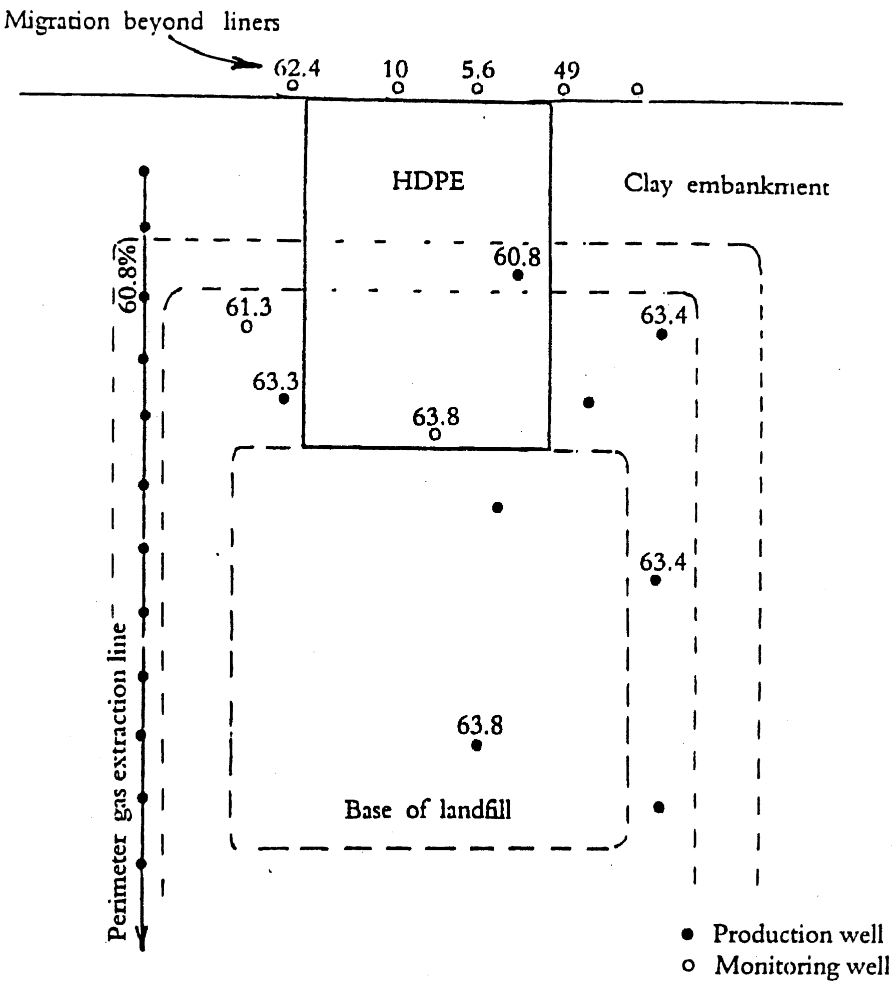
Percentage methane contours
in landfill gas.

Figure 11b Contours of gas pressures in waste and methane concentration in waste and in adjacent gravels (at 46.5 months)



Gas pressure contours in waste. (inches H_2O)

26.2.1996
(51 months)



Percentage methane in landfill gas.

Figure 11c **Contours of gas pressures in waste – methane concentration in waste and adjacent gravels (at 51 months)**

7.3 Limiting Off-Site Migration

The observed presence of gas in the gravels behind the lined embankment, suggests that migration is overwhelmingly influenced by gas pressures in the waste and thus by the efficiency with which gas is extracted. By contrast, the presence of methane at certain points under the liner had always registered zero pressure, regardless of whether the samplers had been kept shut or left open at the sampling tube outlets. Such results suggest that the rate of leakage through the HDPE membrane was very slow and not strongly influenced by gas pressure in the landfill. The leaks provided an insignificant contribution to the flux of gas migrating into the gravels, emanating overwhelmingly from the clay-faced embankments on either side.

The measurements of migrating gas behind both clay and HDPE liners moved in unison, with the levels behind the liner always being lower than those behind the clay. It is probable that evidence for elevated gas levels behind the HDPE liner occurred through the lateral spread of gas in the unsaturated upper 3-4m of gravels from behind the clay. If this were so, the indicated migration levels behind the liner were exaggerated; it would also indicate that the liner width of 50m was insufficient for this trial.

It was noted that, for the duration of the experiment, crops continued to be grown in the field overlying those gravels who edge lay just 5m behind the crest of the embankment and the monitoring tubes. In three successive years, crops of rapeseed, potatoes and beans were grown and at no time were there any signs of distress or die back in the crops. Unfortunately no soil temperature measurements were taken to examine for the possibility of methane oxidation taking place in these soils.

The importance of the influence of the perimeter pipeline became apparent only in the latter stages of the project following the build-up of gas in the waste and after a monitoring point was installed in the line. Before that time there was no indication of whether the perimeter extraction was working or not.

The intermittent function of the perimeter line has distorted the contours of gas pressure and, at times, gas quality in the waste above the liner. This has rendered the interpretation of results more difficult in this corner of the landfill. Instead of there being an area of relatively uniform characteristics, or a flow towards the northern boundary, the perimeter line has created a variable induced flow westwards parallel to the experimental boundary.

From the intermittent records, in only one case (Figure 11c), were the methane concentrations in the waste both high and constant when the influence of the perimeter line was ineffective. Under these conditions the methane migration into the gravels was very high behind the clay (62% and 49%) whereas behind the liner comparable readings were (5.6% and 10%). No concurrent measurements beneath the liner were possible owing to the samplers being flooded with groundwater.

Temperature measurements, taken in production wells, showed large variations between neighbouring wells, and suggested that methanogenic activity in the waste was both patchy and localised. However, spatial differences were not apparent from the well measurements of gas quality and pressure as portrayed by contours across this part of the landfill.

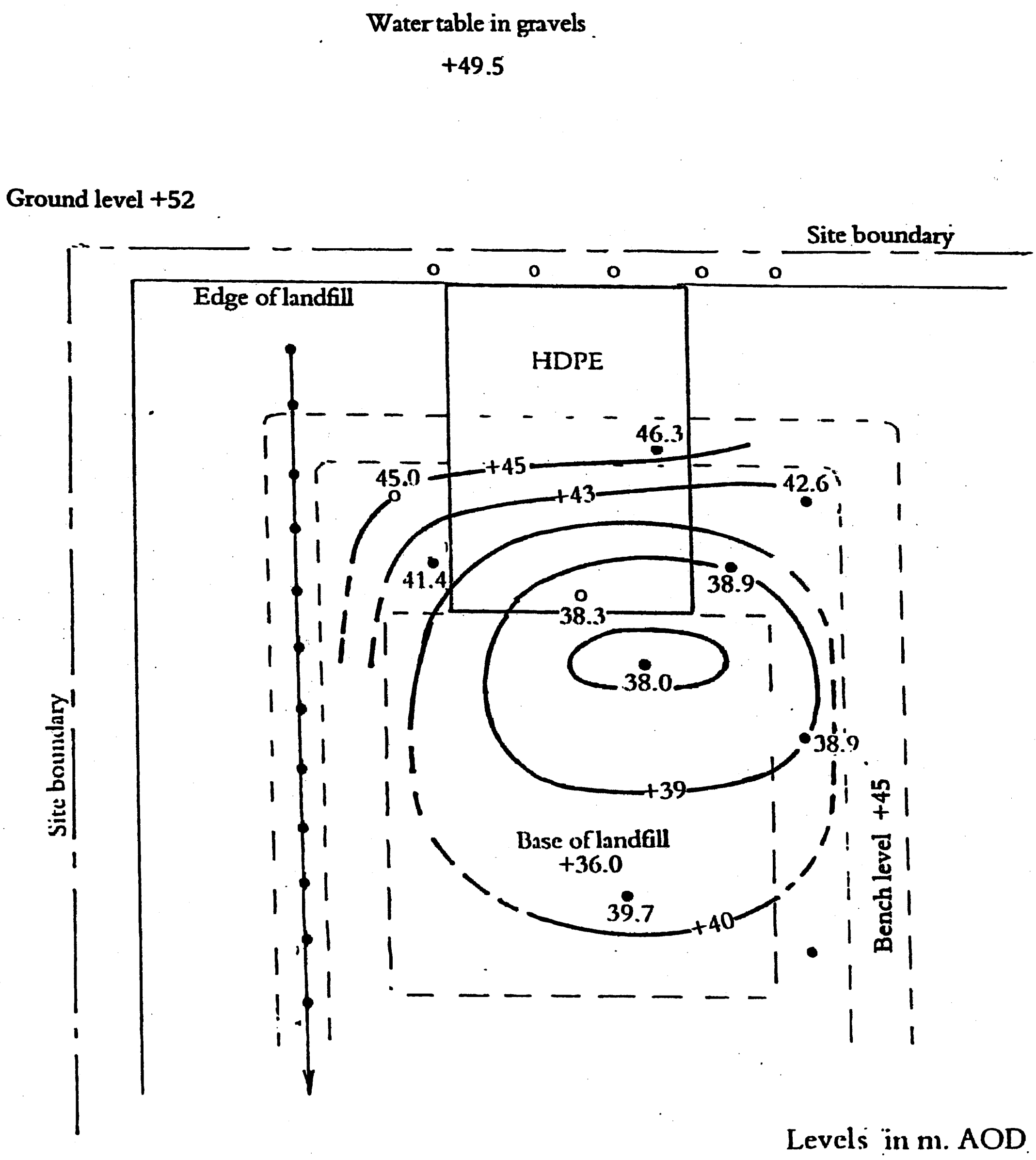


Figure 12 **Contours of leachate level in waste.**

7.4 Accumulation of Leachate

The conversion to methanogenesis in the landfill has been slow, despite early trace measurements of methane in the lower samplers. One of the reasons for this is that the site is considered to be dry at least originally, but the liberal use of clay as intermediate daily cover, has impeded the mass movement of moisture within the body of waste. It is likely that there will be many perched leachate tables within the waste, although this could not be verified from the leachate measurements in production wells, all of which were slotted throughout the depth of waste. Experience with water accumulation at the well heads in winter confirmed that the clay cover combined with the domed profile was effective in impeding infiltration into the waste.

With the numerous layers of impermeable clay sandwiches down the profile of the waste, the resulting infiltration will have been insufficient to account for the rate of leachate accumulation at the base. It is suggested that groundwater may have entered by two routes. The first is that it may have penetrated the base of the surrounding embankment and flowed down the buried face of the undisturbed Gault. The second is that there may have been an inflow of leachate from the previously deposited waste to the south, with which it is in hydraulic continuity. Both of these views are supported by the configuration of the leachate level contours which were elevated around the rim of the hole at the north end, but also showed a cross fall from the south end of the cell, northwards towards the centre.

7.5 Longer Term Implications

This four-year study has demonstrated the undoubted superiority of HDPE over clay as a barrier to gas migration and has provided a detailed record during the methanogenic growth phase in the landfill. However, within the projected life-span of the landfill it has covered only the preliminary phase. While little change is anticipated in conditions and observed monitoring trends, apart from leachate accumulation, it might be valuable to pursue infrequent monitoring in future years. The object would be to establish the extent to which, if any, there has been any deterioration in the synthetic liner. Also, there might be some material change in the current limited integrity of the clay following further consolidation of the replaced and re-worked clays. Such information would be supplementary to the regular monitoring of wells in the waste, carried out routinely by the landfill operator, Greenways Landfill.

8 CONCLUSIONS

HDPE lining material is intrinsically efficient as a barrier to halt the migration of landfill gas into adjoining land. However, it is unrealistic to assume that a membrane will remain completely gas tight after the on-site assembly of the component sheets and the deposition of waste. Experience in this trial has shown that despite every care being taken, small leaks subsequently materialised that were measured immediately beneath the membrane. However, the leakage rate was so low that it gave rise to nil pressure readings regardless of the pressure in the landfill. Any resulting migration was so small that it could not be identified from the much larger migration emanating through the adjacent clay barrier.

The Gault clay, when reworked and consolidated, was confirmed it to be an ineffective barrier to the passage of landfill gas. Nevertheless, its low hydraulic conductivity confirmed it to be an efficient retainer of leachate under the limited heads in this landfill.

These results could have significant implications for guidance on, and recommendations for, suitable liner materials to prevent off-site gas migration from landfill sites. In particular the study has shown that natural clay liners have a limited capacity to inhibit the passage of gas and that their role is perhaps more suited to that of back-up for gas extraction systems installed as the primary protection against migration. It has emphasised the need for having a gas extraction and control/recovery installation of adequate capacity to match the anticipated scale of gas generation.

9 REFERENCES

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(4) Greenways, West Catherine, Personal Communication.

APPENDIX TABLES OF RESULTS

Date	West (Manhole 4)								Centre (Manhole 3)								East (Manhole 2)							
	Double Blue				Single Blue				Double Blue				Single Blue				Double Blue				Single Blue			
	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O
28/5/92	0	21	0	*	0	21	0		-	-	-		0	0	0.8		0	1.5	0.1		0	1.5	0.2	
12/6/92	0.1	12	1	*	0.1	10	1		2	14	1		1	7	0.5		0	0.6	0.1		19	0.5	79	
23/6/92	0	15	7	*	0.6	15	5		2	8	4	*	1	15	4	*	0	0.4	0.4		16	0.1	91	
28/7/92									-	-	-		2	11	24	*	0.6	0.8	0.4		18	0.7	76	
14/8/92	-	-	-		0.1	15	2.5		0.8	12	34	*	2	10	38	*	3	0.9	0.2		20	0.7	79	
28/8/92	1	10	7.3	*	2	7.3	35		0	1.1	1.6	*	2.3	4.8	46	*	5	0.6	0.3		22	0.3	68	
11/9/92	0	14	0.3	17*	0.9	14	0.8	*	0	21	0.7	*	2.2	8.6	50	*	3	4.4	22	*	24	0.4	68	
17/9/92	3	13	26		4	7	48		1	6	36	*	3.5	9.1	11	W								
30/9/92	0	21	0		-	-	-		-	-	-		-	-	-	*	-	-	-		-	-	-	*
20/10/92	3.4	16	3	*	1.2	10	11	*	2	0.6	5.4		2.8	8.4	4.3	*	3	8	3	*	7	17	47	*
4/11/92	0.3				1.4				0				1			*	1							
6/11/92					0.7				1.5			*	0..7			*	12	0.9	0.4		3			*
23/11/92																								
30/11/92																								
1/12/92																								
14/12/92	3.0	5	33	*	0.9	13	30	*	2.6	3.2	30	~	1.5	12	23	~	11	7.5	31	*	2	8.2	34	*
5/1/93	8.7	8.5	28	*	0.9	11	27	*	2.8	10	39	*	3.8	11	38	~	-	-	-	W	4.8	13	28	*
19/1/93	0.4	20	2.0	~	0	21	1	19	0.3	20	2.2	17	0	21	0.3	*	-	-	-	W	2.1	9.9	40	*
2/2/93	0	21	0.7	*	0	21	1.9	*	-	-	-	W	-	-	-	W	-	-	-	W	1	14	26	*
15/2/93	7.2	13	20	~	1.8	17	10	~	5.1	13	12	17	0	19	1	~	5.2	0.3	1.0	14	3.8	13	25	*
2/3/93	7.8	12	29	~	6.6	12	26	~	5.7	13	2.1	~	0.2	19	2.7	~	8.4	0.9	1.2	14	6.4	13	20	~
15/3/93	0.7	15	11	*	1.6	20	4.2	*	13	1	3.4	16	2.8	10	36	*	10.4	0.8	0.8	14	1.1	13	31	~
30/3/93	1.3	14	20	*	1.8	12	31	*	11	3	4.4	16	1	12	6	~	11	0.8	1.0	16	0.9	16	21	*
16/4/93	0.5	-	-	20C	1.5	13	6.5	*	23	0.8	7	14	0.4	12	5.6	*	0	21	0..3	~	0.3	17	14	*
30/4/93	6.1	9.6	36	*	5.5	8.3	44	*	17	1.6	4.8	9	1.1	13	-	~	0.1	17	2.8	*	1.0	12	32	~
17/5/93	4.5	12	30	*	2.2	13	30	*	16	1.2	5	16	1.6	13	25	*	0	13	9.9	~	0.6	12	17	~
7/6/93	3.5	10	35	*	2.4	10	40	*	16	0.1	5.3	16	5.0	4.3	57	*	9.3	0.1	0.6	20	3.1	8.4	46	~
18/6/93	5.4	11	14	*	4.4	12	30	*	16	0.4	5.6	14	5.7	8.3	16	*	9.2	0.3	0.8	18	0.7	13	21	~
2/7/93	4.5	10	37	~	7.4	3.6	60	*	16	0.1	5.6	19	3.1	11	37	~	9.9	0.2	0.7	13	0.6	18	11	W
23/7/93	4.2	8.4	40	*	4.1	7	48	*	16	0.5	6.0	~	3.1	9.6	42	*	10.2	0.3	0.8	17	1.7	10	42	*
10/8/93	2.7	9	36	~	5.5	8	43	*	16	0.1	7.1	~	6.3	3.6	57	*	12	0.1	0.9	16	2.5	9.5	43	~
22/8/93	0.6	14	4.1	9	4	7.7	49	*	17	0.1	17	16	2.0	11	36	*	17	0.1	1	16	1.5	1.8	36	*
7/9/93	2.4	11	34	~	2.5	11	33	~	17	0.1	8	13	5.7	5.4	50	*	17	0.1	1	15	11	3.7	30	*
1/10/93	4.2	1	10	~	6.7	5	50	~	19	0.4	9	19	4.4	6.8	48	*	20	0	1.5	4	27	0.1	29	5
25/10/93	0.8	16	6.6	~	5.1	7.3	44	*	20	0.3	8	17	5.4	6.4	43	*	0.7	13	18	*	1.3	12	22	*
15/11/93	1.5	17	1.5	~	1.4	15	4.8	~	24	0.3	9	17	0.9	17	3	*	7.8	5.4	1.7	~	0.4	18	16	~
30/11/93	0.2	19	4.9	~	1.4	12	3.2	~	26	0.7	9.7	15	1.0	16	3.5	*	0	19	1.4	~	0.5	17	3.6	~
10/12/93	0.6	15	21	~	1.6	15	24	~	27	1.0	10	15	0.9	15	8.1	*	0.6	14.4	19	~	0.8	16	13.4	~

TABLE 1 Upper Level Samplers Under HDPE Liner (20-24m Down Slope from Top of Liner)
Percentage Concentrations of Gases in Samplers

Date	West (Manhole 4)								Centre (Manhole 3)								East (Manhole 2)							
	Double Blue				Single Blue				Double Blue				Single Blue				Double Blue				Single Blue			
	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O
23/12/93	0.2	20	0.7	~	0.6	19	1.5	~	32	0.7	11	15	0.9	18	4.6	*	No readings with trap				1.0	18	2.8	~
10/1/94	1.3	16	6.5	~	4.7	7.5	39	~	31	0.6	11	15	2.5	12	23	~	No readings with trap				0.1	20	2.8	~
25/1/94	0.3	13	21	*	1.8	13	25	*	32	0.4	12	16	8.5	7.3	38	*	No readings with trap				0.3	16	6.5	*
11/2/94	0.4	15	15	~c	0.7	16	11	~c	33	0.8	12	16	0.7	17	6	~w	0	16	11	~	0	19	4.0	~
11/3/94	1.0	11	17	*	3.0	9	36	*	39	1.0	13	13	6.3	9.5	30	*	4	7.8	29	*	4.5	6	47	*
25/3/94	0.5	12	25	*	1.9	13	29	*	41	0.3	13	17	4.9	13	28	*	1.3	11	22	*	0.9	5.6	43	*
8/4/94	1.3	13	23	*	8.7	6.4	37	*	43	0.5	14	17	2.3	13	26	*	1.0	13	21	*	1.6	11	25	*
26/4/94	0.8	9.4	28	*	3.0	12	28	~	42	0.4	14	16	2.0	13	24	~	0	20	0.2	*W	0.4	9.4	32	*
9/5/94	0.3	11	22	*	1.5	13	23	*	42	0.1	13	16	1.9	12	25	*	0.8	4.1	31	*	0.2	9.8	30	*
24/5/94	0.1	12	6	*	5.8	9.2	11	*	44	0.5	14	~	1.7	14	8	*	0.5	13	23	*	0.7	12	21	*
9/6/94	0.8	12	9	*	3.8	11	26	*	45	0.3	14	~	1.6	13	9	*	0.7	14	6	*	24	0.3	19	~
23/6/94	0.2	12	20	*	1.3	13	24	~	43	0.2	14	16	1.7	13	16	*	0.5	11	21	*	21	0.3	18	~
5/7/94	0	14	16	*	1.7	12	26	*	40	0.2	14	16	0.3	16	15	*	0.2	13	18	*	0	15	17	*
25/7/94	0	12	18	~	0.3	9.6	23	~	39	0.1	13	15	0.5	14	21	~	0.3	12	20	~	16	4	20	~
8/8/94	0	13	18	~	0.2	13	19	~	37	0	14	15	0.4	14	19	~	0.5	11	17	~	17	4	17	~
18/8/94	2.6	7.9	7.4	15	0.1	14	18	*	37	0.1	14	16	9.3	0.6	36	*	0	14	18	*	18	1.6	18	*W
5/9/94	4.5	0.7	13	~	0.4	12	24	*	38	0.1	15	16	0.4	11	10	*	22	0	2	17	19	2	19	~
22/9/94	4.3	0.3	13	19	0.3	11	27	*	35	0.3	15	15	0.3	12	24	*	20	0.2	2.4	17	18	1.6	19	~
7/10/94	4.4	0.1	13	18	0.3	14	18	*	36	0.1	16	15	0.1	13	18	*	23	0	2.5	19	0,1	6.4	32	*W
24/10/94	0	16	3.9	*	0.2	15	16	*	36	0.7	15	14	0	15	4.8	*	3.1	11	4.4	*	19	3.3	19	~c
7/11/94	0	15	11	*	0.2	15	17	*	33	0.2	17	14	0	17	2.8	*	0.4	15	3.2	*	20	1.7	24	*
21/11/94	5.4	0.4	15	19c	0	15	6.9	*	32	0.4	23	16	0	15	7.7	*	24	0.3	3.4	17	0.2	17	7.1	*
28/11/94	4.7	1.2	15	18	0.5	19	10	*	34	0.4	25	14	0.2	18	5.4	*	27	0.3	3.2	17	1.8	15	9.7	*
12/12/94	3.0	4.5	12	19	0	19	2.4		21	3.9	21	14	0	20	1.4		21	4.1	2.5	16	2.3	18	7.6	
6/1/95	4.9	0.8	16	~	5.8	8	32	*	25	0.7	26	18	1.4	11	28	*	28	0.8	3.7	19	21	2.4	20	~w
16/1/95	3.7	0.7	16	19c	3.6	10	29	*	30	0.7	27	16c	0.9	16	17	*	29	0.6	4.3	16c	3.6	17	5	*w
30/1/95	1.9	11	22	~	1.0	12	24	~	1.6	16	12	~	0	19	3.7	~w	0	20	0.7	*	0	18	5	*
14/2/95	2.3	8.4	9.6	11	2.2	13	20	~	2.3	14	18	*	1.7	13	20	~	0.8	14	19	*	0.7	13	21	*
6/3/95	5.1	1.6	16	19	0.7	16	9	~	32	0.6	14	19	2.0	14	18	*	1.1	15	14	*	2.0	14	19	*
16/3/95	4.7	1.4	17	19c	1.6	15	17	*	28	0.6	16	19c	1.3	16	15	*	0.6	17	12	*	0.9	15	15	*
31/3/95	3.9	2.1	15	18	0.5	17	8	~	28	1.7	16	18c	5.7	13	18	~c	0.4	15	13	~c	0.4	16	11	~c

Table 1 (continued)

Date	West (Manhole 4)								Centre (Manhole 3)								East (Manhole 2)							
	Double Blue				Single Blue				Double Blue				Single Blue				Double Blue				Single Blue			
	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O
13/4/95	2.4	0.1	17	18	1.3	13	19	*	28	0.2	17	19c	1.8	11	23	*	0.5	14	18	*	0.6	14	22	*
15/5/95	3.7	1.9	16	18c	2.0	14	13	~c	27	1.3	19	19c	1.4	12	15	~c	1.0	8.3	26	~c	0.8	8.5	28	~c
19/6/95	4.3	1.8	16	~	8.0	8	19	~c	29	0.5	19	16	2.0	11	26	~	20	1.5	4	~	1.9	18	6	~w
18/7/95	4.4	1.8	17	~	1.9	9.7	25	~	29	0.2	20	16	1.1	13	21	~	0.5	11	22	~C	18	2.9	19	~
15/8/95	4.1	3.3	14	16C	1.0	13	15	~C	23	3.7	16	~C	5.3	10	19	~C	0.4	10	12	~C	18	2.4	18	~C
25/9/95	6.0	0.5	19	17	5.3	8.4	33	*	28	0.3	21	16	2.6	5.2	40	*	24	0.2	5.2	19	8.7	2.7	45	*
17/10/95	5.3	0.1	19	18	1.3	3.7	39	*	29	0	21	18	1.3	9.3	33	*	0.3	8.1	31	*	21	1.6	23	*
20/11/95	2.7	10	10	12C	0.3	9.2	35	*	28	2.6	19	16C	0.1	16	12	~	0.1	6.2	28	*	2.6	4.3	36	*
12/12/95	5.4	0.6	19	~	0.0	14	26	*	30	0.3	22	~	1.3	11	33	*	27	0.2	6	~	2.8	18	3	~W
31/1/96	0.1	16	11	*	0.6	17	17	*	1.1	15	7	*	1.1	14	9	*	0	18	5	*	0.3	17	14	*
26/2/96	0.1	17	6	W	0.1	19	2	W	W	W	W	W	0.2	18	6	W	0.1	20	1	W	W	W	W	W

Table 1 (continued)

Key: ~ = flow continued at suction > -20" H_2O
w = water in sampler
* = Analox pump cut-out by restricted flow
c = continuity of gas flow through sampler

Date	West (Manhole 4)				Centre (Manhole 3)				East (Manhole 2)			
	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O
11/2/94	5.2	10	30	~c	0.5	9.6	23	~c	0	14	24	~
11/3/94	4.1	7.6	38	*	4.3	6.3	42	*	1.3	3.0	40	~
25/3/94	2.6	11	34	*	1.9	11	33	*	1.9	4.0	27	W*
8/4/94	8.5	6.1	43	*	8.1	12	31	~	1.4	1.4	30	~
26/4/94	4.3	5.7	40	*	4.0	10	33	~	0.5	2.2	33	~
9/5/94	6.1	6.5	38	*	33	0	33	~	0	10	31	~
24/5/94	3.9	8.2	13	*	1.9	12	28	*	0.4	0.9	20	~
9/6/94	2.3	12	6.6	*	2.5	11	28	*	0.1	10	30	*
23/6/94	1.0	12	26	*	22	0.6	2(8)	~	0	10	26	*
5/7/94	5.2	6.7	38	*	0.6	14	24	~	1.0	1.4	33	~
25/7/94	2.5	11	27	~	21	0.1	13	~	1.2	4.4	27	~
8/8/94	1.3	13	18	~	0.5	13	26	~	0.4	2.0	26	~
18/8/94	0.9	13	23	*	0.6	14	23	~	0	2.6	22	~
5/9/94	1.3	11	27	*	34	0.6	4	~	0	4.5	32	20-17
22/9/94	2.3	9.2	34	*	17	1.0	3.8	~	0	3.8	32	~
7/10/94	0	12	23	*	14	1.3	3.7	~	0	1.7	18	~
24/10/94	0.3	14	4	*	26	1.8	20	~W	0	5.9	32	~
7/11/94	0.3	16	12	*	22	0.2	3.3	~	0	6.7	6.8	~
21/11/94	0.6	15	8.1	*	18	3.0	4.2	~	0	6.7	10	~
28/11/94	0.6	17	7.8	*	0.1	7.6	26	*	0.1	12	9.2	~
12/12/94	0.3	19.	2.1	~	6.1	12	8.3	~	0	20	2.3	~
6/1/95	14	3.5	47	*	37	0.7	3.7	~	0	4.5	46	*
16/1/95	6	8.2	37	*	20	0.9	12	~C	0.5	13	30	*
30/1/95	3.5	11	29	*	3	0	34	~W	0	18	1.0	*
14/2/95	4.8	12	27	*	32	0.1	28	~C	0	10	29	*
6/3/95	2.6	18	8.2	~	8	15	5.1	~W	0	10	34	*
16/3/95	2.6	15	18	*	25	2.9	20	~C	0	13	25	*
31/3/95	1.6	16	8.6	~C	10	5.7	9.7	~C	0	13	19	~
13/4/95	2.3	13	25	*	1.5	13	27	*	5	2.8	16	~
15/5/95	3.7	11	24	~C	30	2.5	3.2	~C	0	6.6	37	~C
19/6/95	1.6	11	16	~	23	2.7	3.1	~	0	6.0	39	~C
18/7/95	6.0	6.0	34	~C	37	3.4	15	~	0	8.8	27	~
15/8/95	2.5	10	14	~C	15	5.5	27	~C	0	7.9	32	~C
25/9/95	6.9	3.6	46	*	2.2	8.7	33	*	0.4	2.2	46	~
17/10/95	8.0	3.2	48	*	45	0.2	3.9	~C	0	14	15	*
20/11/95	5.1	7.3	44	*	17	11	2.1	~C	0.1	5.1	35	~
12/12/95	2.2	11	33	*	32	0.2	4.1	~C	0	7.8	40	*
31/1/96	6.5	12	29	*	2.1	13	24	*	0	14	18	*
26/2/96	2.0	16	11	w	0.6	17	9	w	0	20	0	w

Table 2 (continued)

Key: ~ = flow continued at suction > -20" H_2O
* = Analox pump cut-out by restricted flow
w = water in sampler
c = continuity of gas flow through sampler

Date	West (Manhole 4)				Centre (Manhole 3)				East (Manhole 2)			
	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O
18/12/91	2	12	-		2	12	-		2	11	-	
23/1/92	0	20	0		0.1	0.4	0.2		0	17	0.3	
3/2/92	-	-	-		0.5	0	0.2		0.2	0	0	
27/2/92	0	20	0		0.3	2.9	1.8		0	20	0	
17/3/92	-	-	-		2.2	0	0.7		22	0	0.3	
28/5/92	0	21	0	w	16				0	20	0	
12/6/92	0	16	9	15	17	1	2	1	44	2	10	~
23/6/92	0.6	6	47	4	16	0.2	0.4	5	1	12	3	0.3
28/7/92	-	-	-		25	0.4	8	0.2	3	6	44	0.4
14/8/92	-	-	-		33	0.8	0.5	5	39	0.8	14	*
28/8/92	0	21	1.5	*	32	0.4	0.7	6	31	0.5	13	0.3
11/9/92	0.2	15	0.7	*	20	0.6	10	5	20	0.7	14	*
17/9/92	No gas flow under pressure				7	Pressure test - no water			Circulation - no water			
30/9/92	-	-	-		3	0.4	1		-	-	-	*
20/10/92	3.1	6.9	3.7	3	4	0.4	23	3	20	0	20	6
4/11/92	0.6	15	0.7	8	2.5	0.6	23	2	13	0.3	20	11
6/11/92	Pressure test - no water, no reading											
23/11/92	0.4			*	3.4	2.1	32	~	1.1	2.6	32	~
30/11/92	Pressure test- nil result ? blocked				Much water out under pressure				Circulation - no water			
1/12/92				Rapid *				Rapid *	2.4	1.2	10	~
14/12/92	3.9	8.1	-	*	17	6.8	49	~	0.7	15	19	*
5/1/93	4.6	4.7	43	*	15	0	10	~	2.2	15	23	~
19/1/93	0	21	0.9	18	0	21	0.8	18	0.8	8.1	-	~
2/2/93	0	21	0.9	*	1.8	-	6	*	0.5	10	24	
15/2/93	7.2	12	25	~	18	0	3.5	~	1	0.8	17	~
2/3/93	6.0	11	35	~	27	0.9	4.2	-	1.2	9.6	32	~
15/3/93	0.7	14	3.2	*	25	1.0	5	~	2.0	0.8	11	~
30/3/93	0.9	13	17	*	13	0.5	5.5	~	0.2	3.2	9	C~
16/4/93	1.0	16	2.8	*	11	9	0.1	~	3.6	13	3.5	*
30/4/93	1.5	10	36	*	8.7	1.5	4.7	19.9	0	15	5.6	*
17/5/93	0.5	12	29	*	17	1.5	4.9	~	1.8	8.6	43	*
7/6/93	1.8	9	42	*	22	0.1	4.8	~	6.0	0.9	-	W~
18/6/93	2	12	8	*	1.3	13	32	*	0	2.6	9.0	~
2/7/93	1.4	10	40	~	25	0.2	7.4	~	0.6	0.9	41	~
23/7/93	3.0	8	43	*	4.2	3.0	40	~	0.1	7.6	44	*
10/8/93	2.4	3.7	55	~	0.6	1.3	20	~C	3.3	0.6	40	~
22/8/93	1.5	11	37	*	0.2	10	34	~C	1.8	0.2	14	~
7/9/93	1.4	10	31	*	0.7	8.9	37	*	0.8	10	27	*
1/10/93	1.1	3	52	~	14	5.8	16	W	0.8	4.7	35	~
25/10/93	1.1	14	20	~	18.6	1.0	8	~C	2.4	0.8	20	20
15/11/93	0.5	16	2.4	*	12.9	1.9	3.8	~	0	6.6	24	*
30/11/93	1.8	16	1.7	~	0.9	15	2.5	*	0	14	2.4	*
10/12/93	4.7	11	33	*	1.1	13	26	~	0.2	13	23	~
23/12/93	0.4	20	0.8	*	21	1.1	11	~	0.1	14	2.6	*
10/1/94	4.4	8	41	*	1.6	12	30	~c	0	16	13	*
25/1/94	0.6	12	25	*	15	4	21	~c	0	14	19	~

TABLE 2 Intermediate Level Samplers Under HDPE Liner (50m downslope from top of liner)
Percentage Concentration of Gases in Samplers

Date	West (Manhole 4)				Centre (Manhole 3)				East (Manhole 2)			
	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O	CH_4	O_2	CO_2	Suction "H_2O
18/12/91	-	-			2	12			2	12		
23/1/92	0	20	0		0.2	8	0.3		-	16	-	
3/2/92	-	-	-		0	7	0.2		0	21	0	
27/2/92	0	20	0		0	15	0.7		0	19	1	
17/3/92	Blocked				Blocked				0	18	1.5	
28/5/92	0	20	0		Blocked				0	20	0	
12/6/92	0.4	10	28	~	1	13	3	5	0	15	0	4
23/6/92	0.8	7	38	~	0.7	14	13	~	0.7	9	17	~
28/7/92					2	7	74	~	3	9	71	2
14/8/92	-	-	-	*	0.3	9	6	*	2	4	74	~
28/8/92	0.4	5	4.2	12	1.0	13	52	12	0.7	8.7	32	*
11/9/92	0.5	18	0.9	*	0.6	8	2.4	*	1.2	7.5	42	*
17/9/92					water out under pressure -continuity				water out under pressure - continuity			
30/9/92	-	-	-	-	-	-	-	-	-	-	-	-
20/10/92				w	2.4	15	65	14*	2.6	4.4	8.3	12*
4/11/92	0	18	0.8	16*	0	19	0.3	17*	0	20	0.4	18*
6/11/92	very little water ejected - continuity				water ejected under pressure - refilled				water out under pressure - continuity			
23/11/92	0	19	1.7	*	0.3	10	19	*	0.9	14	15.3	*
30/11/92	large water discharge under pressure				much water discharged under pressure				much water discharged under pressure			
1/12/92	0	20	0.1	*	0	20	0.1	*	0.8	-	8.2	*
14/12/92				water	2.1	1.3	40	*	1.1	2.7	40	*
5/1/93	2.2	1.7	53	*	1.9	10	28	*	0	11	28	w~
19/1/93	0	20	2.2	17	0	20	2.7	11	2.7	6.6	40	w~
2/2/93	0	20	1.3	*	0	20	0.8	*	-	-	-	w*
15/2/93	1	12	27	~	0.9	2.3	34	*	2.2	10.3	-	w*
2/3/93	4.9	11	34	~	1	12	22	~	0.5	12	25	w~

Table 3 Lower Level Samplers Under HDPE Liner (65m downslope from top of liner)
Percentage Concentrations of Gases in Samplers

Date	West (Manhole 4)				Centre (Manhole 3)				East (Manhole 2)			
	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20
15/3/93	0.7	6	14	*	0.9	11	33	*	0.5	13	30	*
30/3/93	1.1	13	29	*	1.4	11	5.6	*	0.3	13	10	*
16/4/93	0.3	17	6	*	1.2	19	1	*	0	20	2.3	w*
30/4/93	9.1	2.4	59	*	0.1	21	0	*	0.2	16	3	~
17/5/93	0.8	12	28	~	0.4	12	5	~	2.2	6	4.7	*
7/6/93	2.2	9	44	~	1.9	11	35	~	6.8	3	52	~
18/6/93	4.2	12	14	*	4.7	2.5	43	*	0.8	12	12	*
2/7/93	11.1	3.2	63	~	0.5	7.5	41	*	7.9	1.0	63	~w
23/7/93	4.6	6.5	52	*	6.9	2.1	53	w*	0	20	2	*
10/8/93	2.5	1.4	59	~	0.6	1.3	54	c~	4.6	0.5	41	~
22/8/93	1.6	11	38	*	0	9.4	38	*	0.2	8.9	39	~
7/9/93	2.0	10	33	~	0	8.9	38	*	0	9.9	8	~
31/9/93	1.5	4.3	54	~	0.3	6.8	30	*	3.3	2.0	47	~
25/10/93	1.0	15	18	~	0.1	6.9	40	*	0.5	6.3	40	*
15/11/93	0.3	14	2.2	*	0.2	13	2.8	*	0.5	16	0.5	*
30/11/93	0.3	16	6.7	~	0.4	14	2.6	*	0	18	1.4	*
10/12/93	1.0	9.5	37	*	3.6	12	7.4	w*	6.9	12	27	~
23/12/93	0.2	20	1	*	0.3	20	1.0	*	0.2	20	2	*
10/1/94	4	9	12	~	0.9	13	15	*	0	15	3	*
25/1/94	0.3	12	22	*	0.7	15	14	*	0	15	18	~
11/2/94	7.3	10	35	~c	2.2	6.7	29	~c	0	16	15	~
11/3/94	1.4	5.9	36	*	0	6.2	39	*	0.2	11	26	~
25/3/94	0.9	7.9	34	*	0	9.3	36	*	0.5	12	25	*
8/4/94	0.8	10	28	~	4.9	4.2	31	*	0.3	11	24	*
26/4/94	0.1	8.3	33	~	2.6	6.9	42	~	0.6	11	28	*
9/5/94	0.4	9.6	30	~	0.6	4.3	35	*	0.1	10	27	*
24/5/94	0.1	10	4.2	*	0.3	13	4	*	8.9	2.2	28	*
9/6/94	12.3	2.0	32	*	0.4	1.6	38	*	0.2	8	4	*
23/6/94	0.1	7.3	37	~	0	10	23	*	1.4	8.5	27	~
5/7/94	0	9.1	26	*	0	13	24	*	0	14	20	*
25/7/94	0.1	11	26	~	2.5	6.1	34	~	0.1	12	22	~

Table 3 (continued)

Date	ON TOP OF CLAY				0.5M IN CLAY				1.0M IN CLAY				1.5M IN CLAY			
	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20
24/10/94	18	0.4	36	17	35	0.3	52	19	36	0.3	52	14	3.0	8.3	30	*
7/11/94	22	0.2	36	17	36	0.2	52	20	35	0.2	57	15	0.1	19	4.7	*
21/11/94	29	0.1	40	18	38	0.3	55	~	33	0.2	60	16	0.4	19	3.3	*
28/11/94	33	0.1	42	17	41	0.3	56	19	35	0.5	61	15	0.9	19	5.0	*
12/12/94	39	3.8	37	14	33	3.9	46	14	0.1	19	3.1	w	0.1	20	2.3	
6/1/95	40	0.7	46	17	43	0.6	54	19	34	0.4	61	16	1.5	15	17	*
16/1/95	42	0.5	47	16	44	0.5	54	19	34	0.5	61	17	1.3	17	9.3	*
30/1/95	41	0	49	12	40	0	53	14	32	0	60	12	1.2	15	15	*
14/2/95	44	0	47	11	43	0	52	17	34	0	59	15	2.8	12	27	*
6/3/95	51	0.1	49	17	50	0	53	19	41	0	59	16	2.2	17	17	*
16/3/95	51	0.1	49	16	49	0.1	52	19	41	0	58	15	0.9	19	3.8	*
31/3/95	50	1.2	45	16	48	1.3	49	19	40	1.1	55	17	0.8	19	4.6	*
13/4/95	52	0.1	47	16	49	0	52	20	43	0	57	17	3.0	13	25	*
15/5/95	56	0.4	45	16	49	0.4	52	19	43	0.4	59	16	4.2	12	27	~
19/6/95	56	1.0	39	15	46	1.4	49	19	42	1.3	55	16	14	8	25	~
18/7/95	62	0.2	39	15	49	0.3	51	19	44	0.2	56	16	4.1	13	16	~c
15/8/95	54	2.3	34	12	42	2.4	46	17	40	2.1	53	12	11	7.9	31	~
25/9/95	67	0.5	35	14	52	0.5	49	16	47	0.4	54	15	11	6.6	39	*
17/10/95	64	0.1	35	16	52	0	48	18	47	0	55	17	6.8	9.9	34	*
20/11/95	48	0.6	35	16	54	0.6	48	18	49	0.5	54	16	4.7	10	32	*
12/12/95	53	0.2	33	~	56	0.2	46	~	50	0.2	52	~	3.1	12	28	*
31/1/96	30	11	18	*	50	3.1	40	~	46	4.0	38	~w	w	w	w	
26/2/96	63	18		19	46	4.5	36	17	w	w	w	w	1.0	19	1	*

Table 4 (continued)

Key: ~ = flow continued at suction > -20" H_2O
w = water in sampler

* = Analox pump cut-out by restricted flow
c = continuity of gas flow through sampler

Date	West (Manhole 4)				Centre (Manhole 3)				East (Manhole 2)			
	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20
8/8/94	3.1	4.3	45	~	2.8	6.9	33	~	0.4	6.4	13	*W
18/8/94	0.5	14	27	*	0	14	19	*	0.9	9.2	28	*W
5/9/94	0.6	11	31	*	0.4	2.1	46	*	0	11	28	*
22/9/94	0.3	0.9	55	*	4.4	3.0	42	*	0.1	11	28	*
7/10/94	1.5	8.4	38	*	0.5	12	16	*	0.1	13	28	*
24/10/94	0	11	7.9	*	0.3	7.2	20	*	0	17	2.6	~
7/11/94	0	11	33	*	0.3	11	2.1	*	0	18	8.3	*
28/11/94	0.5	16	18	*	0.8	18	4.0	*	2.4	20	4.0	*
12/12/94	0.1	20	3.2		0	21	0.2		0.2	20	0.6	
6/1/95	3.1	2.6	51	*	0.5	11	26	*	0.3	9.3	28	*
16/1/95	3.7	5.3	47	*w	0.6	15	17	*	0.2	17	12	*
30/1/95	1.5	10	34	*	0.3	18	4	*w	0	16	8.7	*
14/2/95	3.0	11	32	*	4.6	1.2	41	*	0	15	13	*
6/3/95	1.4	15	11	~	7.6	10	17	~	0	16	14	*w
16/3/95	1.2	14	25	*	0.5	13	23	*	0.6	19	4	cw
31/3/95	1.3	15	18	~c	0.9	11	15	~c	4.7	15	11	*w
13/4/95	1.7	12	29	*	0.3	13	17	*	0	13	17	*
15/5/95	3.1	11	28	~	0.2	6	30	~c	0	8	28	~
19/6/95	1.6	9	26	~	0	21	0	~	11	4.4	32	~c
18/7/95	11	4.2	39	~c	3.0	3.4	38	~	1.0	7.6	24	~c
15/8/95	2.4	9.5	29	~c	0	13	14	~c	2.0	8.9	20	~c
25/9/95	3.3	3.3	46	~	0.8	3.3	40	*	2.5	2.2	4.2	*
17/10/95	0	9.0	33	*	4.9	1.5	40	*	0	9.5	27	*
20/11/95	4.0	4.1	38	*	0.2	13	9.8	~c	0.1	6.9	33	*
12/12/95	1.3	9.6	39	*	4.4	7.8	40	*	3.5	3.1	36	*
31/1/96	0.1	12	36	*	1.5	10	28	*	W	W	W	
26/2/96	0.4	14	13	W	W	W	W	W	W	W	W	W

Table 3 (continued)

Key: ~ = flow continued at suction > -20" H_2O
w = water in sampler

* = Analox pump cut-out by restricted flow
c = continuity of gas flow through sampler

(MANHOLE 1)
(Double colour)

Date	ON TOP OF CLAY				0.5M IN CLAY				1.0M IN CLAY				1.5M IN CLAY			
	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20
28/5/92	0.5	13	23		6	0.5	82		7.9	0.5	6		3	14	19	
12/6/92	8	0.6	95		3	7	67		8	0.7	98		5	0.9	47	
23/6/92	7	0.5	97		2	0.5	67	2.5	7	0.4	97		3	7	37	*
3/8/92	12	0.4	91		11	0.4	93		12	0.4	92		-	-	-	
14/8/92	15	0.5	92		11	0.6	93		11	0.5	90		1	8	52	*
28/8/92	18	0.1	83		16	0.2	85		13	0.2	82		0.7	20	3	*
11/9/92	20	0.3	79		17	0.2	84		13	0.3	86		0.2	15	2	*
30/9/92	13	10	43		28	0.4	76		16	0.4	81		-	-	-	
20/10/92	26	0	70		40	0	64		19	0.1	75		2.7	14	9	*
4/11/92	28	1.0	63		30	0.4	69		21	0.5	75		0.1	19	0.9	*
6/11/92													no response to pressure N			
23/11/92	30	1.5		8	18	1.1		10	23	0.4		10				*
30/11/92													no response to pressure N			
14/12/92	33	0.2	70		24	0	85		26	0	86		1.1	8	23	*
5/1/93	34	0.7	69		25	0.2	82		28	0	83		5	13	21	*
19/1/93	22	-	-	W11	21	1.4	60	11	27	0	77	11	1.6	13	31	*
2/2/93	29	0.7	59	11	26	0.4	72	12	29	0.3	77	11	0	20	1	*
15/2/93	37	0	69	10	29	0	79	11	31	0	78	11	3	15	21	*
2/3/93	37	0.1	65	10	29	0.1	72	16	31	0.1	72	13	2.5	14	17	*
15/3/93	35	0.6	65	9	28	0.6	74	13	29	0.6	74	14	0.8	18	15	*
30/3/93	32	1.9	69	12	26	1.3	68	12	28	1.4	69	13	0.3	18	8	*
16/4/93	33	0.9	63	12	30	0.7	73	12	30	0.7	72	13	0.3	20	1.8	*
30/4/93	34	1.4	69	8	30	1.4	73	7	29	1.4	78	8	-	-	-	*
17/5/93	33	1.4	63	10	31	1.0	69	12	29	1.0	70	13	0.3	20	2	*
7/6/93	34	0	67	10	34	0.1	70	12	32	0.1	71	14	2.2	11	42	*
18/6/93	35	1.1	61	10	34	0.2	66	12	32	0.4	67	19	7.2	13	26	*

Table 4 Upper Level Samplers In Clay Embankment (25m downslope from top of liner) Percentage Concentrations of Gases in Samplers

Date	ON TOP OF CLAY				0.5M IN CLAY				1.0M IN CLAY				1.5M IN CLAY			
	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20
2/7/93	33	0	66	7	35	0	68	8	54	0	70	10	0.6	19	4	*
23/7/93	35	0	62	11	32	0	63	12	31	0	67	15	1.2	9	7	*
10/8/93	39	0.4	62	13	36	0	65	16	34	0	69	17	3.5	9	46	*
22/8/93	41	0.1	61	13	37	0.1	64	14	35	0.1	67	~	0.6	20	3	*
7/9/93	41	0	60	16	38	0	63	13	35	0	66	17	1.3	14	4	*
30/9/93	45	0	60	11	41	0	63	10	38	0	67	9	3.7	11	8	*
25/10/93	32	1.6	47	20	23	1.4	46	16	40	0.2	61	17	6.5	9	26	~
15/11/93	4.6	12.4	17	15	0.4	7.6	13	17	31	0.8	53	16	0.3	19	1	*
30/11/93	34	2.1	46	19	39	1.2	54	13	35	1.2	58	15	8.6	15	16	*
10/12/93	42	0.6	56	~	10	0.5	34	17	37	0.5	61	~	1.4	16	12	*
23/12/93	24	4.4	38	19	11	8.2	27	18	43	0.7	60	19	0.9	20	2	*
10/1/94	29	0.2	46	~	25	0.1	46	~	40	0.1	62	19	0.9	18	3	*
25/1/94	35	0.2	52	~	21	0.3	44	~	31	0.1	58	18	1.0	18	3	*
11/2/94	41	0.4	53	~	41	0.5	51	~	36	0.3	53	~	1.7	16	20	*
11/3/94	21	2.9	37	~	48	0.5	53	~	44	0.5	56	~	1.8	17	15	*
25/3/94	44	0.3	54	~	46	0.2	57	~	45	0.2	59	18	1.9	16	11	*
8/4/94	43	1.2	52	20	46	1.0	56	18	9.5	4.0	37	*	1.2	15	23	*
26/4/94	44	0.4	54	~	44	0.2	56	19	43	0.2	60	~	2.3	19	24	*
9/5/94	43	0.2	53	17	44	0.2	54	17	1.8	15	4.7	~w	1.6	14	24	*w
24/5/94	48	0	54	17	48	0.5	56	17	45	0.4	59	~	2.1	15	5.3	*
9/6/94	42	3.4	46	18	34	7	38	16	40	3.6	51	~	0.9	16	3.2	*
23/6/94	45	0.1	42	18	51	0	40	18	43	0.3	51	~	1.4	14	14.7	*
5/7/94	44	0.1	49	17	46	0.2	53	17	42	0.1	58	~	1.4	15	20	*
25/7/94	43	0	54	16	44	0.1	53	14	41	0	60	16	3.5	9.6	32	~
8/8/94	37	0	52	16	43	0	52	~W	9	3.8	19	~w	15	2.5	50	~
18/8/94	32	0.1	51	17	14	1.2	39	*	42	0.1	58	17	1.4	14	14	*
5/9/94	17	0.1	45	17	41	0.1	54	17	39	0.1	58	15	2.7	12	29	~
22/9/94	13	0.1	40	18	35	0	55	17	35	0.1	58	16	0.6	12	22	~
7/10/94	11	0	36	19	33	0	55	~	35	0	58	16	2.1	7.7	20	*

Table 4 (continued)

(MANHOLE 5)

Date	ON TOP OF CLAY				0.5M IN CLAY				1.0M IN CLAY				1.5M IN CLAY			
	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20
18/12/91	13	0.2	-		12	0.2	-		13	0.2	-		13	0.2	-	
23/1/92	9	0	77		5	6	55		8	0	81		6	0	81	
3/2/92	9	0	84		9	0	85		8	0	85		6	0	85	
27/2/92	12	0	83		13	0	82		10	0	83		9	0	84	
17/3/92	12	0	85		13	0	85		11	0	85		10	0	86	
28/5/92	22	0	82		22	0	80		20	0	82		21	0	82	
12/6/92	25	0.3	73		24	0.5	74		22	0.5	78		22	0.4	78	
23/6/92	25	0	75		-	-	-		23	0	81		21	0	84	
28/7/92	31	0.2	76		30	0.5	73	8	28	0.3	75		28	0.2	79	
14/8/92	31	0.6	76		-	-	-	*	28	0.5	79		27	0.5	80	
28/8/92	30	0.5	71		5	9	17	*	25	3	67		27	0.3	76	
11/9/92	31	0.5	73		7	0.9	32	*	29	0.5	75		27	0.5	78	
30/9/92	33	0.1	73		-	-	-		26	2	65		28	0.3	70	
20/10/92	14	11	25	~	4	17	4	*	31	0.1	65		30	0	64	
4/11/92	5	10	16	*	0	21	0.3	*	32	1.3	63		31	0.3	68	
6/11/92	No flow under N presure				No flow under N pressure											
23/11/92	1.7	4	25	*	1	7	8	*	31	0.2	62		31	0.1	63	
30/11/92	No flow under N pressure				No flow under N pressure											
4/12/92	1.4	7	19	~	3.3	5	26	~	-	-	-	w	38	0	72	
5/1/93	6	4	36	*	6	5	44	*	38	0.2	69	~	36	0	76	16
19/1/93	0.8	20	2.5	*	0.5	20	3.7	*	35	1.6	62	7	30	2.5	66	8
2/2/93	0	20	1.4	*	0	18	3	*	37	0.3	66	16	31	0.3	69	17
15/2/93	6.5	12	26	~	10	9	30	~	40	1.4	68	~	34	0	72	15
2/3/1993	5	-	-	~	9	11	27	~	40	0.3	62	~	33	0.3	65	

Table 5 INTERMEDIATE LEVEL SAMPLERS IN CLAY EMBANKMENT
(50m downslope from crest)
Percentage Concentrations of Gases in Samplers

Date	ON TOP OF CLAY				0.5M IN CLAY				1.0M IN CLAY				1.5M IN CLAY			
	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20
15/3/93	2	13	26	*	2	13	27	*	40	0.8	65	~	32	0.8	70	~
30/3/93	2	13	22	*	2	12	28	*	40	0.6	62	20	33	0.6	67	w~
16/4/93	13	5	42	*	4	12	32	*	41	0.7	61	19	33	0.6	68	19
4/5/93	5	8	40	*	3	11	31	*	45	0.8	61		38	0.8	67	
17/5/93	2	12	3	*	2	13	29	~	39	1.0	61	19	32	0.9	65	19
7/6/93	2	16	21	*	4	10	40	*	44	0	60		-	0	-	20
18/6/93	4	12	31	*	5	12	31	*	43	0.5	59	18	35	0.1	65	18
2/7/93	3	10	36	*	4	7	57	*	43	0.1	70	19	35	0.3	71	~
23/7/93	3	9	42	*	2	11	34	*	40	0.2	64	~	36	0.2	66	~
10/8/93	5	4	73	*	5	4	67	~	18			C~	35	0.6	65	20
22/8/93	1	13	28	C~	2	13	29	*	33	2.2	55	W~	36	0.3	64	~
7/9/93	13	2	50	*	2	12	32	*	4	11	34	*	36	0.2	66	19
1/10/93	4	6	58	*	4	5	51	*	3	9	45	*	39	0.1	65	~
25/10/93	3	9	42	*	12	3	53	~	3	2	40	~	40	0.3	60	~
5/11/93									pressure test N-neg flow				40	0.2	61	~
15/11/93	0.7	6	9	*	0.1	19	2	w*	1.4	10	3	*	43	0.5	60	~
30/11/93	1.0	14	2	*	1.4	17	8	~	0.4	19	8	*	43	0.4	61	~
10/12/93	2	12	22	*	2.5	9	39	*	2	11	35	*	42	0.5	61	~
23/12/93	1.7	15	2	*	0.6	19	2	*	1.4	17	2	*	46	0.4	59	~
10/1/94	6	6	52	*	5	6	54	*	4	8	43	*	42	0.1	62	~
25/1/94	6	7	37	*	2	12	36	*	7	6	51	~	43	0.1	61	~
11/2/94	3.6	12	32	~	1.1	20	15	~	2.4	13	28	~	42	1.0	58	~
11/3/94	3.7	9.2	44.0	*	10.1	3.9	56.0	*	3.7	9.6	43.0	*	45	0.3	59	~
25/3/94	3.4	10.0	37.0	*	5.5	5.3	50.0	*	2.7	9.5	43.0	*	44	0.2	60	~
8/4/94	2.0	12.0	33.0	*	2.0	12.0	35.0	*	2.7	11.0	39.0	*	45	0.3	58	~
26/4/94	2.8	9.9	41.0	*	7.8	4.7	55.0	*	13.0	3.7	63.0	*	43	0.1	59	~
9/5/94	17.6	3.1	54.0	~	3.6	7.8	44.0	~	4.8	4.2	61.0	~	41	0	65	~
24/5/94	2.3	11.0	32.0	*	1.2	12.0	32.0	*	2.3	12.0	37.0	*	46	0.4	58	~

Table 5 (continued)

Date	ON TOP OF CLAY				0.5M IN CLAY				1.0M IN CLAY				1.5M IN CLAY			
	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20
9/6/94	6.0	7.1	42.	~	7.1	6.7	44	~	6.5	6.5	47	~	47	0.1	56	~
23/6/94	4.5	4.6	60	~	7.7	3.5	65	~	5.9	6.7	53	~	44	0.1	56	~
5/7/94	1.4	11	35	*	1.6	11	37	*	6.7	3.5	61	*	44	0	56	~
25/7/94	2.1	11	33	~	1.9	12	31	~	3.0	9.9	38	~	36	0.1	61	~
8/8/94	7.8	5	47	~	1.8	11	37	~	4.4	6.6	50	~	34	0	62	~
18/8/94	1.2	13	28	~	0.8	13	26	~	2.9	9.5	42	*	43	0.1	55	~
5/9/94	1.6	11	32	*	1.3	11	33	*	2.2	11	36	*	47	0	54	~
22/9/94	2.4	10	38	*	1.8	11	35	*	6.4	3.9	59	*	45	0	56	~
7/10/94	7.3	4.0	51	*	1.7	12	32	*	4.0	6.5	50	*	46	0	54	~
24/10/94	2.6	11	32	*	1.0	14	24	*	1.4	13	27	*	46	1	51	~
7/11/94	2.2	9.4	42	*	6.1	6.0	36	*	1.6	17	31	*	47	0.2	51	~
21/11/94	2.2	11	36	*	2.1	11	36	*	2.1	13	32	*	48	0.5	55	~
28/11/94	1.1	16	23	*	0.9	16	21	*	1.0	16	22	*	51	0.2	57	~
12/12/94	0	19	3.9		0	20	2.6		0	19	4.5		38	4.6	44	20
6/1/95	6.5	5.3	54	*	9.0	6.6	56	*	11	3.5	62	*	51	0.7	55	~
16/1/95	5.3	7.2	50	*	5.4	7.2	48	*	6.5	6.5	54	*	51	0.4	55	~
30/1/95	1.7	11	35	~	1.7	11	34	~	3.4	7.5	51	~	47	0	55	~
14/2/95	0.5	20	0.7	~	0.3	19	3.0	~	0.4	17	10	~	37	5.3	44	18
6/3/95	2.3	14	22	~	2.7	14	24	~	3.2	13	25	~	49	0.7	53	~
16/3/95	1.7	13	29	*	1.7	13	29	*	6.3	6.8	51	*	51	0.2	54	~
31/3/95	1.1	15	18	~	1.3	15	20	~	0.9	15	22	~	46	2.2.	49	~
13/4/95	9.5	3.5	54	*	2.1	12	31	*	1.7	12	34	*	50	0	52	~
15/5/95	4.4	11	23	~w	3.2	12	31	~	3.4	11	34	~	48	0.8	53	~
19/6/95	10	6.7	58	~	14	4	60	~	9	6.6	54	~	47	0.5	54	~
18/7/95	8.0	8.3	43	~	4	6	40	~	5.5	11	37	~	48	0.6	53	~
15/8/95	2.2	12	25	~	4.9	9.0	32	~	2.5	12	25	~	38	3.4	46	~
25/9/95	13	3.3	59	*	6.7	7.5	48	~	5.4	7.4	48	~	51	0.4	52	~
17/10/95	3.8	8.3	47	*	4.0	8.7	45	*	13	2.2	62	*	50	0	51	~

Table 5 (continued)

Date	ON TOP OF CLAY				0.5M IN CLAY				1.0M IN CLAY				1.5M IN CLAY			
	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20
20/11/95	5.2	7.3	51	*	17	3.3	61	*	6.0	6.7	52	*	54	0.3	49	~
12/12/95	4.4	10	40	*	45	9.6	41	*	10	4.6	53	*	55	0.2	48	~
31/1/96	4.7	10	30	~	12	8	40	*	8.7	7.4	41	*	4	13	14	~
26/2/96	7.8	10	36	~	11	7	39	~	7	9.3	39	~	62	0.4	38	~

Table 5 (continued)

Key:
~ = flow continued at suction > -20" H_2O
w = water in sampler
* = Analox pump cut-out by restricted flow
c = continuity of gas flow through sampler

(MANHOLE 1)
(single colours)

Date	ON TOP OF CLAY				0.5M IN CLAY				1.0M IN CLAY				1.5M IN CLAY			
	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20
18/12/91		12			2	13			12	0.2			1	12		
23/1/92	0.4	16	2		3.2	5	14		6.6	0	78		0	20	2	
3/2/92	0	0	0		5.5	0	19		7.2	0	8.2		0	20	0.3	
27/2/92	0	16	4		5.2	0	20		5.1	8	53		-	20	-	
17/3/92	0	18	4		4.6	0	27		11	0	82		-	-	-	
28/5/92	0	20	0		0.7	14	1		17	1	74		0	19	0.4	
12/6/92	0.8	13	11		0.2	16	12		21	0.7	88		0.1	14	10	
23/6/92	1	11	24		0.8	12	25		24	0.7	84		1	5	28	
28/7/92	2	8	24		2	10	55		3	9	23		2	6	24	
14/8/92	1	14	7	*	1	10	31	*	1.6	12	19	*	1	8	26	*
28/8/92	0.9	16	24	*	1.8	18	41	*	1	10	33	*	1	10	32	*
11/9/92	1.2	11	32	*	0.2	19	2	*	0.3	13	3	*	0.4	13	3	*
30/9/92	-	-	-		-	-	-		-	-	-		-	-	-	
20/10/92	3.1	7	27	*	0.6	17	2	*	2.8	0.7	22	*	2.5	9.3	7	*
4/11/92	0.5	16	2	*	0.4	19	1	*	0.1	20	0.5	*	0.1	18	0.9	*
6/11/92	Water discharge under N pressure				Water discharge under N pressure				Small discharge under N pressure				Large water discharge under N pressure			
23/11/92	1.6	2	21	*	0.7	16	8	*	2.4	-	25	w*	1	15	5	*
30/11/92		0.1		~	Pressure N			w	Pressure N			w	Pressure N			w c
1/12/92	0	4	8	*	0	19	0	*	0	10	3	*	0	20	0.2	*
14/12/92	0.7	1.3	17	~				w	3.7	4.3	30	*	1.0	6.5	25	*
5/1/93	2	8.3	24	~				w	2.9	7.2	28	*	3.9	8.7	33	~

Table 6 Lower Level Samplers In Clay Embankment (65m downslope from crest) Percentage Concentrations of Gases in Samplers

19/1/93	2	10	22	*				w		11	23	*	0.5	17	0.5	~
2/2/93	0	17	6	*	0	Pressure test		w	1.0	Under pressure		w				*
15/2/93	0.3	15	7	*	0.3	16	8	*	0.2	18	5	*	1	13	16	*
2/3/93	1.0	15	15	~	1	18	5	w	2	13	16	~	3	12	27	~
15/3/93	3	13	18	*	29	0.5	75	12	0.9	16	24	*	0.8	13	20	*
30/3/93	0.3	20	2	*	0.1	21	0.7	*	0.3	17	13	*	0.5	17	7	*
16/4/93	2.2	9	26	*	0	20	3	*	0.9	15	5	*	0.8	14	7	*
30/4/93	2.4	9	34	~w	2.9	15	13	~	2.1	14	11	~	2.5	9	25	~
17/5/93	1.1	19	11	~	0.9	18	4	~	0	20	3	~	0.9	12	25	~
7/6/93	3.0	10	28	~	1.0	16	11	~	5.8	7	22	~	3.5	7	33	~
18/6/93	1.6	15	17	*	0.4	20	2	*	1.7	14	22	*	2.0	14	23	~
2/7/93	2.1	11	30	*	0.2	20	0.7	*	1.8	12	24	*	2.1	11	30	~
23/7/93	2.4	10	29	*	0	20	3	*	3.6	5	10	*	2.3	10	27	*
10/8/93	0.9	16	10	c~	1.2	14	20	w	6.4	5	30	*	4.0	7.5	34	*
22/8/93	2.0	13	26	*	1.4	12	15	w	0.7	18	7	*	2.0	13	20	*
7/9/93	2.0	13	21	*	0.1	19	3	w*	1.1	14	5	8	0.9	15	7	*
30/9/93	2.8	10	25	*	2.1	10	7	*	2.2	13	5	*	4.0	8	33	*
25/10/93	12	3.9	35	~	7	7.4	30	~	4.5	9.7	23	~	4.2	10	23	~
15/11/93	1.8	12	4		0	20	1	*	0.4	20	1	*	0.3	18	1	*
30/11/93	3.9	N Pressure test		*w	3.2	N Pressure test		cw	2.5	N Pressure test			2.5	N Pressure test		cw

Finish

Table 6 (continued)

Key: ~ = flow continued at suction > -20" H_2O
w = water in sampler

* = Analox pump cut-out by restricted flow
c = continuity of gas flow through sampler

(MANHOLE 0)

Date	SAMPLER IN WASTE 1m ABOVE CLAY				SAMPLER R(S)				SAMPLER R(D)				SAMPLER ¾ HOSE		
	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2
28/?/92	15	0.3			13	0.3			12	0.3			12	0.3	
3/8/92	16	0.5	86		19	0.6	86		17	0.6	87		18	0.6	86
14/8/92	17	0.4	88		20	0.5	85		19	0.4	86		21	0.4	85
28/8/92	18	0	80		21	0.2	79		21	0	79		21	0.1	78
11/9/92	21	0.2	82		21	0.3	77		22	0.3	79		22	0.3	78
30/9/82	21	0.5	79		24	0.5	81		24	0.5	80		25	0.8	77
20/10/92	22	0.4	74		26	0.2	70		25	0.2	70		9	19	7
4/11/92	25	0.3	71		28	0.4	71		27	0.3	72		0	21	0.1
23/11/92	26	0.5	70	17	25	2	63	12	27	0.5	70	14	Water filled		
14/12/92	2.7	19	6	~	31	0.1	79	~w	9	13	30	~	1.6	18	1.4w
5/1/93	30	1.8	73	~	30	0.8	76	19	29	0	84	18	26	3.6	66
19/1/93	32	0.1	77	~	32	0.6	75	~	29	0.4	80	16	0	20	3
2/2/93	21	6	56	6	29	1	68	17	Low battery			5	Low battery		
15/2/93	33	0	77	15	28	5	62	9	27	1.2	75	15	30	0.3	77
2/3/93	32	0.6	67	19	35	0.8	67	16	30	0.6	71	19	33	0.6	67
15/3/93	32	0.6	74	~	33	0.6	72	19	29	0.4	76	~	31	1.0	70
30/3/93	33	1.0	71	~	34	1.1	70	~	29	0.9	74	~	33	0.5	70
16/4/93	34	0.8	72	19	35	0.8	73	~	31	0.7	75	~	31	0.9	72
30/4/93	34	1.1	72	13w	34	0.9	70	14	29	0.9	75	17	No samples		
17/5/93	31	1.0	67	16	34	1.0	67	17	29	0.8	74	~	26	1.7	64

Table 7 Gas concentrations in samplers installed in sand lens encased in clay - also in waste above the clay

Date	SAMPLER IN WASTE 1m ABOVE CLAY				SAMPLER R(S)				SAMPLER R(D)				SAMPLER ¾ HOSE		
	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2
7/6/93	36	0.1	71	16	37	0	71	17	32	0.1	75	~	None		
18/6/93	337	0.2	67	18	38	0.2	66	17	33	0.2	71	~	5	10	42
2/7/93	38	0	64	13	38	0	67	12	32	0	71	15	18	3	66
23/7/93	35	0	64	19	35	0	65	18	31	0	67	~	24	0.8	65
10/8/93	39	0.3	64	~	38	0.3	63	~	35	0.3	66	~	33	1.3	63
22/8/93	40	0.1	66	19	41	0.1	65	~	36	0.1	69	~	w		
7/9/93	39	0	63	18	39	0	62	19	36	0	65	~	29	0	66
30/9/93	43	0	61	15	45	0	60	15	40	0	66	~	None		
25/10/93	43	0.3	60	~	43	0.4	60	~	37	0.9	60	~	Nothing collectable		
15/11/93	43	1.1	55	19	25	1.8	55	~	23	1.6	57	~	No results after 10 minutes		
30/11/93	43	0.9	58	18	45	0.7	56	~	40	0.6	63	~			
10/12/93	42	0.6	59	20	26	0.7	56	~	34	0.6	62	~			
23/12/93	40	0.7	56	~	32	0.9	32	20	37	2.1	59	~			
10/1/94	37	0.4	57	~	28	0.3	48	~	33	0.3	62	~			
25/1/94	43	0.4	59	~	43	0.3	56	~	43	0.8	64	~			
11/2/94	43	0.3	58	~	35	0.3	53	~	39	1.3	61	~			
11/3/94	21	9.0	31	16	8.8	11	20	13	16	11	29	15			
25/3/94	46	0.2	59	~	47	0.2	59	~	42	0.2	62	~			
8/4/94	41	0.5	54	~	36	0.5	44	~	42	0.5	60	~			
26/4/94	29	1.4	57	~	26	1.8	50	~	43	0.9	60	~			
9/5/94	44	0.1	56	~	43	0.6	54	~	39	0.1	61	~			
24/5/94	45	0.4	58	~	23	0.4	56	~	36	0.5	60	~			

Table 7 (continued)

Date	SAMPLER IN WASTE 1m ABOVE CLAY				SAMPLER R(S)				SAMPLER R(D)				SAMPLER ¾ HOSE		
	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2
9/6/94	40	0.7	56	~	17	1.6	43	~	28	2.0	54	~			
t23/6/94	43	0	57	18	31	0.1	34	~	44	0.3	60	~			
5/7/94	39	2.6	51	20	31	1.2	43	~	37	0.2	54	~			
25/7/94	43	0	57	~	38	0	60	~	38	0	63	~			
8/8/94	37	0.1	61	~	36	0.2	52	~	38	0.0	57	~w			
18/8/94	43	0.1	57	~	41	0.1	60	~	41	0.1	60	~			
5/9/94	27-13	0.1	43	~	29-16	0	46	19	36	0.1	60	~			
22/9/94	9	0	36	~	11	0	41	~	20	0	55	~			
7/10/94	7.3	0	33	~	9.3	0	38	~	21	0	54	~			
24/10/94	21	0.4	43	~	26	0.3	49	19	30	0.4	64	~			
7/11/94	30	0.2	49	~	32	0.2	53	~	30	0.2	56	~			
21/11/94	30	0.1	53	~	31	0.2	57	~	27	0.1	58	~			
28/11/94	33	0.2	56	~	31	0.5	58	~	28	0.1	59	~			
12/12/94	27	4.6	43	17	17	4.2	44	16	18	5.4	43	~			
6/1/95	38	0.5	54	~	23	0.6	51	~	28	0.4	53	~			
16/1/95	36	0.4	54	~	22	0.6	47	~	32	0.4	53	~			
30/1/95	39	0.3	50	15	36	0	53	15	39	0	54	20			
14/2/95	43	0	55	15	39	0	57	14	41	0	55	19			
6/3/95	49	0.2	54	~	46	0.2	55	~	46	0.2	56	~			
16/3/95	48	0.1	55	19	46	0.1	54	19	44	0.1	56	~			
31/3/95	48	0.9	50	~	45	0.8	51	20	45	1.0	52	~			
13/4/95	47	0	55	20	47	0	51	20	48	0	51	~			
15/5/95	48	0.3	56	20	53	0.5	47	19	49	0.4	53	~			

Table 7 (continued)

Date	SAMPLER IN WASTE 1m ABOVE CLAY				SAMPLER R(S)				SAMPLER R(D)				SAMPLER ¾ HOSE		
	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2	Suction "H_20	CH_4	0_2	CO_2
19/6/95	47	1.5	53	19	59	1.4	37	19	52	1.8	43	~			
18/7/95	51	0.3	54	~	21	8	17	~	59	0.6	37	~			
15/8/95	45	3.0	45	~	4.7	15	13	~	51	4.3	26	~			
25/9/95	54	0.5	50	18	38	3.3	46	*	69	0.8	29	~			
17/10/95	55	0	49	~	17	4.2	50	*	71	0.1	28	~			
20/11/95	42	0.6	47	~	75	0.7	25	~	74	0.8	28	~			
12/12/95	48	0.2	47	~	78	0.2	25	~	75	0.1	27	~			
31/1/96	47	4.6	35	~	25	15		*W	56	2.7	25	*			
26/2/96	50	3.8	38	19	3.5	18	8	~W	3.4	19	4.8	~W			

Table 7 (continued)

Key: ~ = flow continued at suction > -20" H_2O
w = water in sampler
* = Analox pump cut-out by restricted flow
c = continuity of gas flow through sampler

	Monitor Schedule	BOREHOLES					Air Pressure mb
		E	D	C	B	A	
	Months	% CH_4 in migrating gas					
23-10-93	23	2.6	8.9	w	20	22	
		0	0.2	2.2	13	11	1030
	24	44	11	18	25	21	996
		20	8.6	9	23	19	996
	25	13	3.2	4.4	21	13	995
		26	15	28	20	19	984
	26	40	13	18	5.6	17	1002
	26.5	47	33	33	28	33	1010
8-4-94	28.5	15	5	7.1	12	12	999
	29	0.8	7.7	16	23	26	1008
		12	12	13	25	29	1004
Main flare on	30	21	9.7	14	29	30	1006
		0.1	0.2	3.1	6.4	4.5	1020
	31	0	0	2.3	5.2	7.9	-
		0	0	2.8	5.9	3.1	1013
		6.3	0.4	1.4	0.2	0	1005
	32	0	0.2	1.1	0.2	1.8	-
		0.8	0	0.3	0.1	0	1002
	33	0	0	0	0.1	0	1011
		0	0	0.2	0	0	1013
7-10-94	34	0.1	0	0.1	0	0	1005
Main flare off		0	0	0.1	0	0	997
	35	0.5	0	0	0	0	1004
Temporary flare on		5	0	0	0	0	-
	36	14	0.1	0.1	3.3	0.5	1004
		35	3.5	0	11	6.4	1014
6-1-95	37	0	0	0	2.3	0.2	1012
		57	14	2.5	28	26	1003
	38	0	0	0	0	0.1	1016
Flare off for 2 days		1.7	6.9	22	29	21	997
	39	0.4	2.6	2	28	8	997
		58	22	28	22	7	997
	40	4.8	17	20	17	16	1019
	40.5	0	8.2	18	20	25	1029
	41.5	12	10	4	23	27	1009
	42.5	39	7	15	24	26	1011
	43.5	32	2.4	7.3	31	26	1005
	44.5	33	2.7	5	23	18	1020
	45.5	18	1.4	5	17	18	1012
	46.5	11	0.9	3.4	10	11	-
	47.5	7.3	0	1.8	1.5	0.5	1017
	48.5	52	0	1.8	14	4.4	1027
12-12-95	49.5	54	1.6	3.4	10	15	1004
23-1-96	51	62	10	5.6	49	W	

Table 8 Migrating Methane in Embankment boreholes
(measured as percentage of gas composition)

Perimeter Line P	Date	WELL N° W CH$_4$ %	W P	14/5A CH$_4$ %	14/5A P	S CH$_4$ %	S P	14/5 CH$_4$ %	14/5 P	14/5B CH$_4$ %	14/5B P	14/6 CH$_4$ %	14/6 P
	18/08/94	34	-	53	12.5	54	-	55	10	54	15	54	17.5
	05/09/94	-	-	35	-57.5	-	-	34	-70	25	-55	16	-50
	22/09/94	0.3	-	37	-35	54	-	37	-45	24	-47.5	17	-27.5
	07/10/94	12	-	51	-10	-	-	28	-87	45	-32.5	12	-35
	24/10/94	21	-	59	-2.5	57	-	61	-47	56	-7.5	55	-17.5
	07/11/94	38	-	59	+20	56	-	56	+35	54	+37.5	53	+40
	21/11/94	17	-	64	+5	58	-	48	+7.5	60	+12	59	+25
	28/11/94	-	-	53	-22	58	-	13	-20	59	-22.5	40	+2.5
	12/12/94	45	-	F	-	56	-	F	-	F	-	44	+87.5
	06/01/95	0		F		0.4		F	-	F		60	+190
	16/01/95	32	-	61	+150	39	-	F		0.6	-220	50	-225
	30/01/95	0.1	-	38	-202	1.1	-	F		0.6	-220	50	-225
	15/02/95	0	-			46	-	F		F		54	-140
	06/03/95	-	-	-	-	0.1	-	5.6	-152	39	-147	60	-150
	16/03/95	46	-	56	+75	57	-	57	+120	52	+100	57	+100
	31/03/95	0.4	-	18	+10	56	-	59	0	58	-10	55	+25
	13/04/95	55	-	D	-	23	-	58	-7.5	57	-20	35	-27.5
+70	15/05/95	51	-	D		57	-	60	+137	45	+102	34	+95
-36	19/06/95	D		D		D		D		D		46	+12.5
-40	18/07/95	D		D		D		D		D		59	+10
+25	15/08/95	54		D		53		D		D		51	+20
+7	25/09/95	31	-	D	-	56	-	61	25	d	-	23	+10
-12	17/10/95	37	-	60	-2.5	57	-	54	-25	59	D	24	2.5
+55	20/11/95	46	-	61	+77	55	-	F		F		54	+102
+55	12/12/95	42	-	59	+97	58	-	F		F		61	+160
-15	23/01/96	55	+170	54	+175	62	+295	F		F		54	+352
-490	31/01/96	0.9	-365	F		55	-292	F		F		64	-252
+605	26/01/96	61	+875	63	+992	64	+1235	F		F		61	+487

F = Flooded D = Damaged and not working CH$_4$ % = Methane P = Pressure in pascals

Table 9 Methane Concentrations and Gas Pressures in Waste

Date	20m DOWNSLOPE				50m DOWNSLOPE				65m DOWNSLOPE			
	Under liner	Depth in clay - m			Depth in clay - m				Depth in clay - m			
		0.5m	1.0m	1.5m	0m	0.5m	1.0m	1.5m	0	0.5m	1.0m	1.5m
18/12/91					-	9.8	10.2	10.3	14.3	13.9	12.5	12.5
23/1/92					13.7	13.5	12.1	12.9	14.6	14.5	13.6	13.5
27/2/92					12.7	11.9	11.5	11	12.9	12.5	11.9	11.2
28/5/92					-	13	14	13	16	13	14	13
12/6/92	11	14	11	9	15	15	14	13	14	14	13	12
23/6/92	15	16	14	12	-	14	14	13	11	12	12	12
28/7/92	14	16	14	13	-	13	13	12	11	12	11	9
14/8/92	15	15	14	12	13	13	12	12	14	13	14	3
28/8/92	14	17	16	14	13	13	13	13	14	14	14	3
11/9/92	-	17.1	15.7	14.3	-	13	12.6	12.6	17.5	15.6	15.6	14.7
30/9/92	17	18	16	18	-	14	14	14	14	15	13	14
20/10/92	16.7	17	16	15.6	-	13	12.8	12.5	14.2	14	13.9	12.9
4/11/92	16.7	18.1	17.1	15.9	-	13.4	13.3	12.9	14.5	14.4	14.4	14.2
23/11/92	16.9	17.4	17.0	16.6	-	14.5	13.7	13.3	15.1	15.4	15.1	14.4
14/12/92	17.8	18.2	17.7	16.9	-	-	15.9	18	16.4	15.4	14.7	14.4
5/1/93	19.7	20.0	18.9	18.5	-	17.8	15.5	15.2	16.8	16.4	16.8	16.3
19/1/93	17.0	18.0	17.3	16.9	Plug replaced	16.3	14.9	14.5	15.5	15.2	15.2	14.5
2/2/93	16.1	16.2	15.6	15.2	-	13.6	13.3	12.5	13.3	13.5	12.7	12.8
15/2/93	16.5	26.6	15.9	15.5		15.1	13.6	12.6	13.1	13.3	14.1	13.4
2/3/93	15.7	16.3	16.0	15.3		14.6	14.4	-	14	13.8	13.9	13.4
15/3/93	16.4	18.2	17.8	17.1		-	13.6	-	15.2	15.0	15.6	14.5
16/4/93	16.8	18.7	17.9	17.2	-	15.4	15.4	-	17.2	15.9	17.7	16.7
30/4/93	18.5	19.8	18.4	18.2	-	-	15.0	15.2	17.0	17.5	18.1	17.5
17/5/93	17.0	15.8	15.7	16.4	-	17.0	15.9	-	16.8	15.9	16.0	14.7
7/6/93	16.5	15.7	13.8	16.6	-	-	20.4	20.5	11.4	12	12.5	12
18/6/93	13.4	13.6	13.6	16.4		13.9	13.8	12.9	14.0	13.9	13.3	14.2

Table 10 Temperature readings from sensors installed down the clay embankment and one beneath the HDPE liner

Date	20m DOWNSLOPE				50m DOWNSLOPE				65m DOWNSLOPE			
	Under liner	Depth in clay - m			Depth in clay - m				Depth in clay - m			
		0.5 m	1.0m	1.5m	0m	0.5m	1.0m	1.5m	0	0.5m	1.0m	1.5m
2/7/93	13.6	14.6	14.3	14.2		13.5	15.9	13.5	13.8	14.1	14.2	13.6
23/7/93	16.1	15.6	16.0	16.3		-	18.9	14.3	16.5	16.7	16.2	15.2
10/8/93	14.2	16.4	16.3	16.4		16.0	16.5	15.7	17.1	16.6	16.5	15.4
22/8/93	16.6	17.2	16.7	16.8		20.5	18.8	17.8	17.7	16.6	17.2	15.9
7/9/93	15.2	15.5	16.4	14.4		19.3	22.3	15.8	-	15.7	15.2	14.8
30/9/93	16.9	16.1	16.7	16.1		16.9	18.8	15.9	17.8	17.5	17.3	18.4
25/10/93	15.9	16.8	16.0	15.7		26.2	24.7	16.0	15.6	15.7	16.3	17.6
15/11/93	16.5	15.6	14.7	15.3	-	-	24.7	20.2	17.1	16.6	17.4	17.1
10/12/93	17.0	16.4	16.3	16.2	-	-	-	24.0	17.2	16.1	16.4	16.3
23/12/93	17.8	16.3	16.0	16.2	-	-	22.6	22.9	17.6	16.6	18.0	16.0
10/1/94	15.5	16.2	15.6	15.6	-	-	28.0	29.2	16.2	16.7	16.0	16.6
25/1/93	14.9	15.5	14.7	15.6	-	24.8	25.8	21.7	16.9	16.7	16.1	15.6
11/2/93	16.0	14.9	14.9	15.0	-	-	-	-	16.5	16.6	15.8	15.4
11/3/94	10.2	15.8	15.6	15.7	-	27.1	22.4	-	17.5	16.6	16.7	16.3
25/3/94	15.7	15.0	15.0	15.0	-	-	16.3	-	16.6	16.2	15.6	15.2
8/4/94	15.5	15.0	15.6	15.3	-	-	16.9	-	19.8	19.3	19.1	18.5
26/4/94	14.9	16.3	16.7	16.9	-	-	17.1	-	17.0	16.8	16.8	16.5
9/5/94	13.9	11.8	13.8	13.1	-	-	-	-	16.0	15.9	16.0	14.1
24/5/94	15.3	14.1	14.0	14.4	-	-	-	-	16.5	15.8	16.2	15.5
9/6/94	14.8	15.3	15.4	15.0	-	-	-	-	17.0	16.5	16.2	15.8
23/6/94	14.6	15.2	15.3	15.0	-	-	-	-	16.5	15.9	16.2	16.0
5/7/94	14.0	-	-	-	-	-	-	-	16.5	16.1	15.9	15.5
25/7/94	11.5	12.1	12.7	11.5	-	-	-	-	13.2	-	14.0	13.6
8/8/94	10.3	11.5	12.2	11.1	-	-	-	-	13.8	13.9	11.8	11.9
18/8/94	12.2	12.5	11.9	12.6	-	-	-	-	15.1	14.1	14.2	13.9
5/9/94	11.1	11.1	11.6	11.5	-	-	-	-	14.2	13.9	14.6	13.2

Table 10 (continued)

	20m DOWNSLOPE				50m DOWNSLOPE				65m DOWNSLOPE			
Date	Under liner	Depth in clay - m			Depth in clay - m				Depth in clay - m			
		0.5m	1.0m	1.5m	0m	0.5m	1.0m	1.5m	0m	0.5m	1.0m	1.5m
22/9/94	12.6	11.5	11.5	12.3	-	-	14.7	-	15.4	14.5	14.5	14.2
7/10/94	12.1	11.2	11.3	12.4	-	-	15.1	-	15.6	15.1	14.8	14.6
24/10/94	11.8	11.0	11.3	11.5	-	-	17.3	15.3	14.5	14.3	14.1	13.6
7/11/94	12.9	12.9	13.8	13.2	-	-	15.1	-	16.1	15.4	15.5	14.7
21/11/94	12.7	12.8	12.8	12.7	-	-	17.4	14.9	15.3	15.1	14.7	14.2
28/11/94	12.9	12.7	12.9	12.6	-	16.7	15.3	15.4	15.6	15.2	15.0	14.4
12/12/94	12.3	12.7	13.4	12.7	-	15.8	15.0	14.5	15.4	14.7	14.6	14.1
6/1/95	13.3	13.1	14.0	12.9	-	-	16.3	15.9	16.5	16.2	17.0	15.1
16/1/95	12.6	12.9	12.9	12.8	-	15.3	16.0	16.4	15.9	15.5	15.0	14.5
30/1/95	13.1	13.4	13.3	13.6	-	16.0	15.7	14.8	16.7	17.8	16.4	15.6
14/2/95	17.7	12.2	12.6	12.6	-	14.7	14.6	14.4	15.9	15.6	15.3	14.7
6/3/95	14.3	12.7	11.3	13.7	-	17.1	17.0	16.5	17.2	16.6	17.1	16.4
16/3/95	13.6	11.4	11.8	11.9	-	15.8	15.9	-	15.7	15.4	15.2	15.0
31/3/95	12.6	13.9	13.8	14.0	-	16.3	16.2	15.7	16.8	16.7	16.6	16.2
13/4/95	13.0	13.6	13.5	13.5	-	16.8	16.5	15.9	16.6	16.4	16.1	15.7
15/5/95	13.4	12.8	13.4	13.6	-	14.3	14.2	14.9	17.5	17.1	16.5	16.5
19/6/95	11.0	10.8	11.8	12.1	-	13.9	13.8	13.3	15.2	15.1	14.6	14.3
18/7/95	11.3	12.3	12.3	11.9	-	14.0	13.6	13.5	15.7	15.4	15.2	14.9
15/8/95	-	11.0	11.5	12.0	-	14.7	14.3	13.6	14.8	14.7	14.6	14.5
25/9/95	12.6	13.2	13.5	13.6	-	15.0	16.1	14.9	16.3	16.2	16.3	16.2
17/10/95	-	12.7	12.7	12.3	-	15.4	15.8	15.1	16.2	16.1	15.7	15.4
20/11/95	14.1	12.1	12.6	11.9	-	14.5	15.2	14.3	16.3	15.0	15.5	15.3
12/12/95	14.5	13.3	13.5	13.7	-	19.0	20.0	16.8	18.2	18.2	17.7	17.9
31/1/96	14.2	13.3	13.8	13.3	-	15.9	16.2	-	18.1	17.7	17.3	16.9
26/2/96	-	13.2	13.3	13.5	-	16.9	16.9	-	18.5	18.1	17.7	17.6

Table 10 (continued)

	WELL Nº					
Date	**14/6**	**S**	**W**	**14/4**	**14.5A**	**14/5B**
8-8-94	Dry 45.64	Dry 36.63	Dry 44.92		37.68	38.48
18-8-94	"	"	"		37.76	38.45
5-9-94	"	"	"		37.83	38.58
22-9-94	"	"	"		37.84	38.58
7-10-94	"	37.88	"		37.88	38.64
24-10-94	"	37.92	"		37.95	38.66
7-11-94	"	37.96	"		37.95	38.70
21-11-94	"	37.94	"		U/S	38.70
28-11-94	"	38.06	"		U/S	38.72
12-12-94	45.84	38.11	45.12		U/S	F
6-1-95	46.13	38.16	45.29		U/S	F
16-1-95	46.19	38.18	45.35		U/S	F
30-1-95	46.24	38.15	45.42		U/S	38.80
15-2-95	46.24	38.23	45.37		U/S	F
6-3-95	46.31	38.26			U/S	38.87
16-3-95	46.34	38.28	45.33		U/S	38.79
31-3-95	46.34	38.31	45.42	39.70	U/S	38.81
13-4-95	46.29	38.28	45.19	39.71	U/S	38.87
15-5-95	46.28	38.42	45.06	39.76	U/S	39.01
19-6-95	46.26	-		39.77	U/S	U/S
18-7-95	46.26	38.54	45.20	39.76	U/S	U/S
15-8-95	46.24	38.56	45.07	39.78	U/S	U/S
25-9-95	46.22	38.62	45.04	39.78	U/S	U/S
17-10-95	46.22	38.60	45.02	38.80	U/S	39.26
30-11-95	46.33	38.85	45.77	39.82	39.08	F
12-12-95	46.42	38.79	45.65	39.81	38.78	F
23-1-96	46.55			40.60	39.23	F
26-2-96	46.62			40.45	-	F

U/S = unserviceable F = Flooded

Table 11 Leachate Levels in Landfill (m - A.O.D.)