



Appendix 8

Gas Management Plan

February 2011



HESPIN WOOD LANDFILL SITE

Note 2

Section 6.2 of the plan explains ~~the~~ ^{that} the ~~let~~ ^{let} ~~the~~ ^{the} ~~could~~ ^{could} not be put in the ECP. It says we will put it in later. In Dec 12 I'll prepare GWS as a ~~land~~ ^{land} ~~gas~~ ^{gas} / water l/h Landfill Gas Management Plan

Submitted to:
Cumbria Waste Management Ltd
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This is a draft
Sent to EA as
Part of gas audit
not approved until it
EA'd. only diff is
Gas has Energy gas
balancing procedures in.

- EA approved Gas after Audit but needs
to be formally approved which we will
do as part of the Phase 6 consolidating
version. Also the attached balancing
procedures (V2) has now changed to V5

Report Number:

1151429018.503A.4
(EUP) ~~gas~~ ^{gas} report
1051429003.512
Version A.3)

Distribution:

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with LFC from ~~Phase 6~~ ^{Phase 6} version
by approval by Email from MPA 29/6/11. &
US now after V2 in the draft

February 2011

CELEBRATING
50
YEARS
in 2010

HESPIN WOOD LANDFILL SITE

CURRENTLY
APPROVED BUT NOT¹ SUBMITTED
29/6/2011

Landfill Gas Management Plan

Submitted to:
Cumbria Waste Management Ltd
Unit 5A Wavell Drive
Rosehill Industrial Estate
Carlisle
Cumbria
CA5 2ST

REPORT



A world of
capabilities
delivered locally

Report Number. 11514290018.503/A.4
(supersedes report
10514290003.512
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Drawing ESID8 – Landfill Gas Management

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Gas Monitoring and Balancing Protocol



1.0 REPORT CONTEXT

This report provides the revised landfill gas management plan to be implemented at Hespian Wood Landfill Site (the 'Site').

This plan should be read in conjunction with the PPC Permit Application, (Ref: 03523593 dated May 2004), in particular Section D *Landfill Gas Risk Assessment*. This plan incorporates all of the relevant sections of Appendix 6 of that application, *Landfill Gas Management Plan*, and is augmented by the information required by the permit improvement programme (IC1 of permit as originally issued), and Environment Agency (Agency) letter dated 27 November 2008 with reference to the waste input permit variation application submitted by Golder Associates (UK) Ltd (Golder) on behalf of Cumbria Waste Management Ltd (CWM) dated October 2008. This plan wholly supersedes Appendix 6 and **Version A.3** of the Landfill Gas Management Plan.

The Site is operated by CWM, under Environmental Permit BM6026IB/V006 and V007 (due to be consolidated into V008). This plan has been produced by Golder under instruction from CWM in order to meet the requirements of the Environment Agency by including the gas monitoring and balancing protocol followed by EnerG Natural Power who manage the gas field at the Site.

2.0 LANDFILL GAS MANAGEMENT PLAN

A detailed assessment of the generation of landfill gas is given in Section D of the original permit application, *Landfill Gas Risk Assessment*.

A scheme for the monitoring and control of landfill gas within the performance specifications detailed in the Agency's *Guidance on the Management of Landfill Gas, September 2004* is set out below. It is anticipated that within the period of operation of the Site, changes in the understanding of the technology will occur, which will be reflected in amendments to the advice given to the industry or the regulations issued by Government. This plan will be periodically reviewed to reflect such changes.

Gas management and control is achieved by:

- a) The installation and operation of internal and, where necessary, external gas monitoring systems;
- b) A progressively installed active gas extraction and utilisation system, incorporating the internal monitoring system above, in accordance with the details below; and
- c) The low permeability liner installed across the base, the perimeter bunds and top of the Site.

An active gas control system is required for the Site, due to the waste types and quantities that are deposited. The active landfill gas extraction system comprises connection of the gas extraction wells to the landfill gas management compound by pipe work and manifolds. The wells will be installed progressively as the phases are completed, and Drawing ESID8 will be updated accordingly.

CWM has responsibility for the day-to-day environmental control of landfill gas and gas utilisation plant. A third party company Natural Power Ltd (Natural Power) is responsible to CWM for the operation of the gas extraction and utilisation system. Environmental control is in accordance with the exact instruction of CWM and it is CWM that ensures compliance with permit conditions through (amongst others) the offices of the Site Manager employed at the Site. The gas utilisation plant shall therefore continue to be regulated by the landfill permit.



3.0 LANDFILL GAS MONITORING

3.1 Internal Waste Monitoring

3.1.1 Landfill Gas Extraction

Landfill gas control is based on an active gas extraction system incorporating a network of gas extraction wells, flare stack and power generation plant as shown on Drawing ESID8.

The active gas extraction system will be progressively installed and commenced upon completion of each phase to pre-settlement, pre-restoration levels. Details of the gas wells and well heads can be found in Section A *Environmental Setting and Installation Design* of the original permit application.

The gas collected by the landfill gas extraction system is disposed of by means of combustion either within a flare or electricity generation engine. The flare and engine(s) are located within the gas management compound shown on Drawing ESID6A.

The landfill gas extraction wells are spaced with an approximate 20 m minimum radius of influence (40 m grid) to ensure that the landfill gas is drawn back towards the centre of the Site and away from the side slope liner, as shown on Drawing ESID8.

Each extraction well will be constructed of High Density Polyethylene (HDPE) pipe or similar material with a minimum diameter of 90 mm slotted along all but the upper 2 m. The annulus of the gas extraction wells will be filled with gravel and the upper 2 m will be sealed with bentonite. The gas wells will extend to no more than 80% of the depth of the waste. The well liner will be slotted to 2 m below the capping layer.

Gas extraction pipelines from individual wells connect to a ring main as described in Section A *Environmental Setting and Installation Design* by means of gas manifolds, and shown on Drawing ESID8.

3.1.2 Internal Landfill Gas Monitoring

The landfill gas extraction wells are used as monitoring points to determine gas concentrations, or for active extraction when required. When gas is being actively extracted leachate monitoring wells are used to determine gas concentrations. ??

Monitoring of gas in the leachate monitoring wells within a phase will commence within 3 months of the first waste placement within that phase. ??

The wells are monitored at monthly intervals for methane, carbon dioxide, oxygen and atmospheric and differential pressure as shown in Table 1. Methane, carbon dioxide and oxygen are reported as concentration v/v, to an accuracy of $\pm 0.1\%$, and atmospheric and differential pressure as mbar, to an accuracy of ± 1 mbar.

Monthly monitoring for carbon monoxide is undertaken at the same monitoring locations described above. Carbon monoxide may be reported as ppm v/v, between a range of 0 to 1000 ppm, to a resolution of 1 ppm. The accuracy of the reading obtained will be between $\pm 10\%$ of the reading between 0 and 100 ppm, or ± 10 ppm, whichever is the greater, and therefore the lower limit of detection is 10 ppm.

Table 1: Monitoring Frequencies for Landfill Gas within the Engineered Containment

Determinands	Monitoring Frequencies	Units and Accuracies	Trigger Levels
Methane (CH ₄)	Monthly	v/v $\pm 0.1\%$	None
Carbon Dioxide (CO ₂)	Monthly	v/v $\pm 0.1\%$	None
Oxygen	Monthly	v/v $\pm 0.1\%$	None
Atmospheric Pressure	Monthly	± 1 mb	None
Differential Pressure	Monthly	± 1 mb	None
Carbon Monoxide (CO)	Monthly	v/v ± 1 ppm	100 ppm



Where the results of ^{monthly} quarterly monitoring of carbon monoxide undertaken exceed a trigger level of 100 ppm, the Agency will be notified within 24 hours and additional monitoring will be undertaken in the affected and adjacent wells for temperature to determine whether there is a possibility of a landfill fire within the waste body. Temperature measurements will be taken with a probe at 5 m intervals throughout each well monitored.

Biodegradation of wastes, when occurring in the mesophilic to thermophilic ranges, may produce temperatures within the waste mass typically between 38°C and 65°C. Accordingly, no further action will be deemed necessary if temperatures are measured within or below this range. Where temperatures in excess of 80°C are measured, discussions will be held with the Agency and further actions agreed.

As the volume and quality of gas decreases with time after site closure and gas collection ceases, on-Site landfill gas concentrations will be monitored in a limited number of wells or in the passive leachate monitoring wells to be identified and agreed with the Agency.

3.1.3 Gas Field Balancing

The landfill gas field is managed by EnerG Natural Power under contract to CWM. EnerG Natural Power undertakes this in accordance with its most recent gas monitoring and balancing protocol, the current version of which is provided in Appendix D.

4.0 MONITORING TRACE COMPONENTS WITHIN LANDFILL GAS

The forthcoming section details how, in accordance with Agency guidance, monitoring of trace components is undertaken, including the frequency and location of the monitoring.

4.1 Monitoring Methodology

The monitoring methodology is divided into two stages:

- Preliminary checks and field measurements that are completed at the Site; and
- Sampling and analysis that requires work at the Site and in the laboratory.

4.1.1 Preliminary Checks and Field Measurements

Preliminary checks are undertaken to establish a suitable monitoring point and to confirm that the gas sample is not temporarily atypical due to perturbations such as a fire.

4.1.1.1 Preliminary Monitoring Methodology

- 1) An appropriate sampling point is selected (see Section 4.3).
- 2) The bulk constituents of landfill gas (methane, carbon dioxide and oxygen) along with Hydrogen Sulphide (see Table 3), are determined prior to detailed sampling using hand held instruments which utilise infra-red and electrochemical cells. The field measurements are undertaken with a hand-held field instrument (an Analox GA2000 or similar). All instruments used will be maintained and calibrated in accordance with the manufacturer's recommendations.
- 3) Carbon monoxide may also be recorded if deemed appropriate. However, it is noted that if the concentration is taken using an Analox, or similar, the instrument may be subject to positive interference and is indicative at best. Concentrations of carbon monoxide greater than 100 ppmv (as verified in the laboratory) may indicate the presence of a deep seated landfill fire within the landfill and therefore the resulting trace gas analysis could be abnormal as it may temporarily contain other combustion products. Therefore, if carbon monoxide is detected during the field testing, a further sample in a Gresham tube or a Tedlar bag will be obtained and sent to the laboratory for gas chromatography analysis to determine the actual carbon monoxide concentration.



LANDFILL GAS MANAGEMENT PLAN, HESPIN WOOD

- 4) Prior to detailed sampling of trace compounds the vacuum on the gas line will be measured and recorded using a manometer. If the vacuum is greater than 10 kPA (0.1 bar) a standard sampling pump cannot reliably withdraw gas from the sampling point, and therefore an alternative sampling point will be identified.
- 5) The tendency of the gas sample to form condensate will be observed. If conditions exist where a heavy condensate is being formed, an alternative sampling point will be evaluated.

4.1.1.2 Preliminary Monitoring Results

The results of the preliminary sampling will be recorded using the units shown in Table 2 below.

Table 2: Bulk Gases to be Analysed during Preliminary Sampling

Gas	Units
Methane	% v/v
Carbon Dioxide	% v/v
Oxygen	% v/v
Nitrogen	% v/v

Additional information that will be documented typically includes:

- Location of sampling point;
- Nature of sampling point (i.e. flare manifold, engine manifold);
- Type of waste in sample area (i.e. inert, non-hazardous);
- Age of waste in sample area (i.e. 1996 - 2000);
- Vacuum on gas line;
- Gas flow (if possible);
- Tendency to form condensate;
- Ambient temperature; and
- Temperature of gas.

4.1.2 On-Site Sampling and Subsequent Laboratory Analysis

4.1.2.1 Sample Collection On-Site Methodology

In order to collect representative samples for subsequent analysis the following methodology has been adopted as described in detail in the 'Guidance for Monitoring Trace Components in Landfill Gas' (Environment Agency, 2004).

Landfill gas will be drawn through solid sorbent material, packed in a tube, by means of a pump or manually operated metering system. The sorbents selectively extract and concentrate the target analytes, allowing those components that are not absorbed to pass through.

For each determination, duplicate samples will be taken and a trip-blank tube (not exposed) will be assigned.

The recommended approach for the collection of samples on-Site will be followed as detailed in Section 5 of the 'Guidance for Monitoring Trace Components in Landfill Gas' (Environment Agency, 2004) given in Appendix A.



4.1.2.2 Sample Collection Considerations

During the sampling of trace constituents, the following actions will be taken to ensure the sample is representative:

- Sampling will not take place within a minimum of 3 hours of major changes to the gas flow such as switching on or off the gas engines to reflect that gas composition may take some time to stabilise after such changes;
- The gas sample will be metered to provide an accurate value for the sample volume;
- Precautions will be taken during sampling to avoid moisture or condensate entering the sampling system;
- The sampling methodology (listed in Table 3 below), as recommended in the '*Guidance for Monitoring Trace Components in Landfill Gas*' (Environment Agency, 2004), will be adopted wherever possible; and
- To minimise potential contamination, all monitoring equipment will be cleaned to remove any potential organic contaminants.

4.1.2.3 Transportation of Samples to Laboratory

- The samples will be transferred to the laboratory in clean, sealed containers with minimum exposure to other volatile substances prior to analysis to avoid contamination and degradation of the sample. Ideally, the sampling tubes will be kept chilled until analysis.

4.1.2.4 Laboratory Analysis of Samples

- Samples will be analysed as soon as reasonably possible after collection, if possible within a week of collection;
- The sample will undergo appropriate preparation for analysis to avoid contamination and degradation of the sample;
- The analysis methodology (listed in Table 3 below) as recommended in the '*Guidance for Monitoring Trace Components in Landfill Gas*' (Environment Agency, 2004) will be adopted wherever possible; and
- It is recognised that the analysis methodologies stated in Table 3 will also quantify certain substances that have similar properties to those nominated in Table 3. The detection of an unusually high concentration of a substance not contained within Table 3 below will be investigated.

4.2 Monitoring Frequency

In line with the '*Guidance for Monitoring Trace Components in Landfill Gas*' (Environment Agency, 2004) the monitoring of trace components within landfill gas will be carried out annually. In addition, monitoring of trace components will be undertaken when Site-specific circumstances alter, for example, significant changes to the gas management system.

4.3 Sampling Location

The sampling location will be from the gas extraction line, prior to the disposal system. In practice at the Site, the sample will be taken from the main gas line to the flare/utilisation plant as this is deemed to be representative of the gas collected at the Site. In addition, no cells at the Site contain 'atypical' waste with respect to gas generation therefore additional monitoring at individual cells has not been proposed.

The sampling point will, where possible, be located where significant condensation does not form as the gas sample is taken, as the condensate will selectively remove some polar substances from the gas and may affect the performance of the monitoring method.



4.4 Parameters to be Monitored

In order to ensure the gas sample is typical and representative of the source landfill gas, the detailed sampling for trace components will be preceded by a check on the composition of the bulk gases. A list of bulk gases that will be monitored are shown in Table 2 above. A list of trace gases which are to be monitored at the Site are contained within Table 3 below.

Table 3: Trace Gas Constituents to be Monitored

Significant Trace Component	CAS Number	Sampling Method	Analytical Method
1,1-dichloroethane	75-34-3	Dual solid sorbent	ATD-GC-MS
1,1-dichloroethene	75-35-4	Dual solid sorbent	ATD-GC-MS
1,2-dichloroethene	540-59-0	Dual solid sorbent	ATD-GC-MS
1,3-butadiene	106-99-0	Dual solid sorbent	ATD-GC-MS
1-butanethiol	109-79-5	Dual solid sorbent	ATD-GC-MS
1-pentane	109-67-1	Dual solid sorbent	ATD-GC-MS
1-propoahethiol	107-03-9	Dual solid sorbent	ATD-GC-MS
2-butoxy ethanol	111-76-2	Dual solid sorbent	ATD-GC-MS
Arsenic (as As)	7440-38-2	Solid sorbent	ICP-MS/AAS
Benzene	71-43-2	Dual solid sorbent	ATD-GC-MS
Butyric acid	107-92-6	Dual solid sorbent	ATD-GC-MS
Carbon disulphide	75-15-0	Dual solid sorbent	ATD-GC-MS
Chloroethane	75-00-3	Dual solid sorbent	ATD-GC-MS
Chloroethene (vinyl chloride)	75-01-4	Dual solid sorbent	ATD-GC-MS
Dimethyl disulphide	624-92-0	Dual solid sorbent	ATD-GC-MS
Dimethyl sulphide	75-18-3	Dual solid sorbent	ATD-GC-MS
Ethanal (acetaldehyde)	75-07-0	Reactive sorbent	ATD-GC-MS
Ethanethiol	75-08-1	Dual solid sorbent	HPLC
Ethyl butyrate	105-54-4	Dual solid sorbent	ATD-GC-MS
Furan (1,4-epoxy-1,3-butadiene)	110-00-9	Dual solid sorbent	ATD-GC-MS
Hydrogen sulphide	7783-06-4	Direct on-Site measurement of raw gas*	Hand held instrument
Methanal (formaldehyde)	50-00-0	Dual solid sorbent	HPLC
Methanethiol	74-93-1	Dual solid sorbent	ATD-GC-MS
Tetrachloromethane	56-23-5	Dual solid sorbent	ATD-GC-MS
Trichloroethene	79-01-6	Dual solid sorbent	ATD-GC-MS

* where hydrogen sulphide is detected above 50 ppmv, the sampling method may be by laboratory analysis.

4.5 Reporting of Monitoring Results

The results will be summarised in a way that allows clear interpretation.

The sample will be representative of the whole Site, as it will have been collected from the flare/utilisation plant inlet.

Where reasonable, the results will be presented in a format and units following the template report contained within Appendix 4 of 'Guidance for Monitoring Trace Components in Landfill Gas' (Environment Agency, 2004) given in Appendix A.



In line with recommendations within the 'Guidance for Monitoring Trace Components in Landfill Gas' (Environment Agency, 2004) reported data will not be normalised to standard temperature and pressure.

Any priority trace components that are not positively identified using the recommended methods will be reported as being below their respective detection limits. Recommended detection limits that will be adopted are those provided in Appendix 3 of the 'Guidance for Monitoring Trace Components in Landfill Gas' (Environment Agency, 2004) given in Appendix A.

Data will be assessed for consistency with previously reported data (if any). The report will highlight instances where variation from normal procedures has been necessary and should inform future monitoring requirements.

4.6 Summary

In line with the 'Guidance for Monitoring Trace Components in Landfill Gas' (Environment Agency, 2004), monitoring of trace components within landfill gas will be undertaken annually at Hespian Wood Landfill Site. A preliminary on-Site check will be undertaken of the bulk landfill gases listed in Table 1. If these are found to be representative, monitoring of trace components detailed in Table 2 will be undertaken.

5.0 MONITORING SURFACE EMISSIONS

The forthcoming section details how, in accordance with Agency guidance, surface emissions monitoring will be undertaken, including the frequency and location of the monitoring.

5.1 Monitoring Methodology

The monitoring of surface emissions at the Site will be undertaken in accordance with the 'Guidance on Monitoring Landfill Gas Surface Emissions' (Environment Agency, 2004) and will be undertaken in two stages:

- 1) **Survey of Site:** to demonstrate whether there are inadequacies in the gas containment and collection system. Only when deficiencies have been located and remediated such that the concentration of gas above the surface is low is it appropriate to begin the second stage comprising a quantitative survey of surface flux; and
- 2) **Flux Box Survey:** the flux of methane emitted through the intact cap is measured at a number of representative points using an array of flux boxes. From these individual measurements, the average flux from the capped zones will be calculated and compared to the Agency's standards.

5.1.1 Survey of Site

- 1) Background data relating to the Site will be gathered by CWM along with Natural Power Ltd which provides day-to-day support to CWM regarding gas utilisation at the Site;
- 2) The Site's major characteristics will be identified at the outset and recorded on a suitable form similar to the example contained within Appendix B of the 'Guidance on Monitoring Landfill Surface Emissions' (Environment Agency, 2004);
- 3) Based on a site plan the landfill will be divided into a number of zones dependant on the cap properties;
- 4) Prior to the walkover survey any major faults in the gas management system will be identified and rectified;
- 5) Prior to the walkover survey the general weather conditions will be noted including barometric pressure, recent precipitation, wind speed and direction. Also the nature of areas adjacent to the survey will be noted e.g. activities that may emit gas or lead to gas migration;
- 6) The site walkover survey will be conducted with a flame ionisation detector (FID) or similar. The sample probe will be held as close to the surface (<5 cm) as possible. The air at head height will periodically



be sampled (to enable distinction of surface emissions from the landfill from other potential upwind sources). The Site will be traversed in a systematic manner, typically along regular lines 50 m apart on a permanent cap and 25 m apart on a temporary cap. These distances will be reduced where failures in the containment of gas are more likely. In addition the walkover survey will be directed by observations of the surface, methane emissions measured and secondary factors such as odour. Where high concentrations of methane are detected, the survey will deviate to locate the likely source of the emission. Care will be undertaken when taking measurements in the vicinity of heavy plant, as the un-burnt hydrocarbons in diesel exhausts will register on the FID and give potentially misleading results;

- 7) The survey will also identify:
 - Surface cracking or fissures;
 - Stressed vegetation;
 - Interfaces between capped zones;
 - Landfill edges and side slopes;
 - Gas wells and monitoring points;
 - Junctions in gas collection pipework if exposed;
 - Pathways where pipework may be buried in trenches; and
 - Leachate sumps, towers, risers and other monitoring points.
- 8) Where the survey identifies locations with particularly high emissions, these will be marked with paint or poles for attention during subsequent remedial work. It is noted that many fluorescent survey paints are very high in VOCs and will give misleading results for several days if sprayed directly on the landfill surface;
- 9) If the survey demonstrates the cap is not consistent and there are discrete features emitting substantial amounts of landfill gas, remedial action is required as soon as possible; and
- 10) The site survey and subsequent remedial action will continue until the concentration of methane in air is:
 - Less than 100 ppmv immediately above the surface of the cap; and
 - Less than 1000 ppmv close to any discrete features.

5.1.2 Flux Box Survey

If deemed necessary, through the initial site walkover phase, and in agreement with the Agency, a flux box survey will be carried out at the Site. The flux box survey will be carried out in line with the methodology contained within 'Guidance on Monitoring Landfill Gas Surface Emissions' (Environment Agency, 2004). The methodology that will be adopted is outlined below:

- 1) The most recent site walkover and desk study results will be used to define emission zones and features at the Site, where a zone is an extensive area of the landfill surface over which the average emissions can be calculated and a feature is a discrete area or installation within a zone where abnormal emissions might be found;
- 2) An appropriate number of samples points and average spacing will be determined using the methodology outlined in Section 5.6 of the 'Guidance on Monitoring Landfill Gas Surface Emissions' (Environment Agency, 2004) given in Appendix B; and
- 3) The survey will be carried out when the emissions are representative of normal operation of the gas management system.



The survey will be carried out under appropriate meteorological conditions as summarised below:

- During periods of falling or low pressure;
- Not during and following periods of unusually heavy rainfall; and
- Not during periods of frost.

The flux box survey will be designed based on information gathered during walkover surveys already conducted, which will define zones and features on the cap that could contribute differentially to the overall emissions. The flux box survey will be designed in line with Chapter 5, 'design of flux box surveys' contained within *'Guidance on Monitoring Landfill Surface Emissions'*, (Environment Agency, 2004), given in Appendix B.

Any flux box survey undertaken at the Site will be carried out following the methodology outlined in Chapter 6, 'measuring emissions using a flux box' contained within *'Guidance on Monitoring Landfill Gas Surface Emissions'*, (Environment Agency, 2004) given in Appendix B.

Monitoring data from any flux box surveys undertaken at the Site will be processed following the methodology outlined in Chapter 7, 'data processing' contained within *'Guidance on Monitoring Landfill Gas Surface Emissions'*, (Environment Agency, 2004) given in Appendix B. Data will be processed and a mass emission rate for each zone or feature calculated.

Emissions data from any flux box survey will be assessed and the average flux of methane from the surface of the cap in each zone will be compared to the following emissions standards set by the Agency:

- Permanently capped zone: 0.001 mg CH₄/m²/second; and
- Temporarily capped zone: 0.1 mg CH₄/m²/second.

5.2 Monitoring Frequency

In line with the Agency's *'Guidance on the Management of Landfill Gas'* (Environment Agency, 2004) Table 5.4, *'Guidance on Monitoring Landfill Gas Surface Emissions'* (Environment Agency, 2004), it is proposed that an annual walk over FID survey for surface emissions is appropriate for this Site. A more detailed flux box survey may be carried out at a frequency of 1-5 years based on the results of the walkover survey and agreement with the Agency.

5.3 Reporting of Results

Monitoring data from any flux box surveys undertaken at the Site will be processed following the methodology outlined in Chapter 9, Reporting, contained within *'Guidance on Monitoring Landfill Gas Surface Emissions'*, (Environment Agency, 2004). Data will be processed and a mass emission rate reported for each zone or feature.

The results of any walkover survey, flux box survey or remediation plan developed subsequent to a flux box survey conducted will be presented to the Agency.

5.4 Remediation

If any zone is found to be non-compliant, the results of the survey will be used to review the overall gas management plan.

Remediation measures will be carried out as soon as reasonably practicable and within timescales agreed with the Agency.



5.5 Summary

In line with the Agency Guidance document, 'Guidance on Monitoring Landfill Gas Surface Emissions' (Environment Agency, 2004), surface emissions monitoring at the Site will initially comprise an annual walkover survey of the Site. The walkover survey will be followed by a flux box survey if deemed necessary.

6.0 MONITORING LATERAL EMISSIONS

6.1 General

Hespin Wood Landfill is a land raise. As such, the conceptual model does not incorporate a pathway for subsurface gas migration from the Site whilst the waste at the base of the Site is saturated by leachate to above ground level, therefore comprehensive monitoring of gas levels around the perimeter of this Site is not currently undertaken.

6.2 External Monitoring Boreholes

External gas monitoring will be undertaken at eleven locations around the site perimeter. Currently monitoring is undertaken in Boreholes GA3 to GA11, and GA13. An additional Borehole GA12 is to be installed at the site boundary adjacent to Bents Farm on the northeast of the Site, to verify that landfill gas does not migrate at unacceptable concentrations from the landfill towards this receptor, however this has been delayed as a result of access restrictions and land ownership issues relating to the Compulsory Purchase Order at the Site. The borehole locations are shown on Drawing ESID8 at a distance of no less than 20 m from the boundary of the waste.

Additional or replacement landfill gas boreholes will be drilled to a diameter of 150 mm to the depth of 5 m. Landfill gas wells will comprise a 50 mm inside diameter PVC or HDPE casing, perforated throughout its length except for the top metre. The casing will be surrounded with a filter wrap to prevent ingress of fines, and will be surrounded with a 6 to 10 mm gravel pack, except for the top metre that will be fitted with a bentonite seal. End caps will be fitted to the base of the well casing and the top of the casing will be fitted with a removable cap, fitted with a gas tap. Secure lockable headworks will be fitted over the top of the well and concreted into position. A drawing of the specification is provided in Appendix C.

6.3 Construction Quality Assurance of Landfill Gas Monitoring Points

Installation of new or replacement landfill gas monitoring boreholes will be undertaken in accordance with the following Construction Quality Assurance (CQA) plan which covers the elements of the design and installation.

Gas monitoring boreholes shall be drilled and recorded in accordance with BS 5930 Code of Practice for Site Investigations and shall be constructed and installed as shown on Drawing ESID8. Borehole logs and as-built installation details shall be forward to the Agency within 6 weeks of drilling and shall provide the following information:

- Labelling of the borehole;
- Date of drilling/installation;
- Geological strata descriptions;
- Groundwater level (and any perched water levels);
- Design of the borehole if more than one type is being used on the Site;
- Depth of borehole (metres) and level of the bottom of the borehole in metres above ordnance datum;



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- The surveyed height of the top of the borehole in metres above ordnance datum, and the surveyed ground level at the point if it differs; and
- The National Grid Reference of the boreholes (10 figures).

A CQA validation report will be provided which includes the above details and borehole construction detail drawings. All boreholes will be surveyed to Ordnance Datum. The CQA validation report will be submitted to the Agency within one month of completion.

6.4 Maintenance of Landfill Gas Monitoring Points

Landfill gas monitoring boreholes will be maintained in a condition that allows them to fulfil their required purpose. Landfill gas monitoring boreholes will be inspected for damage each time that they are monitored or sampled. Any damage noted will be repaired within seven days of detection or as soon as practicable.

Details of inspections of landfill gas monitoring boreholes, remedial actions undertaken or replacement boreholes installed will be recorded in the site diary, to include relevant dates of inspections and remedial works and details of who carried out the inspection or works.

6.5 Landfill Gas Monitoring

The monitoring schedule for landfill gas outside the engineered containment is shown in Table 4 as follows:

Table 4: Monitoring Frequencies for Landfill Gas Outside the Engineered Containment

Determinands	Monitoring Frequencies	Units and Accuracies
Methane (CH ₄)	Monthly	v/v $\pm 0.1\%$
Carbon Dioxide (CO ₂)	Monthly	v/v $\pm 0.1\%$
Oxygen	Monthly	v/v $\pm 0.1\%$
Atmospheric Pressure	Monthly	± 1 mb

Table 5: Landfill Gas Control and Trigger Levels

Borehole	Methane (CH ₄)		Carbon Dioxide (CO ₂)	
	Control Level (% v/v)	Trigger Level (% v/v)	Control Level (% v/v)	Trigger Level (% v/v)
GA3	N/A	1.0	5.1	6.6
GA4		1.0	3.2	4.7
GA5		1.0	2.4	3.9
GA6		1.0	1.6	3.1
GA7		1.0	2.0	3.5
GA9		1.0	4.3	5.8
GA10		1.0	3.2	4.7
GA11		1.0	7.6	9.1
GA13		1.0	3.5	5.0

All monitoring results obtained from the landfill gas monitoring will be compared against trigger concentrations. The trigger and control concentrations will be established for the recently re-installed/remediated Borehole GA8 following collection of twelve months monitoring data.



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Where results for any borehole(s) exceed(s) the trigger levels, then the requirements of the landfill gas emergency plan will be implemented.

On recording a trigger level which has been exceeded, the emergency measures outlined below will be implemented. These will incorporate agreement of further actions in conjunction with the Agency.

All monitoring data will be assessed at monthly intervals to establish whether there are any changes to the normal and seasonal trends which may be indicative of a problem and could require additional monitoring or emergency measures to be taken. Any variance from the established trends will be reported to the Agency and remedial measures will, if required, be agreed in conjunction with the Agency.

6.6 Landfill Gas Emergency Plan

In complying with the following sections, where a trigger level is exceeded, the Agency and Natural Power will be informed immediately and where additional monitoring is required under the following sections, this will be forwarded to the Agency and Natural Power. If, after reverting back to normal monitoring, a trigger is subsequently again exceeded the Agency will be re-notified of the exceedence.

The following actions, responses and procedures will be taken in respect to methane and carbon dioxide data obtained from perimeter monitoring boreholes.

Table 6: Landfill Gas Action Plan

Action Level	Immediate Action by Technician	Action by Site Manager	Subsequent Action
CH ₄ levels above 0.5%; CO ₂ levels above control level	Inform Site Manager, move to weekly monitoring	Assess trends. If only CO ₂ present at or above control level but below trigger level after six weeks weekly monitoring, send report to the EA and revert to monthly monitoring. If CH ₄ continues to exceed action level but is below trigger consider installation of additional boreholes in sensitive locations	If boreholes continue to show levels approaching trigger levels, agree further actions with the Agency
CO ₂ trigger level exceeded	Move to weekly monitoring of the boreholes subject to exceedence, and adjacent boreholes. Inform Site Manager	EA notified	None
CH ₄ levels in any boreholes exceed 1% v/v	Move to daily monitoring of the boreholes subject to exceedence, and adjacent boreholes. Inform Site Manager	EA notified	Further investigation and/or control measures as agreed with the Agency

6.7 Monitoring Personnel

Landfill gas monitoring will only be undertaken by personnel who are familiar with the equipment and its limitations. The Company will ensure that the personnel engaged in monitoring activities are trained to undertake the task. These will comprise the companies own technical personnel, the Site Manager or nominated deputy, following appropriate training by technical personnel. Technical personnel have a



relevant scientific background to HNC/D or BSc level (or equivalent). All monitoring staff undergo a period of job training and in addition external courses are used to supplement internal training.

6.8 Quality Assurance Plan and Quality Control Procedures for Results

6.8.1 Validation of Results

Validation of results will be undertaken by the trained monitoring personnel, who will also be familiar with landfill gas management and the contents of the landfill gas emergency plan and trigger levels.

6.8.2 Reporting of Results

All landfill gas monitoring results will be logged electronically on the gas measuring instrument where electronic data logging instruments are being used. Alternatively, a hard copy will be made whilst the monitoring is in progress. Monitoring data is transferred to a dedicated spreadsheet which is held centrally by CWM and used to assess monitoring infrastructure performance. They are also retained on-Site and may be made available for inspection by officers of the Environment Agency upon request. Results of landfill gas monitoring undertaken will be forwarded to the Agency in line with the permit requirements.

CWM shall inform Natural Power immediately when a trigger level is exceeded. The results of routine monitoring below the trigger level need not be reported to Natural Power.

7.0 MONITORING PERIMETER AND RECEPTOR AERIAL EMISSIONS

Golder carried out a Landfill Gas Generation and Risk Assessment, as part of the PPC application, for Hespín Wood Landfill Site in May 2004. In this assessment the long-term combustion emissions of nitrogen dioxide, sulphur dioxide, carbon monoxide and hydrogen chloride were modelled. The results of this modelling showed that no emissions exceeded the 70% headroom condition at any site boundary. A similar analysis was carried out, for the same emission substances, modelling the predicted concentrations at each sensitive receptor. This also demonstrated that all the emissions were well below 70% of the headroom at all the receptors. Fugitive emissions modelling of hydrogen sulphide, benzene, vinyl chloride, dichloromethane and tetrachloroethylene was also carried out which showed that the 1% threshold was not exceeded at any of the site boundaries and thus the emissions were considered to be negligible.

As part of the 2004 PPC application Golder also carried out a Nuisance and Health Risk Assessment in which all identified hazards, including dust, were concluded to pose a negligible risk to all the receptors due to the site management procedures.

The PPC risk assessments conclude that no combustion emissions, fugitive emissions, or dust emissions were found to be significant at the Site. Since aerial monitoring is not considered mandatory in the Agency's 'Guidance on the management of landfill gas' (2004), perimeter and receptor aerial emissions monitoring is not considered necessary at Hespín Wood Landfill Site.



Report Signature Page

GOLDER ASSOCIATES (UK) LTD

Rebecca Hodgkinson
Project Manager

Stewart Davies
Reviewer

Date: 10 February 2011

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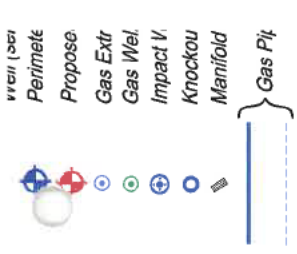
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DRAWINGS

Drawing ESID8 – Landfill Gas Management



Project
Section A: Environmental
Installation Design

Location
Hespin Wood Landfill

Title
Landfill Gas Mana

Project No. 07514290286
File No. 522193614
Created by A.P.

Enq	Rev
07514290286	522193614
522193614	A.P.

ADDITION OF PERIMETER GAS BOX

ADDITION OF PROPOSED PERIMETER

BOREHOLES

CELL 2B (STABLE NON-REACTIVE 1)

CELL REMOVED AND PHASE 4 CELL

REPOSITION OF GAS MONITORING WITH ESID8 REV B

PROVISION OF DETAILS OF EMISSION FROM THE LANDFILL GAS COMPOUND

LATEST SURVEY AND GAS INFRAS

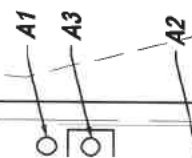
MINOR RELOCATION OF GAS13

UPDATED GAS MONITORING NETW (PRODUCED UNDER 10514290003 (1

Description



(Lost due to CPO)





APPENDIX A

LFTGN 04 Extract

DRAFT

Sampling and off-site analytical methods

This section identifies – in template format – the purpose, recommended approach, requirements, method, results, known interference/causes of error, and alternative methods for on-site sampling and subsequent analysis of landfill gas for trace components. The taking of blanks is also included.

5.1 Sample collection on-site

Purpose

To collect representative samples for subsequent analysis off-site. Separate samples are required for:

- speciated VOCs
- aldehydes
- inorganic arsenic
- mercury
- PCDDs and PCDFs.

Recommended approach

Landfill gas is drawn through solid sorbent material, packed in a tube, by means of a pump or a manually operated metering system. The sorbents selectively extract and concentrate the target analytes, allowing those components that are not adsorbed to pass through.

For each determination, duplicate samples are taken and a trip-blank tube (not exposed) is assigned. For speciated VOCs, a 100 ml volume sample is taken unless the trace components are known to be present in low concentrations; in which case, a low volume (100 ml) and a high volume (400 ml) sample will be necessary. For the other methods, a smaller range of analytes is sampled and a single volume sample can be taken (Table 5.1 gives indicative values).

The various samples may be taken simultaneously using a manifold to hold the sorbent tubes and valves to stop flow once the required volume has been drawn. Alternatively, each type of monitoring sample may be drawn separately, although the duplicates should be taken together.

Some sorbent tubes (e.g. for PCDDs) will have been pre-spiked with standards at the laboratory for calibration purposes.

The quantity of sorbent required is proportional to the time sampled, flow rate and the expected concentration of trace components. Too little sorbent may cause the tube to become overloaded, resulting in an underestimate of the total amount of analyte.

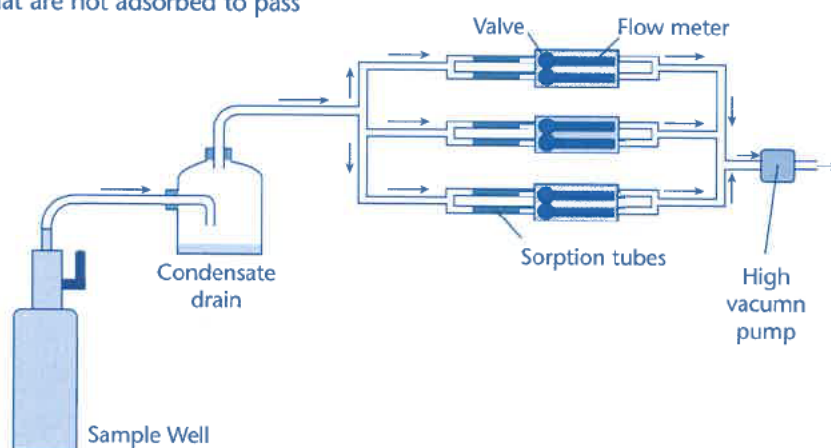


Figure 5.1 | Example sampling assembly

Conversely, too much sorbent or too little sample will result in poor limits of detection. It is important to use *a priori* site knowledge and laboratory experience when selecting the most appropriate quantities of sorbent material.

The sorbent recovery efficiency should be known for priority analytes. General advice on sorbent selection for other VOCs is given in ISO 16017-1 (ISO, 2000)

An example sampling assembly is shown in Figure 5.1. As far as is reasonably possible, a minimum of hardware (e.g. valves or connecting tubes) should be used to connect the source of the sample gas to the sorbent tubes. Whatever hardware is used must be constructed from non-sorbing and non-emitting materials.

The exact sampling requirements may vary on a site-specific basis. An example on-site set-up of appropriate equipment is shown in use in Figures 5.2 and 5.3.

Universal requirements

- Hand-held bulk gas analyser
- Pumps (e.g. a battery-powered SKC Universal constant flow pump is appropriate for low/medium vacuum; an Air Dimensions Inc. 12V Micro Dia-Vac Model B101 for sampling against high vacuums), or a manually operated metering system
- Condensate drain between the gas tap and the sample tubes
- Gas sample manifolds and connection tubing with low adsorption properties (e.g. Tygon 2275 high purity tubing, plasticiser-free), assembled and leak-tested in the laboratory
- Frame-mounted tube holders (e.g. SKC sorbent tube holders with individual adjustable flows)
- Rotameters on gas lines (e.g. an influx direct reading variable area flowmeter (calibrated) glass

tube and float, stainless steel needle valve)
20–250 ml/minute for routine sampling

- Moisture trap between the sample tube and rotameters.

Requirements for sampling specific trace components

- Uniquely numbered ATD sorption tubes with an inert coating and dual sorbent packing (200 mg each of Tenax TA and Unicarb) for speciated VOCs (see Figure 5.4). Such tubes are commercially available.
- DNPH-coated silica gel sorption tubes for aldehydes (commercially available with a front and back section containing 300 mg and 150 mg of sorbent, respectively)
- Activated charcoal/cellulose filter for arsenic sorption (commercially available with a front and back section containing 100 mg and 50 mg of sorbent, respectively)
- Where necessary iodinated charcoal (Carulite) for mercury sorption (commercially available with a front and back section containing 150 mg and 75 mg of low-background sorbent, respectively, with background levels of mercury consistently less than 1 ng)
- Where necessary amberlite XAD-2 resin packed tube for PCDDs and PCDFs. Simple glass tubes can be self-packed; at least 30 g of sorbent are required to cope with the recommended sampling regime.

Spare tubes should be carried where it is anticipated that condensate formation could result in a sample being abandoned. Table 5.1 gives typical sampling volumes and sampling flow rates for the principal types of sampling tube.

Table 5.1 Indicative volumes and flow rates for landfill gas trace component sampling

Determinand	Tube type	Indicative landfill gas sampling volume*	Indicative flow rates (ml/min)
VOC	ATD dual sorbent	0.1 litre (to give high quality quantification with typical variations in trace gas concentrations)**	50
Aldehyde	DNPH silica	1 litre	100
Arsenic	Activated charcoal	5 litres	100
Mercury [#]	Iodinated charcoal	20 litres	100
Dioxin [#]	XAD resin	100 litres	2,000

* Sample volumes are approximate and are based on the stated capacities of solid sorbents and current experience with UK landfill gas (Environment Agency, 2002b and 2004b).

** The ATD sample volume has a critical bearing on the quality of the results in sampling landfill gas at a site. Where a landfill gas may have a low concentration of trace components, an additional 0.4 litre, high-volume sample may be required.

[#] Additional components that may be monitored.



Figure 5.2 | On-site sampling system connected to a landfill gas well



Figure 5.3 | Sampling tubes and rotameter assemblies

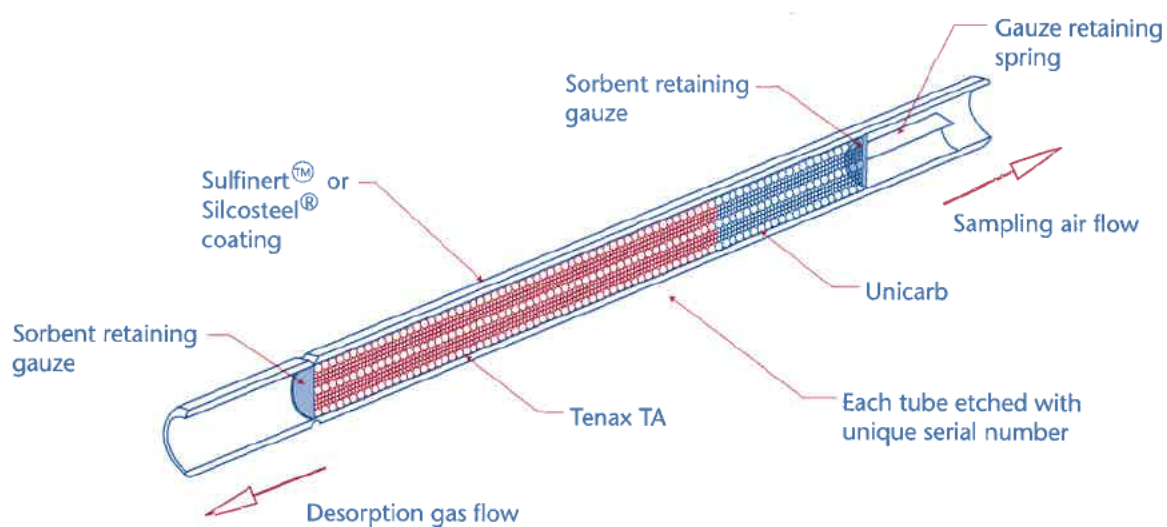


Figure 5.4 | ATD packed with dual sorbent

Method

- i. Use the hand-held gas analyser to re-confirm that the bulk gas composition is suitable for monitoring trace gases.
- ii. Use a hand-held manometer to check that the vacuum on the gas line is less than 10 kPa (0.1 bar) relative to atmospheric pressure. Neither standard battery-powered pumps nor manually operated metering systems can draw reliably at vacuums greater than this. Specialised pumps are required in this instance. If the selected sampling point has a vacuum greater than this, the gas valves or pumps must be adjusted and allowed to re-stabilise before sampling begins. Note the pressure reading. If heavy condensation is observed, consider using insulation or heating to maintain the gas temperature through the lines and tube.
- iii. Set up the sample apparatus with the appropriate packed sorbents, pumps, splitters and tubing. Connect it to the sample point with Tygon tubing (see typical layout in Figure 5.1).
- iv. Leak test the system using the pump to generate a 5 kPa (50 mbar) vacuum and ensuring that the system will hold this for 5 minutes. If this is not achieved, check all connectors and repeat.
- v. Re-check that the pressure is within the acceptable range.
- vi. If pumps are to be used to draw the gas, start these and open the master valve. If all flows are within 30 per cent of expected values, tune the flows and begin sampling. If flows are outside of 30 per cent of expected values, adjust the valves as rapidly as possible. Note the flow rate and sampling time.
- vii. At the end of the sampling sequence, close the master valve and shut off the pumps. Remove the sample tubes from the manifolds and seal them using long-term storage caps. Fit metal screw-type caps with combined PTFE ferrules on the ATD tubes and attach suitable caps to the other types of tube (ISO, 2000).
- viii. Place the tubes in individual zip-lock polythene bags or similar clean, non-emitting containers. Label each bag with the unique number of the tube and relevant sampling details. Do not use solvent-based inks and adhesive labels on the sorbent tubes. Immediately place the samples in appropriate containers for transportation to the laboratory. Such containers are metal cans containing about a third of their volume of scavenging charcoal.
- ix. Recheck the bulk gas composition using the hand-held instrument.

Results

Volumes of gas samples are calculated from the flow rate and duration of sampling.

Known interference and causes of error

- Sorption of components on the sample connection tubing – this can be minimised by conditioning the tubing with analytical grade nitrogen and re-use of tubing at the sample points on a particular site.
 - Condensate accumulation (see Figure 5.5) may remove polar components from the gas phase. The preliminary tests should have identified whether this would be a problem at the sampling location, thus allowing avoidance or preventative action to be taken. Formation of condensate in the line can be minimised by:
 - keeping the connection tubing as short as possible;
 - only extracting gas for the short time required in sampling;
 - maintaining the temperature of the gas using insulation or gentle warming.
- Because some substances will desorb thermally from the sorbent, the tube should not be heated above the ambient conditions. It is not practical to use driers because these may selectively remove some components of the gas. Mixing the sample with a dry inert gas during sampling will reduce the condensation, but it is difficult to meter gases accurately in these circumstances and this approach could introduce significant errors. If condensation has formed close to the inlet to the sample tube, water is likely to have interfered with the sorption and the sample is therefore invalid.
- Rotameter errors due to water collecting on the bob – this can be minimised by avoiding condensate formation and/or placing a drying tube between the samples and the rotameters (note that in this position it will not interfere with adsorption of the sample).
 - Rapid fluctuations of gas flow. The preliminary tests should have indicated that this is a problem and the sampling period adjusted to minimise the risk.
 - Tubing faults, particularly breaks and leaks can be minimised by care during sample changes and prior testing for weakness and leaks.

Blanks

To provide adequate quality assurance/quality control (QA/QC), the following blanks and checks are required.

- To ensure the tubes are not contaminated and have not been affected by environmental factors during the journey, one trip-blank per method per site is transported, unopened, from the beginning to the end of the sampling programme and subsequently analysed. If the blank for a particular trip is higher than routinely found, re-sampling may be required.
- Before the start of sampling programme, the sampling rig (including tubing) is assembled to collect analytical grade nitrogen at typical conditions. The sorption tube is then checked for VOCs to ensure off-gassing from the tubing will not interfere with results during monitoring. Assuming this is satisfactory, then this tubing type is used in the sampling campaign. Fresh tubing from the batch is tested is used at individual sites to prevent contamination being carried over from location to location.



Figure 5.5 Condensate in connection tubing during sampling

Alternative methods

- Portable mass spectrometers with time-of-flight analysis can measure and quantify the organic components. However, these may require significant calibration and referencing for analysis of a complex mixture such as landfill gas.
- Individually packed tubes can be used instead of dual sorbent tubes. These allow greater optimisation for individual compounds, but are

more complicated to set up, have double the analytical costs and require multiple blanks.

- Column packings that require solvent desorption are unacceptable for general use because commonly used desorbents such as carbon disulphide are on the list of priority substances to be monitored in landfill gas.
- Canister or Tedlar bag grab samples, which are quickly concentrated onto an adsorbent, may be used for VOC analysis. If a Tedlar bag sample is not concentrated post-sampling, the analytical method is unlikely to achieve the required detection limit for the priority trace components. During transport to the laboratory in Tedlar bags, some compounds may adsorb irreversibly to these containers and others may decompose. Tedlar bags are only accredited by the USEPA for a small number of the trace components of concern in landfill gas. If these sample collection methods are used, additional blanks must be used to allow sampling losses to be estimated.

5.2 Sample handling and storage

Sorbent tubes should be analysed as soon as possible after sampling and preferably within a week. While awaiting analysis, they must be kept in a clean environment, away from laboratory vapours, within the transfer container. If a longer delay is necessary, store the samples under clean refrigerated conditions to minimise migration of analytes within the sorbent tube. This is particularly important with dual sorbent tubes where there is differential sorption on the two types of packing. Re-tighten the screw-type seals as soon as the tubes reach the minimum storage temperature.

Tubes stored under refrigerated conditions must be allowed to re-equilibrate at room temperature before the seals are removed for analysis. This will prevent water from the laboratory atmosphere condensing inside the cold tube and interfering with the subsequent analysis.

5.3 Laboratory analysis

Purpose

To quantify the components adsorbed in the sample tubes.

Each of the analytical methods is dealt with separately below. A recommended minimum detection limit for each trace component is given in Appendix 3. The laboratory undertaking these analyses should have the appropriate United Kingdom Accreditation Service

(UKAS) accreditation, although the regulator recognises that this is not yet available (March 2004).

5.3.1 Speciated VOCs by GC-MS

Recommended approach

Before analysis, pass 2 litres of pure nitrogen through the ATD tube in the same direction as the original sample. This dry nitrogen purge will considerably increase the peak shape and response of the trace components in GC-MS by removing moisture from the tubes.

The sample is thermally desorbed from the solid sorbent and focused on a suitable cold trap. The sample extract is desorbed a second time onto the capillary column of the gas chromatograph, where compounds are separated and identified by mass spectrometry.

Requirements

ATD unit interfaced to a gas chromatograph-mass spectrometer.

Method

- i. Fit the ATD unit with a back-flushable focussing trap containing two or more sorbents in series and covering the same retention range as the Tenax and Unicarb (formally Spherocarb) sampling tube. Focussing traps packed with Tenax (front) and Unicarb (back) are suitable. Equivalent sorbent combinations may also be used provided it has been demonstrated that active sites on the sorbent do not cause degradation of priority compounds during the analytical thermal desorption process.
- ii. Minimise the inlet and outlet splits to maximise the sensitivity of the system. Install a thick film capillary column suitable for VOCs in the gas chromatograph and operate the mass spectrometer in scan mode.
- iii. Calibrate the system with standards containing as many of the target compounds as possible, loaded onto the sorbent tube from the gas or liquid phase as described in ISO 16017-1 (ISO, 2000). These standards should be loaded at a number of different concentrations to obtain multi-level calibration for each compound of interest.
- iv. Identify target compounds (the priority odorous and health VOCs) by their mass spectra and retention time. Where other significant peaks correspond to basic analytes in standard analytical suites (e.g. C1-C5 alkanes and BTEX), these should be assigned. Judgement should be used to assess whether identification (with the aid of mass spectral libraries) of any other significant peaks present is justified.

Results

Express in $\mu\text{g}/\text{m}^3$ of gas as sampled.

Known interference and causes of error

The assignment and quantification can only be assured if the instrument is calibrated with the nominated compound in the full gas mixture. Although calibration is normally with a representative range of gases, it is impractical to include all the target compounds and the report should specify which compounds have been used as calibration standards.

Significant peaks not included in the standard list should be identified with the aid of mass spectral libraries. There may be ambiguity in assigning peaks to compounds not on the priority list.

The results are normally expressed with precautionary statements regarding assignment and quantification.

Sample adsorption capacity of the ATD sorbents is affected by variables such as moisture and temperature. Normal recommended 'safe' sampling volumes may thus be too high for landfill gas, leading to breakthrough and under-reporting of concentrations for some substances. If the ATD sorbents are overloaded, the weakly adsorbed compounds that would normally be held on the Tenax beads will leak through onto the stronger adsorbent. These will subsequently not desorb and thus will be under-reported.

The relatively low sample volume (0.1 litre) of samples recommended for typical operation in this method minimises the risk of breakthrough and/or overloading of sorbent during sample collection. Migration of analytes within the sample tube can be prevented by minimising storage times between sampling and analysis, and by using refrigerated storage conditions.

The GC-MS system may also become overloaded with high levels of VOCs such that the mass quantification becomes non-linear for a target compound or leads to the signal for the target compound being swamped by a non-target compound. The risk of this is minimised by following the recommended sampling volumes for typical landfill gas.

Butadiene is retained less well than other priority substances on the dual sorbent column. It will thus have a poor detection limit compared with other species and may suffer interference from other butenes and butanes. Hence, the reported values

should be seen as semi-quantitative and a more specific investigation may be required if high concentrations are indicated.

Alternative methods

- Time-of-flight mass spectroscopy on full sample.
- Use of dual detectors can extend the GC technique. For instance, splitting the gas chromatogram output to pass through both a mass spectrometer and flame ionisation detector allows identification of the peak by MS and quantification by flame ionisation detection (FID). However, significant problems with the identification of analytes are likely to arise when using FID to analyse such complex chromatograms.

5.3.2 Aldehydes as their DNPH derivative

Recommended approach

Carbonyl compounds in the gas are captured by reaction with the DNPH coating on a silica gel. This solid phase holds the resulting mixture of derivitised aldehydes during sampling. These products are subsequently desorbed and the derivatives, which now have a strong UV chromophore, are analysed by HPLC to distinguish the different carbonyl compounds. This method is described in NIOSH Method 2539 (NIOSH, 1994).

Requirements

HPLC with UV detector

Method

Desorb the sample tubes with acetonitrile and make up to volume. The sample extracts should be analysed using a chromatogram capable of gradient elution. Typically, separation is achieved with an octadecyl phase column under reversed-phase conditions. The carbonyl derivatives are detected at 365 nm, following the USEPA Method TO-5 (USEPA, online).

The analytes are identified on the basis of retention time and are quantified against pre-derivitised standard solutions.

Results

Express in $\mu\text{g}/\text{m}^3$ of gas as sampled.

Known interference and causes of error

High ozone concentrations will affect the sample, but these are unlikely in landfill gas.

Other aldehydes and ketones (particularly acetone) will be adsorbed by these tubes and may result in

overloading of the tubes well below the expected capacity for the priority aldehydes.

Alternative methods

- An alternative is NIOSH Method 2541 (NIOSH, 1994). Sampling is carried out with XAD-2 treated with 2-(hydroxymethyl) piperidine. The solvent extract is analysed by GC-MS.

5.5.3 Inorganic arsenic by ICP-MS

Recommended approach

The inorganic arsenic adsorbed on the activated charcoal/cellulose filter tube is extracted with nitric acid and quantified by ICP-MS.

Requirements

Ultrasonic bath, ICP-MS

Method

The contents of the activated charcoal/cellulose filter tube are extracted using 0.01M nitric acid in an ultrasonic bath for 1 hour. The resulting solutions are measured for arsenic using ICP-MS, calibrated using the method of standard additions. Internal standards are added to monitor and correct for instrumental drift. USEPA Method 6020 CLP-M (Version 3.4 Special Analytical Services) outlines analysis by ICP-MS and includes detailed instructions in the use of internal standards (USEPA online). The determination of total arsenic is by NIOSH Method 6001 Issue 2 (NIOSH, 1994).

Results

Results from the measurement are expressed as total ng As per tube and then converted to $\mu\text{g}/\text{m}^3$ of gas as sampled.

Known interference and causes of error

A potential polyatomic interference at ^{75}As is caused by $^{40}\text{Ar}^{35}\text{Cl}$.

Alternative methods

- The OSHA method (OSHA, online) uses a mixed cellulose ester filter that is digested in nitric acid with a nickel stabiliser and analysed by atomic absorption spectroscopy (AAS) with a heated graphite furnace atomiser.
- NIOSH Method 5022 (NIOSH, 1994) uses a polytetrafluoroethylene (PTFE) backed filter membrane and extraction with borate-carbonate buffer for separation by ion chromatography and processing through an arsine generator connected to a mass spectrometer. This method can quantify organic arsenic compounds.

5.3.4 Mercury by ICP–MS

Recommended approach

The mercury adsorbed on the iodinated charcoal tube is extracted with hot sulphuric acid, hydrogen peroxide and nitric acid, and quantified by ICP–MS.

Requirements

Microwave digestion system, ICP–MS

Method

The contents of the iodinated charcoal tube are transferred to a microwave vessel. A mixture of sulphuric acid, hydrogen peroxide and nitric acid is added and the samples are extracted under high temperature and pressure in a microwave system. The resulting solutions are measured for mercury using ICP–MS, calibrated using the method of standard additions. Internal standards are added to monitor and correct for instrumental drift. USEPA Method 6020 CLP-M (Version 3.4 SAS) outlines analysis by ICP–MS and includes detailed instructions on the use of internal standards (USEPA online).

Results

Results from the measurement are expressed as total ng Hg per tube and then converted to $\mu\text{g}/\text{m}^3$ of gas as sampled.

Known interference and causes of error

None known.

Alternative methods

- NIOSH Method 6009 (NIOSH, 1994) samples onto a Hopcalite sorbent tube, which is extracted into nitric acid and hydrochloric acid at room temperature. The resulting solutions are measured by CV–AAS. This method determines elemental mercury.
- OSHA Method ID-145 (OSHA, online) describes an ester filter that is extracted in nitric and sulphuric acids followed by the addition of potassium permanganate and hydroxylamine hydrochloride. The resulting extracts are measured by CV–AAS.

5.3.5 PCDDs and PCDFs

Recommended approach

The PCDDs and PCDFs are adsorbed onto Amberlite XAD-2 resin (an XAD resin trap). The resin is extracted with solvent and the extract analysed by gas chromatography with detection by high resolution mass spectrometry (GC–HRMS).

Requirements

Established extraction and clean up technique

Gas chromatograph with high-resolution mass spectrometer.

Method

The dried XAD resin is spiked with a selection of ^{13}C labelled dioxin/furan isomers before being solvent extracted (Soxhlet or accelerant solvent extraction). The extract is concentrated before undergoing column clean-up. The concentrated extract is analysed by GC–HRMS alongside standards and blanks with a typical minimum resolution of 10,000. Calibration is achieved using a relative response standard containing known amounts of native and ^{13}C dioxin/furan isomers. This sample preparation and measurement should be carried out in accordance with BS EN 1948 Parts 2 and 3 (BSI, 1997).

Identification of individual isomers is achieved by a combination of GC retention times and mass spectra. Identities of isomers significantly above the limit of detection are confirmed by isotope ratio.

Results

Express in $\mu\text{g}/\text{m}^3$ of gas as sampled.

The amount present should be calculated as an I-TEQ (International Toxicity Equivalent Factor) value according to the NATO/CCMS scheme, which takes into account the relative toxicities of the various isomers.

Known interference and causes of error

None known.

Alternative methods

None

Appendix 3:

Recommended minimum detection limits

Trace component	Recommended detection limit	Units
1,1-dichloroethane	60	$\mu\text{g}/\text{m}^3$
1,1-dichloroethene	90	$\mu\text{g}/\text{m}^3$
1,2-dichloroethene	70	$\mu\text{g}/\text{m}^3$
1,3-butadiene	70	$\mu\text{g}/\text{m}^3$
1-butanethiol	300	$\mu\text{g}/\text{m}^3$
1-pentene	160	$\mu\text{g}/\text{m}^3$
1-propanethiol	200	$\mu\text{g}/\text{m}^3$
2-butoxyl ethanol	200	$\mu\text{g}/\text{m}^3$
Arsenic (as As)	0.04	$\mu\text{g}/\text{m}^3$
Benzene	30	$\mu\text{g}/\text{m}^3$
Butyric acid	400	$\mu\text{g}/\text{m}^3$
Carbon disulphide	100	$\mu\text{g}/\text{m}^3$
Carbon monoxide	1	ppmv
Chloroethane	120	$\mu\text{g}/\text{m}^3$
Chloroethene (vinyl chloride)	300	$\mu\text{g}/\text{m}^3$
Dimethyl disulphide	100	$\mu\text{g}/\text{m}^3$
Dimethyl sulphide	110	$\mu\text{g}/\text{m}^3$
Ethanal (acetaldehyde)	12	$\mu\text{g}/\text{m}^3$
Ethanethiol	300	$\mu\text{g}/\text{m}^3$
Ethyl butyrate	90	$\mu\text{g}/\text{m}^3$
Furan (1,4-epoxy-1,3-butadiene)	70	$\mu\text{g}/\text{m}^3$
Hydrogen sulphide	150	$\mu\text{g}/\text{m}^3$
Mercury	0.5	$\mu\text{g}/\text{m}^3$
Methanal (formaldehyde)	12	$\mu\text{g}/\text{m}^3$
Methanethiol	1,000	$\mu\text{g}/\text{m}^3$
PCDDs and PCDFs	0.1	ng/m^3 I-TEQ
Tetrachloromethane	70	$\mu\text{g}/\text{m}^3$
Trichloroethene	40	$\mu\text{g}/\text{m}^3$



Appendix 4:

Example report format

A. Site information

Sample point details	Enter details	Sample point details	Enter details
Date		Site	
Ambient temperature		Atmospheric pressure	
Monitoring organisation(s)		Analytical laboratory	
Location of sampling point		Area of influence of collection system sampled	
Type of sample point		Temperature of gas	
Vacuum on sample point		Type of waste	
		Age of waste (if known)	
Status of gas system		Other	

B. Preliminary checks and field measurements

Parameter	Concentration	Units	Comments
Methane		%	
Carbon dioxide		%	
Oxygen		%	
Nitrogen		%	
Hydrogen sulphide (field value)		ppmv	
Carbon monoxide (field value)		ppmv	

C. Laboratory analysis results

Trace component	CAS Number	Concentration in landfill gas sample	Units	Recommended method (Y/N)*	UKAS (Y/N)
1,1-dichloroethane	75-34-3		µg/m ³		
1,1-dichloroethene	75-35-4		µg/m ³		
1,2-dichloroethene	540-59-0		µg/m ³		
1,3-butadiene	106-99-0		µg/m ³		
1-butanethiol	109-79-5		µg/m ³		
1-pentene	109-67-1		µg/m ³		
1-propanethiol	107-03-9		µg/m ³		
2-butoxyl ethanol	111-76-2		µg/m ³		
Arsenic (as As)	7440-38-2		µg/m ³		
Benzene	71-43-2		µg/m ³		
Butyric acid	107-92-6		µg/m ³		
Carbon disulphide	75-15-0		µg/m ³		
Chloroethane	75-00-3		µg/m ³		
Chloroethene (vinyl chloride)	75-01-4		µg/m ³		
Dimethyl disulphide	624-92-0		µg/m ³		
Dimethyl sulphide	75-18-3		µg/m ³		
Ethanal (acetaldehyde)	75-07-0		µg/m ³		
Ethanethiol	75-08-1		µg/m ³		
Ethyl butyrate	105-54-4		µg/m ³		
Furan (1,4-epoxy-1,3-butadiene)	110-00-9		µg/m ³		
Hydrogen sulphide	7783-06-4		µg/m ³		
Methanal (formaldehyde)	50-00-0		µg/m ³		
Methanethiol	74-93-1		µg/m ³		
Tetrachloromethane	56-23-5		µg/m ³		
Trichloroethene	79-01-6		µg/m ³		
<i>Additional site-specific</i>					
Mercury (as Hg)	7439-97-6		µg/m ³		
PCDDs and PCDFs	N/A		ng/m ³ I-TEQ		
Carbon monoxide	N/A		ppmv		
[Others]					

* State method and provide justification if not by recommended method.



APPENDIX B

LFTGN 07 Extract

DRAFT

Design of flux box surveys

5.1 Survey approach

A flux box survey will normally not be undertaken until the main faults in the gas management system have been rectified. If features that emit methane can still be located easily with a sensitive, portable instrument such as an FID, this instrument should be used to guide further remedial work. An intact cap is likely to be relatively homogeneous such that a small number of regularly spaced monitoring points are representative of the main zones of the cap.

The objective of a flux box survey is to quantify the total releases of methane from the surveyed area. This may identify locations where the gas flux through the cap exceeds an emission standard set by the regulator and thus will initiate further remedial work.

The design of the flux box survey should ensure that:

- areas with similar characteristics are monitored together
- zones and features are uniquely identified and measured
- all zones and features aggregate to the total capped part of the landfill site
- monitoring locations are representative of the zone or feature.

A representative survey depends on the spatial frequency (see Section 5.5), meteorological context (see Section 5.6) and temporal frequency of the

monitoring (see Section 5.8). The criteria used in this document for selecting the total number and location of flux measurements take account of guidance issued by the United States Environmental Protection Agency (USEPA, 1986).

5.2 Selection of survey zones

Before beginning a flux box survey, the information gathered during the desk study and walkover surveys should be reviewed together. The latest walkover survey following remediation will be the most relevant guide to defining zones and features on the cap. The general definition of a zone and a feature is given in Section 2.4. Typical zones and features that could contribute differentially to the overall emissions are identified in Table 5.1 and described in more detail in Section 5.3.

Although most features will lie within or adjacent to a capped zones, they are considered individually because they may have emission rates that differ significantly from the rest of the zone. Remediation of these identifiable features is vital in improving the overall surface emission rate.

Table 5.1 Categories of emission zones and features

Designation	Examples
Zones	<ul style="list-style-type: none"> • Permanently capped areas • Temporarily capped areas
Features	<ul style="list-style-type: none"> • Surface fissures • Leachate chambers and monitoring points • Gas wells and monitoring points • Pipework leakage • Cap disruptions, e.g. wells and buried pipelines • Side slopes • Landfill edges or capping junctions • Areas showing affects of gas, e.g. stressed vegetation

5.3 Typical zones and features

5.3.1 Zone

A zone is an extensive area of the landfill surface over which the average emission can be calculated from a number of representative monitoring points. It will generally be covered uniformly with a single capping system that is intact and has a consistent slope. A zone need not bear any explicit geographical relationship with a landfill cell and thus could cover part of a landfill cell or a series of cells.

Two types of zone need to be considered – a permanently capped zone where no more waste will be accepted and a temporarily capped zone that will not be receiving waste for a period of at least three months. A landfill site may have several zones in each category as the standard of capping may differ across the various cells.

An example of a temporary cap is shown in Figure 5.1. Temporary capping may have been installed where placement of a permanent cap is delayed until adjacent cells are filled to final levels. Alternatively, there may be plans to import additional wastes to achieve final profiles before constructing the final capping system. A timetable for replacing the temporary or interim cover with a permanent cap must be agreed with the regulator.

On more mature sites, agricultural activity may affect the measurement of methane at the surface. It is therefore important to record the form of land use at each of the zones.



Figure 5.1 | Temporarily capped zone of a landfill

5.3.2 Features

A feature is any discrete area or installation within a zone where abnormal emissions might be found (these are usually relatively high). Discrete features are easily defined because they are visibly different from the surrounding area (e.g. leachate wells). Some features may be visible but have less clearly defined boundaries (e.g. a fissured area, see Figure 4.2), whereas others may only be revealed through the detection of a high flux at a number of adjacent sampling locations.

Although a feature may be as small as the surface area of a flux box, it must be potentially emitting significant amounts of gas to warrant attention and remediation. Hence, a single elevated flux measurement in an apparently homogeneous zone would not of itself warrant designating it as a feature. To be regarded as significant, a feature must show elevated emissions over several traverse lines in the walkover survey or very high releases from a point source.

Visible evidence of a feature might be:

- lack of uniformity in the surface
- a gap at the interface between the cap and another item
- signs of vegetation stress around gas wells (see Figure 4.1) indicating gas emissions.

Surface emission scanning should help to determine whether it is necessary to sub-divide the zone to take account of such features. The key issue is that features should be identified so that, if they do not comply with emission standards, they could be readily defined and remediated.

Potential features may have been apparent from the walkover survey. Although the most significant faults in the gas management system should have been remedied before flux box measurements began, the FID may have identified potential points of weakness that can be classified as features.

The main categories of features are considered below.

Surface fissures

Although large fissures will have been remediated during the initial work, smaller fissures will remain in the surface. These may be individual cracks or an area within which there is a network of finer fissuring. The surface cracking may not accurately reflect the actual permeability of the area to gas since it is difficult to establish the depth and continuity of the fissures. However, during a survey, these areas will normally be treated as features to be monitored separately.

Intrusions

A number of wells, boreholes and posts will penetrate the surface of a landfill. Each of these will be a potential weak point through which there could be a high flux of landfill gas. Because installations such as gas wells penetrate deep into the active area of the landfill, the seal between these and the cap is a crucial barrier that can be damaged or deteriorate. Hence, the survey should class the following as potential features:

- the area around leachate and gas wells
- the sealing on the inspection covers
- any associated pipework.

Gas pipelines

These are unlikely to be emission sources during active gas extraction because any pipeline leaks would allow air into the pipes rather than permit gas to escape. When the pumping system is inactive, however, such leaks can become emission points for gas. Leaks from exposed pipework are easy to identify and the necessary remedial action can be assessed.

The cover soil above any buried transmission pipeline may be less stable than surrounding material and trenching may have disturbed lower levels. Hence, the line of these pipelines should be established and investigated as potential features during the survey.

Side slopes

Sloping areas could be affected by differential settlement and it is therefore important to identify places where there is a significantly different gradient as features for particular attention.

Compacted waste with layers of daily cover may have greater permeability to gas in the horizontal plane rather than the vertical plane (i.e. it will show anisotropic permeability to gas). This will lead to lateral migration toward the side slope and a higher potential for surface emissions from the slope. The effectiveness of any gas abstraction system is likely to be lower near the landfill edges, with a consequent increase in the potential for emissions.

Junctions in liners or capping material

Where a synthetic membrane has been used as a lining or capping material, unwelded junctions may provide a lower permeability pathway for gas. Although the clay covering will mask this, failures along the line of these junctions may create an emission feature.

The edge of the cap is a potential line of weakness in the containment and can create an emission feature. This region of discontinuity should be investigated during the walkover survey to check whether there is evidence of high concentrations of gas.

5.4 Annotation of site plan to indicate zones and features

Figure 5.2 (see end of section) illustrates the manner in which the different zones and features may be indicated on a site map. The naming convention should aid later interpretation and grouping of similar features and zones.

5.5 Number of monitoring locations

The number of monitoring locations required is a function of the zone size. For the purposes of this guidance, there are two sizes of zone, i.e. >5,000 m² and <5,000 m².

The classification is based on practical rather than scientific considerations in order to provide a pragmatic spatial distribution of the monitoring:

In both classes, the minimum number of monitoring locations in a zone is six. In order to make the survey representative, the monitoring locations should be regularly spaced within the zone.

Having determined the number of necessary monitoring locations, the survey area should be divided in the form of a regular grid pattern (see Figure 5.3 at the end of the section).

Each grid location should be referenced uniquely and recorded on the site plan. Subsequent surveys on that zone can use the same or an equivalent grid pattern, but the monitoring locations should always be uniquely defined.

5.5.1 Zones of area greater than 5,000 m²

The number of required flux measurements (n) depends on the size of the zone (Z m²) and, based on USEPA (1986), is calculated as follows:

$$n = 6 + 0.15 \sqrt{Z}$$

Using this equation, Table 5.2 shows the number and average spacing of monitoring locations for zones of particular size. These recommended spacings on extensive areas of a cap are consistent with geostatistical analysis of research data.

Table 5.2 Recommended numbers of sample points and average spacings in large zones

Zone size (m ²)	Number of locations	Average spacing (approx.)
5,000	16	18 metres
10,000	21	22 metres
50,000	40	35 metres
100,000	53	43 metres
200,000	73	52 metres
1,000,000	156	80 metres

Example calculation:

$$\begin{aligned}
 \text{Zone area (Z)} &= 205 \text{ m} \times 135 \text{ m} = 27,675 \text{ m}^2 \\
 \text{Number of measurements (n)} &= 6 + 0.15 \sqrt{27,675} = 31 \\
 \text{Average monitoring spacing} &= \sqrt{(27,675 \text{ m}^2/31)} = \sqrt{892.7 \text{ m}^2} = 29.9 \text{ metres}
 \end{aligned}$$

5.5.2 Zones or features of area less than 5,000 m²

For smaller zones or extensive features, the criterion for determining the number of locations is:

$$n = (\text{zone area}/5,000) \times 16 \text{ subject to a minimum of six locations}$$

Table 5.3 Recommended numbers of sample points in smaller zones or extensive features

Zone size (m ²)	Number of locations
1,000	6
2,000	6
3,000	10
4,000	13
5,000	16

5.6 Meteorological factors

Data quality can be directly influenced by the meteorological conditions prevailing before and during the monitoring period. In particular, surface emission rates can be affected by factors such as rain and changes in barometric pressure.

If surface soils and clay capping are saturated with water, they will be less permeable to gas and this will greatly reduce the surface flux. Survey work should therefore be avoided during and following periods of unusually heavy rainfall. Surveys must never be conducted on areas where there is standing water.

Frost can similarly reduce the permeability of the cap due to the expansion of the water held in the soil pores of the cap. Conversely, frosty conditions could lead to higher methane emissions due to a reduction in the rate of biological methane oxidation within the

soil capping. This makes results ambiguous and may have an impact in zones with a low flux.

The internal pressure of gas in the landfill is generally only marginally above atmospheric pressure. This means that small changes in the weather can alter the observed emissions from the surface. When the barometric pressure is falling or is below the norm for that area, methane fluxes can be higher than normal, and vice versa. Ideally, the survey should be conducted when barometric pressure is not at either extreme. Meteorological effects can be self-cancelling because low barometric pressure is usually accompanied by rainfall, which reduces the permeability of the soil and can reduce surface emissions.

Wind speed can also affect the flux measurements due to the increased potential for air ingress through the base seal of the flux box. Therefore, routine surveys should generally only be carried out under Beaufort Force 2 conditions or below (i.e. <3 metres/second). If the site is normally windy, measurement may have to be undertaken when wind speeds are higher than recommended. Particular care must then be taken when sealing the box to the surface in order to nullify any interference. If wind speeds are high during the survey, this should be noted and taken into consideration during data interpretation.

5.7 Control station

A flux box positioned at a control station may be used as a reference if a survey is carried out over more than one day. Variation in the flux at the control station should be recorded alongside atmospheric pressure, rainfall and wind speed data. Assessment of the variation at the control station over the survey period will be useful when calculating and appraising

the overall site flux. However, single control stations cannot be relied upon to provide unambiguous reference data where surveys extend over large areas or extended periods.

5.8 Temporal frequency

Because emissions monitoring is periodic, sampling needs to be undertaken at a time when the emissions

are representative of normal operation of the gas management system. Data already collected on the routine operation of the system (e.g. gas flow, field balance, engine operation) should be checked to confirm that the periodic monitoring coincided with normal operational conditions at the site. Sampling performed during atypical periods may be judged invalid for assessment purposes.

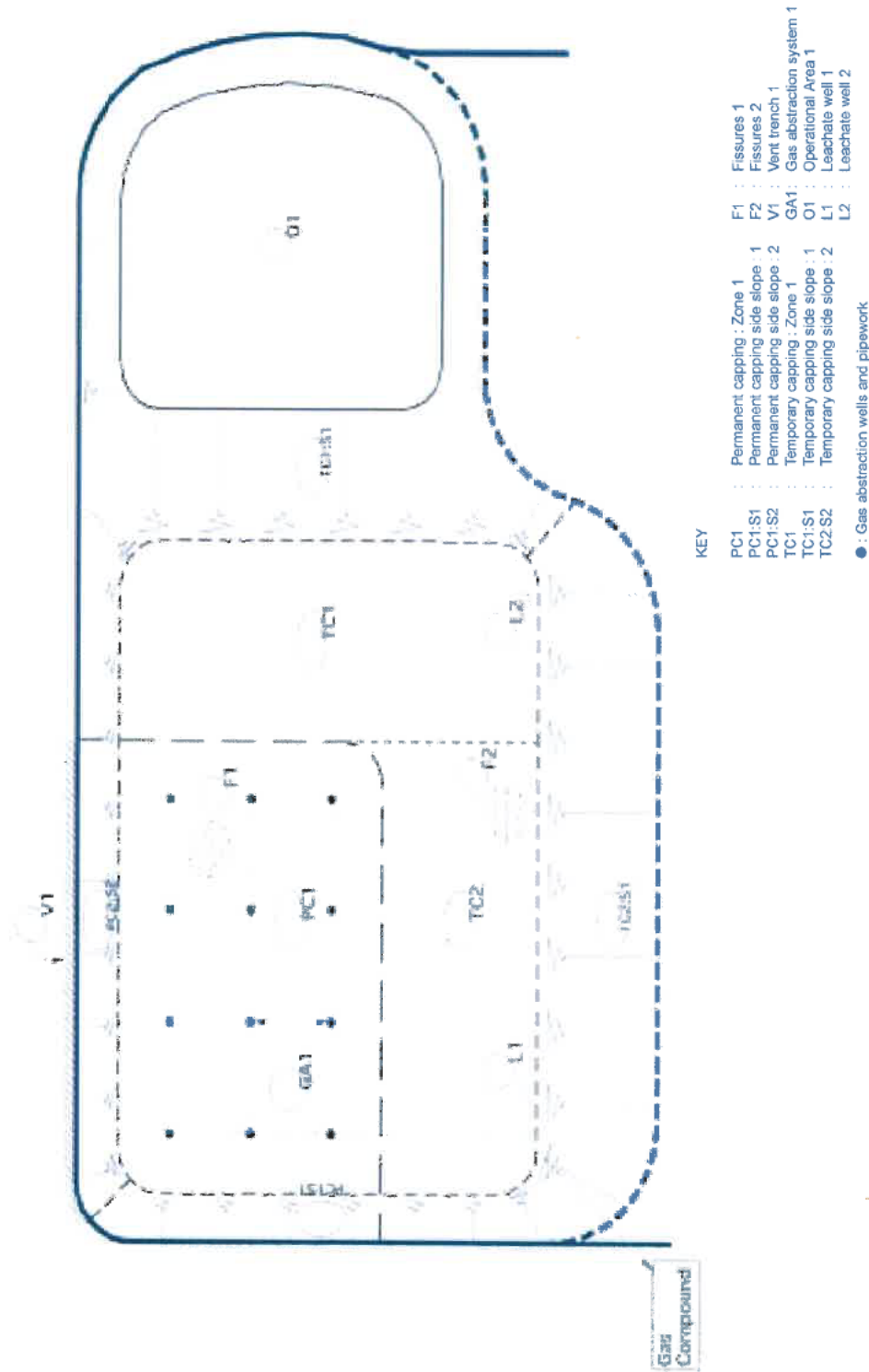


Figure 5.2 Example of landfill site zones/features

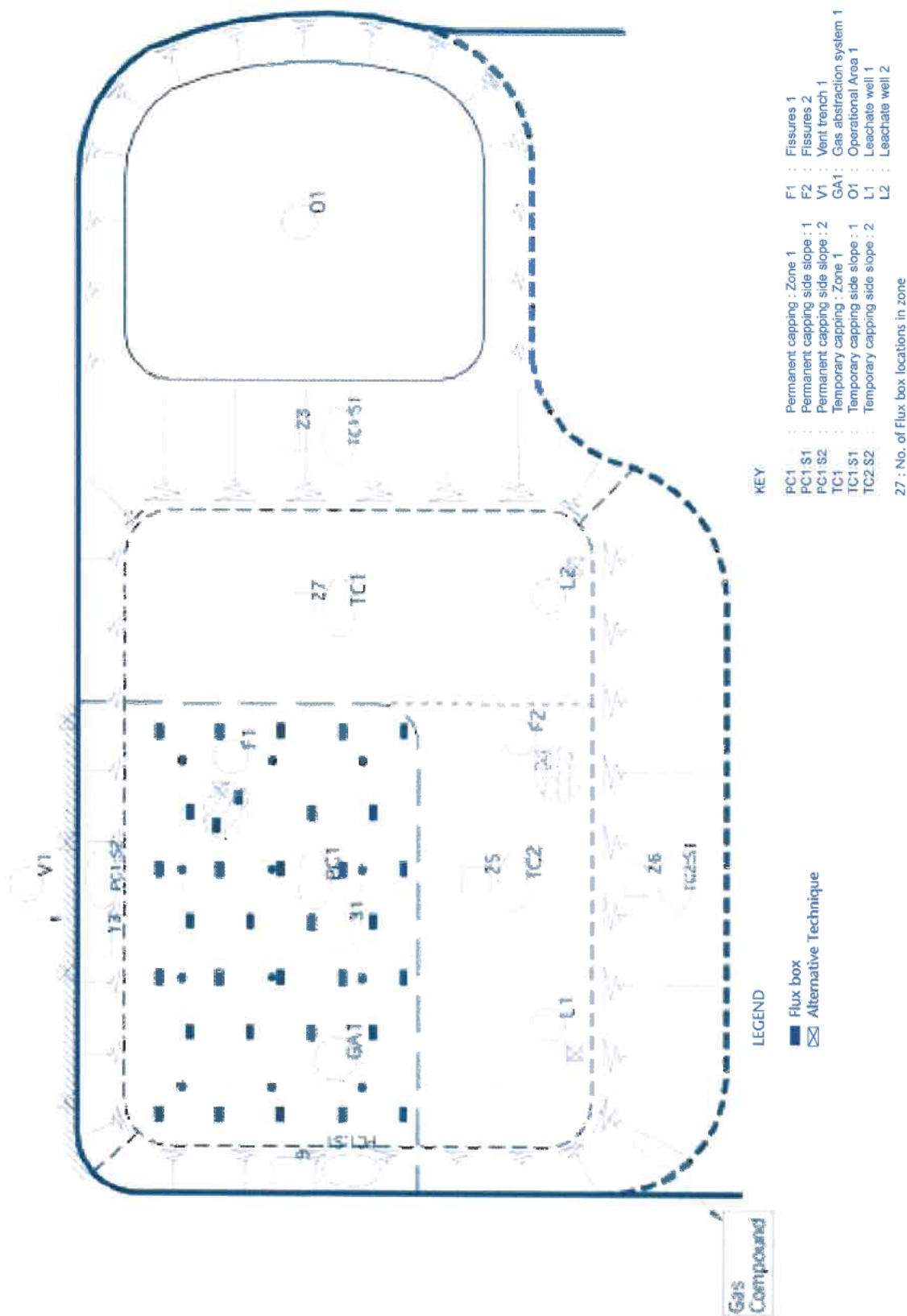


Figure 5.3 | Example of emission monitoring – spatial frequency and patterns

Measuring emissions using a flux box

6.1 Range of application

The protocols for using the flux box described here are for making individual measurements during the emissions survey. Following the initial stage of the walkover survey and remediation, the cap should be generally intact and uniform. The flux box survey will have been designed, as described in Section 5, with regularly spaced sampling points in the various zones and features on the cap. However, some minor anomalies may still be encountered and adjustments will be necessary in placing individual boxes. Any changes to the original design of the survey must be recorded and accounted for in the assessment.

A flux box is suitable for measuring emissions on relatively smooth landfill caps where the device can be readily sealed against the surface. The device is not suitable for measuring flux where the emission surface cannot be enclosed or covered by the box.

The lower limit of detection for a flux box is an emission rate of methane through the surface of 5×10^{-5} mg/m²/second, which is well below the emission standard set by the Agency (see Section 2.5). The upper limit of effective measurement for the flux box is 5 mg/m²/second (equivalent to 250 m³/ha/hour of methane). Hence, a flux box is only suitable for measurements where the concentration of methane in the air close to the surface is low. It is not appropriate to use a flux box where a substantial amount of gas is escaping from the gas management system or through very permeable areas of the cap.

If the weather deteriorates such that the conditions outlined in Section 5.6 are no longer met, measurements with flux boxes should cease.

6.2 Flux box method for capped zones

6.2.1 Basic principles of a flux box

The flux box is a container, open at the base, with a sampling line connected to gas monitoring equipment. The device described in this guidance is a passive flux box, which is inexpensive to construct;

for example, the flux box shown in Figure 2.1 is adapted from a plasterer's bath (see Appendix A for details of its construction). It consists of an enclosure of known volume, with two ports fitted at the top. The inlet port is used for pressure equilibration and the outlet port leads to the gas monitoring equipment.

A FID detector is generally most suitable for measuring the concentration of methane encountered in monitoring the emissions from a landfill cap (see Appendix A for details). A FID will actually respond to a range of hydrocarbons, but methane is the predominant hydrocarbon in most landfill gas. For the purposes of surface emission measurement, the FID reading is an adequate measurement of methane.

The box is placed with the open face downwards and the bottom edge is temporarily sealed onto the ground during the monitoring. The equipment should be painted white to minimise any thermal effects caused by heating of the wall of the box by sunshine.

A flux tent can be used as an alternative to a flux box, but is not dealt with in this guidance. The tent covers a larger area and, if well designed, is easier to seal on uneven ground. However, to assure representative sampling, the user must demonstrate that:

- the large enclosed volume of air and gas is mixed adequately;
- the volume enclosed by the flexible material is consistent under operational conditions at the site.

The flux box monitoring procedure, which is described in detail in Section 6.2.3, involves the following steps at each sampling location.

- The flux box is placed on the capped area and 'sealed' against the ground surface.
- The concentration of methane within the box is measured at short time intervals over a period of up to an hour.
- The concentration of methane (in mg/m³) versus time is plotted on a graph and the 'best-fit slope' is taken as the rate of change in methane

concentration in the box ($\text{mg}/\text{m}^3/\text{second}$).

- The methane flux (in $\text{mg}/\text{m}^2/\text{second}$) is calculated by multiplying the rate of change of concentration by the internal volume of the flux box chamber, and dividing this value by the box's 'footprint' area.

This procedure converts a series of time-based measurements of a single value of flux for each location. The result only applies to the particular area of ground upon which the flux box stands. To calculate the total flux of the zone under investigation, a number of flux box measurements must be taken at locations that are representative of this whole zone.

The flux box will perturb the normal emissions from an area, but this effect will be insignificant over the timescales indicated in this guidance. Factors such as changes in the biological oxidation of methane due to reduced access to air will also be insignificant over the monitoring period.

6.2.2 Sealing against landfill surface

An effective seal between the flux box and the site surface will depend on ground smoothness. A good seal with the ground is essential for accurate measurement of the emitted gas. This is particularly important in windy conditions, when the system is most vulnerable to air ingress.

Carefully consolidation of the ground on which the box edge will sit can establish a basic seal. It is important to ensure that the soil permeability within the box footprint is not affected by this tamping to consolidate the edges

A template placed on the proposed monitoring location can help define both the need for any particular preparation and the nature of that preparation.

A number of simple procedures may improve the seal.

- If there is no established vegetation on the landfill capping, a spade can be used to create the necessary plane of contact for the edges only. However, this should not involve excavating the ground to sink the edges of the box because this will affect the pathway of gas through the soil pores.
- Placing a weight on the box can help to improve the ground sealing process.
- Moist, plastic clayey materials from the site can facilitate the sealing of the box to the ground. Where these are not available, elastic 'socks' filled with sand can be used.
- Areas of long grass or other more substantial

vegetation should be cut down so that they do not interfere with sealing or mixing within the flux box. The area should be left vacant for a few minutes to allow dispersion of the small amounts of volatile organic compounds (VOCs) that might arise from freshly damaged plants.

A container without a bottom lip will have a sharp edge that can be pushed directly into the capping soil. Although this could be an ideal sealing method on many soil surfaces, the absence of a lip may make a plastic box less robust and less durable. A metal container is inherently more stable, but is much heavier for surveyors to carry and may conduct solar heating into the enclosed chamber (thus affecting the gas measurement).

Some sealing imperfections will stem from the heterogeneity of the surface profiles at the measurement locations. If no other suitable locations are available, monitoring should proceed but any reservations about the effectiveness of sealing should be recorded so that the greater uncertainty in these data can be taken into account during the assessment.

6.2.3 Using the flux box

Equipment requirements

- Set of flux boxes with appropriate fittings (see Appendix A)
- Tools to clear the surface
- Tape measure for recording the flux box position
- Trowel/shovel for flux box sealing
- FID gas measuring equipment for each active box (one FID can be moved from box to box)
- Stopwatch
- Unique ID markers for each location.

Step 1: Location confirmation

- Inspect the proposed sampling locations to ensure practicability and safety.
- Modify the exact positions as necessary, taking care not to distort the survey by avoiding locations that appear to have high rates of emission or over-representing areas of low emission rate.
- Optimise the deployment of the available flux boxes based on the information collected during the walkover survey.
- Assess the likely time needed to acquire the necessary data at each location.
- Assign a unique ID to each location and mark it on the site plan.

Step 2: Monitoring conditions

- Record the weather, wind, temperature and local ground conditions on site record sheet (see Appendix B). Include details of the recent

barometric trends and weather conditions and record the source of all meteorological information.

- Record the operational status of the relevant parts of gas management system on the record sheet.

Step 3: Instrument preparation

- Start the FID in a safe area following the procedures described in the manufacturer's operating manual. (The instrument should not be switched on in areas where flammable gases could have accumulated such as an office.) An intrinsically safe FID is recommended.
- Allow the FID to stabilise while placing the upturned flux boxes near the selected positions for analysis. Do not attempt to seal the boxes until all preparations have been made for taking concentration measurements, otherwise the gas environment in the flux box may have a 'false zero'.
- Zero and calibrate the FID with a certified calibration gas. Calibration will normally be valid for the remainder of the monitoring period.
- During monitoring, record the time and methane concentration at each successive reading. This can be either done manually or via a data logger. If the latter is used, make a back-up paper copy in the field.

Step 4: Initial gas concentration reading

- Seal the flux box on the site cap and complete the flux box assembly with sampling T-bar and inlet filter.
- Only connect the gas analyser to the flux chamber for the minimum required period before each reading because gas analysers withdraw significant volumes of gas that can affect the measurements. A sampling period of 30 seconds is usually required to obtain a stable reading. Note that in the design shown in Appendix A, it takes approximately 15 seconds for the gas sample to reach the analyser. Table 6.2 gives examples of gas extraction rates for commonly encountered gas analysers.
- A data logger can be set up to take ten readings over a 20-second interval and will calculate the mean of these ten values. For manual measurements, the reading should typically be an

average taken over a 15-second period.

Step 5: Measurements during first five minutes of monitoring

- Initial measurements should be at regular intervals of not more than one minute.
- Following this, the interval can be increased to a maximum of five minutes, depending on the observed rate of change in gas concentration (see first two items in Step 6).
- Flux boxes can be monitored in groups, i.e. following the initial period of frequent monitoring at the first flux box, measurement can then be started at the second box (repeating Steps 4–6), etc. However, sufficient time should be allowed for moving to the next box, sealing it, taking measurements at the necessary intervals, and returning to the previous flux box. To achieve this, flux boxes should be placed on the ground in the order in which they will be monitored.

Step 6: Measurements of rates over sampling period

- **Locations with very low flux.** A minimum concentration change of 5 ppmv over a maximum of 30-minutes monitoring time is necessary to give an acceptable error on the measurement. If no positive concentration change is detected after 30 minutes, this should be reported as less than the 'lower detection limit value', namely 5×10^{-5} mg/m²/second for a flux box of comparable dimensions to that described in Appendix A.
- **Locations with moderate flux:** In areas with a moderate flux, there are larger changes in concentration resulting in better monitoring accuracy over a particular period. Typically, 10–20 measurement points taken over a period of up to 30 minutes will be sufficient to allow a rate of change in concentration to be calculated. At emission rates close to the standard, it may be necessary to take measurements over a period of an hour to achieve adequate levels of confidence in the measurement of the rate.
- **Locations with high flux:** Where the flux is high, the concentration within the flux box can change rapidly. Measurements should therefore be taken:
 - (i) until a continuous set of rising readings has been taken over a 15-minute period, or
 - (ii) the concentration within the flux box has stabilised or has decreased after five consecutive rising fluxes.

The time interval between successive measurements and the total length of time over which measurements should be taken can both be much shorter than at locations with a low flux.

Table 6.2 Typical gas sampling rates for commonly available gas analysers

Instrument	Flow rate (ml/minute)
Gas-Tec	900
Autofim I	625
Autofim II	650

- **Locations with very high flux:** Where the upper detection limit of an FID (i.e. 1 per cent v/v methane) is exceeded in the flux box in less than 5 minutes, the flux can be assumed to exceed the emission standard. The feature will therefore require remedial action.

The number of boxes that can be monitored simultaneously at any site will depend on the rates of change in concentrations observed in the individual flux boxes. Thus, for high fluxing zones, the time taken to complete monitoring at each location will be shorter but the number of simultaneous activities will be fewer. It is generally not practical to monitor more than 20 flux boxes/locations in a day.

The monitoring data from each location should be recorded as indicated in Appendix B. All site data sheets should have an individual reference that defines the following uniquely:

- landfill site name
- zone or feature being monitored
- monitoring position number
- date and time of monitoring.

These sheet references should be included in the Site Monitoring Record (see Appendix B2), which should also include details of the prevailing and preceding weather conditions.

6.2.4 Monitoring small features

It may be physically impossible to use a flux box to contain small features that stand proud of the surface. In these circumstances, it is recommended that the gas concentration alone be checked.

If the local concentration of methane in air is less than 100 ppmv and there is no measurable gas flow using a hot-wire anemometer, it may be assumed that a small feature is not contributing substantially to overall emissions of methane. If these conditions are not met, either remedial work will be required or the monitoring method will need modifying in order to quantify the flux.

Point source emissions of gases other than methane, which may have a local impact on health or odour; should be addressed through the site-specific risk assessment.

6.3 Monitoring anomalies in the cap

Discrete features are potential anomalies in any capped zone and require particular attention. Such features, which are examined in more detail below, fall into four main classes:

- fissures or cracks in the capping material
- intrusions such as gas wellheads and pipework leaks
- intrusions such as leachate wells/chambers and monitoring points
- engineering faults such as side slopes, joins, edges and buried pipework.

6.3.1 Fissures

Some surface fissures do not extend to the base of the capping. The scale of gas leakage can therefore vary greatly between apparently similar fissures.

- **Large fissures.** These are defined as generally more than 30 mm wide (at the surface) and more than 5 metres long (see Figure 4.2). It is unlikely that large fissures will remain after completion of the walkover survey stage and remediation.
- **Medium fissures.** These are defined as generally less than 30 mm wide (at the surface) and less than 5 metres long. Good practice is to remediate any medium fissures found in the walkover survey. However, where these have formed, the emissions are monitored as follows:

- Determine total area of all medium fissures on the site.
- Carry out flux box measurements at a minimum of six randomly selected measurement locations from the sum of all medium fissures/fissured areas that make up the feature.

Particular care is needed to seal the box where the fissure underlies the edge.

- **Small-fissure areas.** These are features where the surface is 'crazed' (e.g. clayey surfaces with no vegetation cover). They may therefore have emission characteristics that are not typical of the general capping system. These areas should be monitored as per the normal flux box guidance with a spatial frequency equivalent to at least one per 100 m².

6.3.2 Gas wellheads and pipework leaks

If a gas abstraction system is in operation, any gaps in the capping around the wellhead could allow air into the waste rather than allow gas to escape (see Figure 6.1). These leaks must be remediated to avoid the risk of fires and the dilution of extracted gas by air. Any major leaks should have been dealt with during the initial survey and remediation.

Where there are doubts about the quality of the seal around the wellhead, the air in the vicinity should be checked carefully with an FID. If the local methane

concentration is more than 100 ppmv, the wellhead area should be treated as a discrete feature and assessed separately.

It may be possible in some instances to place the flux box directly on top of the wellhead. However, it is normally necessary to improvise by taking flux box measurements on the ground surrounding the well, targeting the areas at which high methane concentrations were detected by the FID. If this is impractical, the wellhead should be assessed as a small feature (see Section 6.2.4).

Faults in the pipework are likely to allow gas to escape during operation. There will be significant risk associated with working on these, and monitoring and remediation should be carried out on a case-by-case basis.

6.3.3 Leachate wells/chambers and monitoring points

Any intrusions that are not sealed will have high emission rates. Features of this type will normally be identified in the walkover survey and the faults remedied before the flux box survey begins.

Where there are doubts about the quality of the seal on the chamber cover (see Figure 6.1), the air in the vicinity should be checked with an FID. If the local methane concentration is more than 100 ppmv, the emission point should be treated as a discrete feature as described above for a wellhead.

6.3.4 Side slopes, joins, edges and buried pipework

High permeability features can develop during engineering work done after capping or due to settlement of the waste.

The number of measurements required will depend on the scale of the feature. In all cases, the minimum number of measurements required should normally be six, or one per 100 m².

For large areas of greater than 3,500 m², measurements should be taken on the grid spacing recommended for a normal capped zone.

Where the gradients of side slopes are no more than 1:2, it should be possible to carefully place a flux box safely on such slopes. Suitable risk assessments for performing such tasks should be performed.

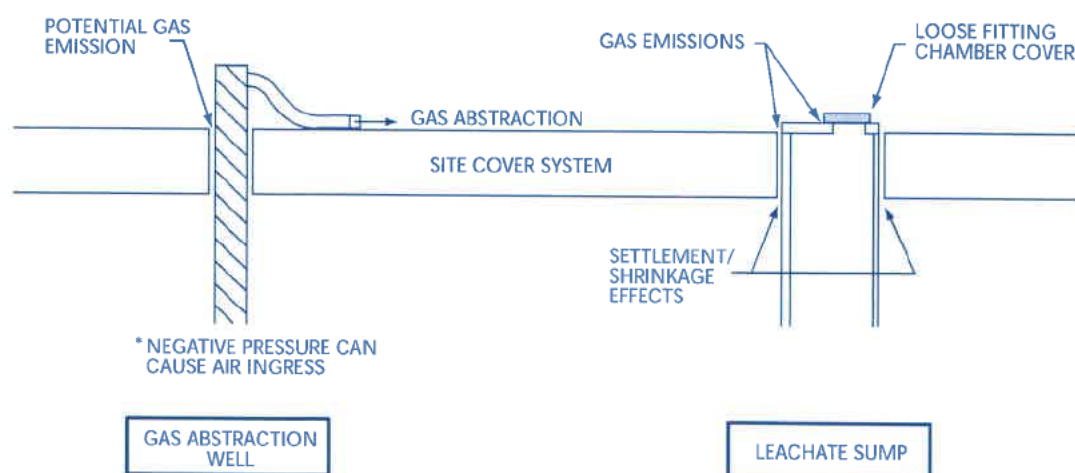


Figure 6.1

Gas leakage from gas abstraction wells and leachate sump

Data processing

7.1 Flux measurement

The monitoring data from the flux box locations are used to calculate emissions for the individual zones and features. These values are then aggregated for the whole site or the part subject to this guidance.

The basic principles of the calculation process are described below. Examples of detailed calculations are given in Appendix C.

Since most portable gas detectors such as the FID measure concentrations in ppmv, these volumetric concentrations should be converted to mg/m³ (i.e. mass units) at standard temperature and pressure (STP - 273K and 101.3 kPa) using the following calculation:

$$\begin{aligned} \text{Concentration (c) [mg/m}^3] &= \frac{c \text{ [ppmv]} \times \text{Molecular weight of methane}}{\text{Molecular volume of methane}} \\ &= \frac{c \text{ [ppmv]} \times 16 \times 10^3 \text{ [mg/mole]}}{22.4 \times 10^3 \text{ [mole/m}^3]} \\ &= c \text{ [ppmv]} \times 0.7143 \end{aligned}$$

The small correction factors from ambient temperature and pressure to STP are considered negligible against other larger errors that are accepted as part of the measurement technique (e.g. the correction factor for temperature would be in the range 273/283 to 273/298).

7.2 Calculating flux in individual flux boxes

The flux can be calculated for each flux box location using the following equation.

$$Q = \frac{V}{A} \times (dc/dt)$$

where:

Q = flux density of the gas (in mg/m²/second)

V = flux box volume (in m³)

A = flux box footprint (in m²)

dc/dt = rate of change of gas concentration in the chamber with time (in mg/m³/second)

The rate of change of the gas concentration (dc/dt) is determined by plotting the data on charts with the x-axis representing time (in seconds) and the y-axis representing the mass concentrations (in mg/m³).

Typical monitoring data from flux boxes at locations with a low and a high flux are plotted in Figures 7.1 and 7.2, respectively. These data show that, after a certain period of time, the concentration of methane within the flux box stabilises or can fall. This may be due to factors such as methane saturation in the flux box, back diffusion into the ground, or the effects of methane oxidation. In other cases, the first few minutes of monitoring may be characterised by steady or even slightly decreasing methane concentration instead of the expected increase. This phenomenon can be the result of wind effects in the period before the box is fully sealed or the effect of the gas abstraction system.

To eliminate these effects, individual data points are removed from the ends of the dataset – first from the last data collected and then the initial readings, until a correlation coefficient (r²) >0.8 is obtained. The data will then show a correlation coefficient illustrating a high degree of association between time (t) and concentration (c).

The data are considered acceptable if the following criteria are achieved:

- r² >0.8
- the graph has more than five data points
- the change in concentration is >0.

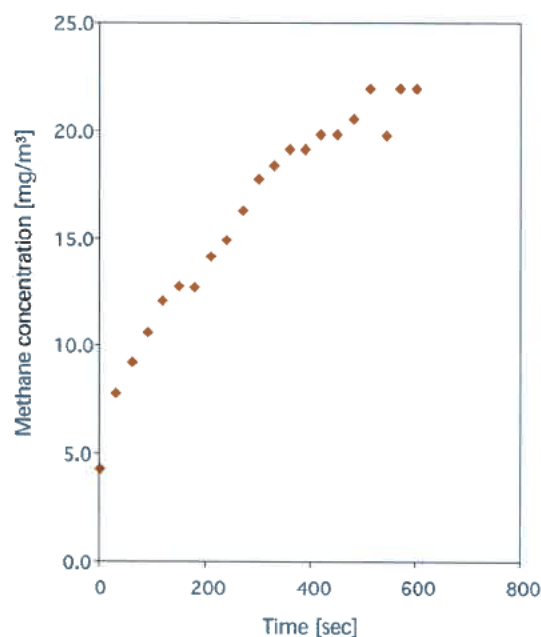
The initial rate of change is the most representative of the flux in the absence of the enclosure. Therefore, least priority should be given to later samples if eliminating data points.

If these criteria are not satisfied, the methane flux must be reported as being at the lower detection limit of the method (i.e. 5 x 10⁻⁵ mg/m²/second or the limit of detection of the flux box used).

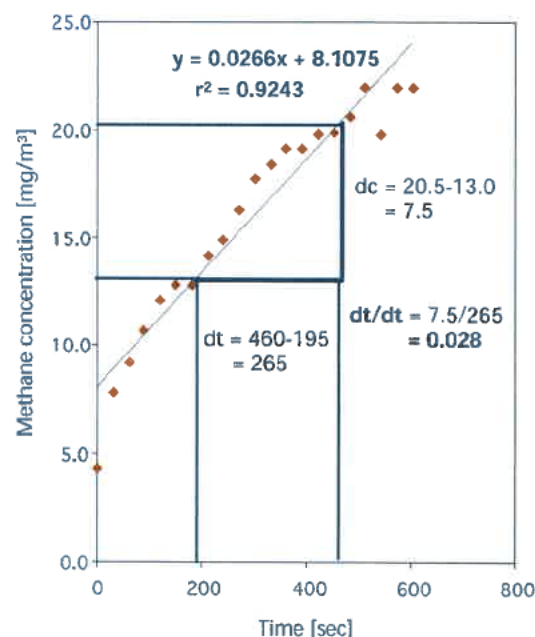
7.2.1 Emissions from narrow features

When a flux box is placed over a relatively narrow feature such as a fissure, the total flux is that from fissures and from the area of unfissured capping

covered by the flux box. In practice, however, the flux from the capped zone surrounding the fissure is probably insignificant and the measured emission can be regarded as that of the feature alone.



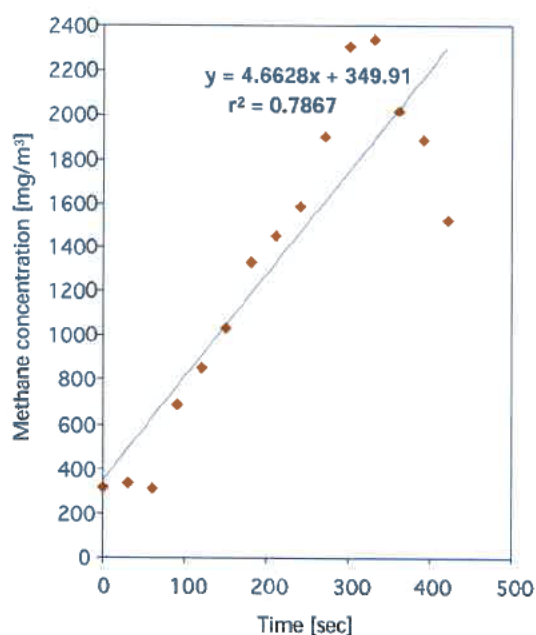
(a) Concentration profile*



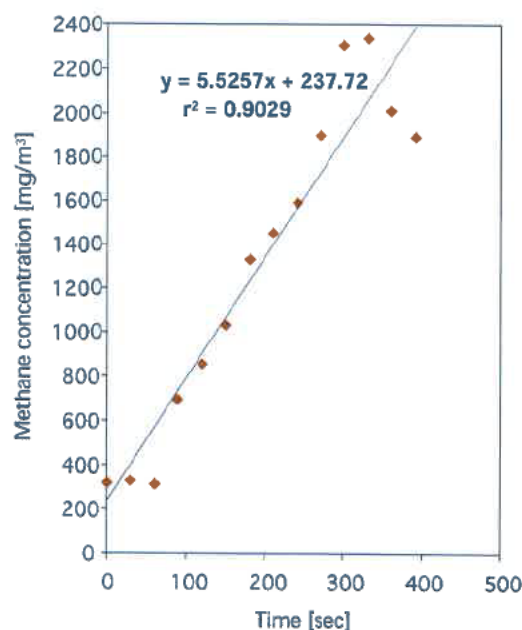
(b) Best-fit line trendline*

* After manipulation of data

Figure 7.1 Typical low flux scenario



(a) Concentration profile*



(b) Best-fit line trendline*

* After manipulation of data

Figure 7.2 Typical high flux scenario

7.3 Quantification of flux from zones and discrete features

Flux from a homogeneous zone or a discrete feature where flux boxes have been used can be calculated using a simple spreadsheet.

The average flux (in mg/m²/second) of a zone or feature is the sum of all the flux measurements from the individual flux boxes divided by the number of monitoring points used on the zone or feature.

More sophisticated approaches (including geostatistics, Thiessen polygons or other spatial interpolation techniques) could be used, but are generally not warranted for routine monitoring and lie outside the scope of this guidance.

7.4 Calculation of emissions from overall site

Table 7.1 gives an example of how a series of emissions from different zones and features are calculated and compared. These hypothetical data, which are based on the landfill site shown in Figure 5.2, illustrate the wide variation in the flux and the mass flow from different site elements.

The mass emission rate for each zone and feature is obtained by multiplying the average flux per unit area by the area of the zone or feature. The sum of all these mass emission rates gives the total emission rate of methane from the site.

It may be more convenient to convert the total mass emission rate to units of tonnes/year for use in reporting the annual emission for the Pollution Inventory. To convert from mg/second to tonnes/year, multiply the emission rate by 0.031536.

If the magnitude of surface emissions is to be compared with other emission sources, it is convenient to convert the flux measurements to m³/hour – the units used to describe the capacity of landfill gas flares and engines.

The scale of local emissions may best be appreciated in volumetric terms as a rate in litres/m²/hour. Table 7.2 shows the relationship between data expressed in four sets of units.

Table 7.1 Example calculation of total site emissions

Zone/feature ¹	Average flux (mg/m ² /second)	Number of measurements	Surface area (m ²)	Mass emission rate (mg/second)
<i>Permanent capping² (PC1)</i>	0.0005	31	27,675	14
<i>Temporary capping</i>				
Zone 1 (TC1)	0.789	27	19,425	15,326
Zone 2 (TC2)	0.095	25	16,400	1,558
<i>Side slopes</i>				
PC slopes (PC1:S1)	0.0032	9	2,800	9
(PC1:S2)	0.0018	13	4,000	7
TC slopes (TC1:S1)	1.174	23	13,500	15,849
(TC2:S1)	0.56	26	18,000	10,080
<i>Fissures/fissure zones</i>				
Fissures 1 (F1)	75	3 ³	400	30,000
Fissures 2 (F2)	23	3 ³	350	8,050
<i>Leachate wells</i>				
Well 1 (L1)	6,600 (mg/second)		Included	6,600
Well 2 (L2)	33,000 (mg/second)		Included	33,000 ⁵
Net landfill area = 102,550 m²	Total surface emission rate = 120,493 mg/second			
Vent trench (V1) ⁴	2.23	6 ³	250	558

¹ As in Figure 5.2.

² Net of fissures

³ Minimum number

⁴ These measurements were not included in the site surface emission assessment.

⁵ This feature should have been picked up in the walkover survey so may be a recent fault.

Table 7.2 Comparison of measurements expressed in different units

Measured flux in mg/m ² /second	Equivalent flux for methane in m ³ /ha/hour	Equivalent flux for landfill gas in m ³ /ha/hour [†]	Equivalent flux for landfill gas in litres/m ² /hour [†]
10	500	1,000	100
1	50	100	10
0.1*	5	10	1
0.01	0.5	1	0.1
0.001**	0.05	0.1	0.01

* Emission standard for a temporarily capped zone

** Emission standard for a permanently capped zone

† Assuming methane @ 50 per cent v/v.

7.5 Potential sources of error or uncertainty

Uncertainty in quantifying the overall emission from a zone or feature can arise from three sources:

- the precision and accuracy of individual measurements made at the sampling locations
- the selection of sampling locations
- linking the individual measurements to the overall value.

These factors are considered in detail in Appendix D.

7.5.1 Ranking of errors

The errors associated with a flux box survey fall into three categories:

- errors at individual monitoring points such as temperature variations, poor sampling or instrumental errors;
- uncertainty due to the timing of the survey or failure to locate the individual box appropriately;
- factors likely to make the measurement invalid such as interference from other sources of methane or unrepresentative sampling locations in the zones.

7.5.2 Overall errors and uncertainty

Instrumental errors in individual measurements can be managed and minimised by following the guidance given here. Similarly, the errors arising from local environmental factors and seasonal effects will be small if the guidance is followed.

Errors associated with identification of sample location will also be low provided good sampling practice is followed.

The greatest uncertainty will arise from calculating the total emission from individual emission measurements made at the representative sample locations. On a homogeneous cap, the difference in emissions at the various locations will be small, and so the uncertainty in the overall emission will be similarly

low. However, on a site with heterogeneous cover and variable surface composition, this uncertainty can be as high as one order of magnitude. Inspection of the individual flux measurements and their spatial relationship may identify features that were not apparent on the site but could be treated separately. However, this should not be done without confirming that the 'feature' can be distinguished physically and delineated on the site.

It is important that reporting of the overall emission rate takes account of the variability in the individual measurements and the number of different zones or feature that have been aggregated to give this value.

- If the surface of the site is demonstrably homogeneous, an average value for total surface emissions may be reported with evidence of why this is representative (e.g. the individual readings are similar).
- If the surface of the site is heterogeneous and there are large differences in the emission rate at individual monitoring points within a zone, a range of emissions must be reported (typically the maximum, minimum and most probable values).

It is likely that such zones will be subject to remedial action to deal with the higher flux features. The remediation plan should include actions that will reduce the uncertainty in the overall emission. This is likely to involve work on the high emission areas. The gas management plan must also indicate how subsequent surveys will reduce uncertainty either by refining the extent of the features and zones and/or by increasing the number of sampling locations in the variable regions.

Reporting

9.1 Initial monitoring stage

The results of walkover surveys and any surface scanning will form the basis of plans for immediate remediation work. The licence holder or permit operator should provide the Agency with a written report that specifies:

- the survey conclusions
- the proposed remediation
- the plans for subsequent re-monitoring.

The gas management action plan should be revised to take account of any changes. Since this stage is an event-driven, iterative process, reporting will differ depending on site circumstances.

9.2 First flux box measurement report

The walkover surveys and any arising remedial actions should be completed within one year of capping so that a full flux box survey can be undertaken. It is the responsibility of the licence holder or permit operator to report the monitoring results and associated interpretation to the Agency.

The initial flux box survey report to the Agency (see Appendix E1) should set out the key characteristics of the site prevailing at that time (see the example form in Appendix B). These data should be linked clearly to a suitably large site plan and be provided in the following groups:

- **General site data**
 - Basic design parameters and permitted waste inputs
 - Gas control and utilisation systems installed (and proposed)
 - Time since waste disposal commenced and expected completion date
 - Gas abstraction data.
- **Specific data**
 - Gas monitoring results and conclusions
 - Proposed remedial actions and their timetable
 - Further gas monitoring proposals.

Where an emission standard is not met, the licence holder or permit operator should identify necessary remedial actions (and their location) and the proposed timescales for their implementation (see Appendix E).

Where the licence holder or permit operator considers that the collected data do not adequately reflect emission conditions and that remedial actions are not necessary, this should be stated in the report and proposals made for repeating or expanding the monitoring and assessment exercise.

Where the cap is heterogeneous and the maximum emission rate is reported as above the standard even though the most probable rate is below the standard, the report should explain how it is intended to reduce uncertainty in future surveys, e.g. by reducing the spacing on sampling locations.

The report should include a timetable for replacing any temporary or interim cap with a permanent cap.

9.3 Remedial actions and reporting

Appendix E3 contains a summary form for describing remedial actions necessary to achieve compliance with the relevant emission standard. This schedule addresses the key zones and features on the site, identifies the range of appropriate actions and sets out an action programme. This forms the basis of the remediation plan that will be agreed between the operator and the Agency. This plan will be regularly updated in the light of subsequent activities and monitoring data.

When remedial actions have been carried out, those works should be monitored as soon as possible after completion to check for compliance. The results of this should be reported to the Agency in the format recommended for subsequent reports (see Appendix E2).

9.4 Assessment by the Agency

The Agency will undertake an assessment of the data provided in the standard formats by the licence holder or permit operator. This assessment will cover:

- the results of the annual emissions survey
- the remediation plan
- reports of any remedial work undertaken to reduce emissions
- the appropriateness of monitoring carried out for the particular zones
- compliance with emission standards
- the site's total methane emissions
- the adequacy of the remedial action plan (where appropriate)
- the timescale for testing after any remedial work.

The assessment will take account of the potential impact of the gas emissions on local receptors.

9.5 Second and subsequent reports

Second and subsequent regular reports (see Appendix E2) should include a summary of any key **changes** to the general site data. The new monitoring data and their interpretation should be presented in full and, where relevant, compared with the results of previous monitoring exercises and related to the conceptual model of the site.

For a stable zone where a walkover survey is reported rather than a full flux box survey, the reasons for assuming the results of the previous flux box survey are still valid must be stated. Progress towards the replacement of any temporary cap with a permanent cap should also be reported. These statements are necessary to allow the Agency, as well as the licence holder or permit operator, to see the overall pattern of operations and emissions from the site since monitoring began.

Gas management is dynamic and some changes will occur over a period of years. The fact that a zone has historically complied with the surface emission standard does not mean that this will necessarily continue as the landfill matures and operations on the site change. The reports should form part of a regular review of the gas management plan for landfill site.

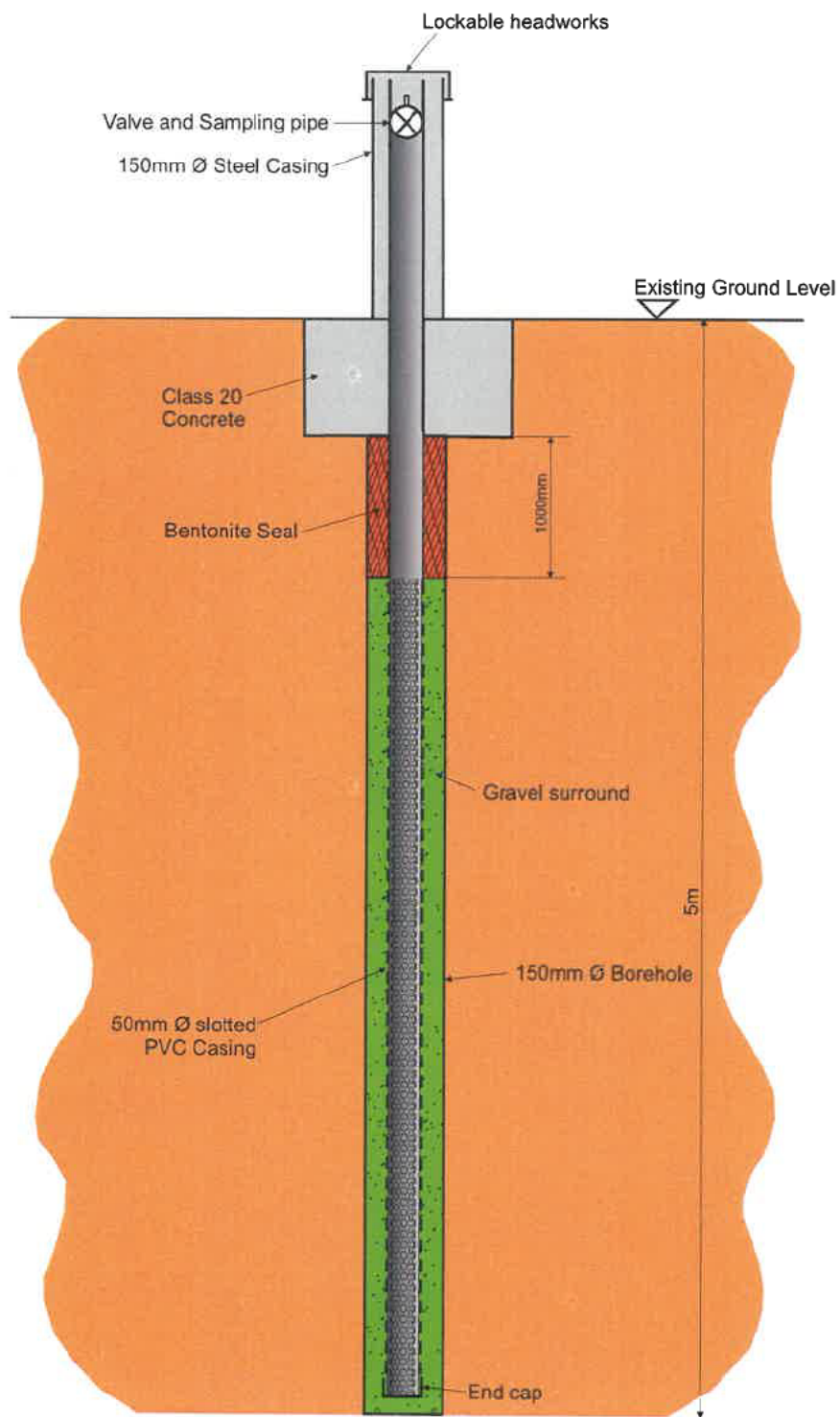
Over a period of years, a body of information will build up on the long-term emission pattern from zones and features on a particular landfill site. On a stable site, this information may be used to target a more limited flux box survey towards features that have historically been potential weaknesses in the gas management.



APPENDIX C

Borehole Specification

DRAFT





APPENDIX D

Gas Monitoring and Balancing Protocol

Landfill Gas Extraction Monitoring and Balancing Protocol

General

To maintain environmental control and ensure maximum gas yield is available for generation at all times, it is vital that gas production is equal to the rate of extraction. There are many factors that have an affect on this process. The aim of this procedure is to provide guidance on proven monitoring techniques, control of aerobic activity, identification of leaks, maintenance and gas field review on both equipment and landfill infrastructure.

1.1 Monitoring and gas field maintenance is required on a regular basis. This is normally a weekly task depending on local conditions and agreements. It will only be performed by suitably competent/trained staff with the required equipment.

1.2 All monitoring equipment will be calibrated and serviced in accordance with the manufacturer's instructions. Before use checks will be carried out in accordance with Work Instruction (WI) 016 - Operate Gas Meter. The gas meter accuracy should be checked at least monthly or if faulty operation is suspected. Never use a gas meter without an in line water trap filter (preferably x2) or H₂S/Hydrocarbon Filter fitted.

1.3 All works on site will be carried out in accordance with the relevant site, company and national H & S guidelines. This includes DSEAR, Environmental Permits and Industry Code of Practice (ICOP).

1.4 The ENPL lone working procedure will be adopted for works when the site is unmanned or closed. The area supervisor will be aware of site attendance during the normal working day. During silent hours or weekend working the CHUBB Emergency procedure is to be followed. All works should be Risk Assessed and Method Statements followed.

1.5 Records will be updated on all visits and will include the following information:

Name of Site:

Date/Time:

Name of Operative:

Weather/Barometric Pressure:

Equipment Type/Serial Number used:

1.6 Gas extraction rates for generation or flaring whenever possible should be kept at a consistent level of gas quality, vacuum and flow. During balancing this is essential to ensure stable and accurate results on individual wells and manifolds are recorded. Notes should be taken of any interruptions to extraction rates e.g. Engine Downtime.

1.7 The use of GAM Identities should be used together with automated downloads. Copies should be held on site in electronic format with copies sent to Head Office for central record. Results should be copied into Summarised Format to follow and adjust wells and/or manifolds in line with historic data.

2. Field Balancing Procedure

All landfill balancing works on ENPL sites will be carried out to ensure that maximum, controlled volumes of gas are recovered at sustainable rates. Great care will be taken to ensure that sites are not over extracted and the monitoring and balancing will be targeted to minimise the risk of localised aerobic conditions. Details on how to carry out a Gas Field Balance are contained within WI 001 – Monitor Gas Field. It is essential to obtain prior knowledge of the gasfield idiosyncrasies prior to attempting to perform a balance. This knowledge should include site suction, engine pressure and gas quality parameters.

Balances should ideally follow the same route and reads/information recorded in the following areas:

3. Gas Compound

Gas extraction system balancing and monitoring should commence and finish with reads in the generation/flare compound. It is an important part of analysis to compare reads before, followed by after adjustment of wells and/or manifolds.

3.1 The following monitoring determinants will be recorded on both the suction and pressure side of the Gas Booster using GAM ID's, before and after balancing:

Determinants	Units
Methane (CH ₄)	% by volume
Carbon Dioxide (CO ₂)	% by volume
Oxygen (O ₂)	% by volume
Suction	mbar
Pressure	mbar
Flow rate	m ³ /hr
Temperature	°C
Valve position	% open or increments of 1 to 5

3.2 A visual inspection of the gas plant will occur during the balance and notes made of any required works or maintenance. Particular attention should be given to any gas leaks, WI 030 - Check for Gas Leaks. Any leaks are to be recorded and repaired as soon as possible. If resolution cannot be made on the day, it must be reported to the Area Supervisor for further advice and action.

3.3 The following Blower/Flare operational criteria should be recorded:

Determinants	Units
Blower Hours	hrs
Flare Operating Temperature	°C
Flare Operating Hours	hrs
Flare Flow	m ³ /hr

4. Gas Condensate - Compound

Condensate knockout is essential to protect Operating Equipment. If not controlled, condensate can cause serious damage to the Gas Blower and/or Engine/s.

All condensate systems are required to be checked to ensure they are working correctly. A visual inspection of the integrity of the compound sump and any other condensate discharge pipes and/or air lines will be completed. The site compressor and compound air pumps will be checked to ensure they are operating correctly. WI 049 – Compound Daily Checks, WI 011 – Compound Sump Operation and WI 013 Check Pump Operation refer.

4.1 The following operational criteria should be recorded:

Determinants	Units
--------------	-------

Compound sump Operation	Yes/No
Air Pump Strokes	Qty
Air Receiver Pressure	PSI

Any problems encountered or remedial actions taken will be recorded on a Work Statement and within the site diary.

5 Gas Collection System

System monitoring will then continue onto the Gas Collection System (GCS). If there are known low spots in the GCS, collector lines should be drained before commencing with reads.

5.1 Well collection systems follow various designs but will be one of the following:

- Well head access with control valve.
- Gas main based with control valve and well head access.
- Gas main based with control valve and no/buried well head access.
- Manifold based with control valve and well head access.
- Manifold based with control valve and no/buried well head access.

5.2 Following the same route as often as possible, manifolds should be monitored and adjusted on the main control valve in conjunction with individual collector reads to distribute available site suction to specific areas depending on the gas yield being generated.

5.3 Individual gas wells will be monitored and balanced after all reads are taken on that manifold in accordance with current and historic data to ensure that landfill gas is extracted at sustainable levels. Attention is to be focused on controlling local aerobic activity and identification of any leaks on both either GCS and/or landfill infrastructure.

5.4 Any faults noted on the GCS should be addressed as soon as possible or reported to the area supervisor. Any issues with the landfill infrastructure should be reported to the site operator.

5.5 Aerobic conditions at most sites can be identified by two standard methods:

- **CH₄ to CO₂ ratio** – Gas production under normal anaerobic conditions often results in a 60:40 ratio. If the level of CH₄ declines then the control valve should be reduced to maintain at least a 2% higher difference in quality compared to CO₂.
- **Balance/Free Nitrogen** – Balance gas is predominantly Nitrogen (N₂) and appears as a result of air being drawn into the landfill waste mass. This is not to be confused with a high Oxygen (O₂) reading as this indicates a leak or path close to the well zone of influence, collector line or connection for sampling. High balance gas with low O₂ shows depleted air resulting from aerobic activity. The level of aerobic activity can be assessed by subtracting x4 times the O₂ value from the balance. The remainder represents depleted air (free nitrogen) with the O₂ consumed by aerobic activity. Under normal operating conditions the levels of free N₂ recorded in a well should not exceed 7.5% to 18%. With good balancing, operation and maintenance, the operator should maintain levels at the lower end of the scale:

EG – A gas reading showing 1.5% O₂ and 11% balance would result in:
 $11 - (4 \times 1.5) = 5\%$ free N₂ (Well under scale of 7.5% to 18% - not aerobic).

EG - A gas reading showing 1.0% O₂ and 28% balance would result in:

$28 - (4 \times 1) = 24\%$ free N_2 (Well over scale of 7.5% to 18% - aerobic).

- **O₂ Readings** - Can be used to gauge conditions within the system. If an O₂ reading is approximately 1/5th of the balance reading, this indicates an atmospheric leak close to the well head or within the GCS to the point of monitoring. Readings progressively lower than 1/5th of the balance indicate a leak path more remote which has resulted in atmospheric ingress into the waste mass leading to aerobic conditions.
- **High O₂ Levels** – Can lead to increased risk of explosion and damage to running engines. Wells above 5% O₂ should by routine be investigated and if no fault can be found, the well should be isolated pending further investigation. Only in exceptional circumstance i.e. Odour Control, should the well be left on and only then under minimal suction. If this need arises, the Site Operator is to be consulted for approval. Wells displaying 2% or more should again be investigated and if no fault can be found, the well should be throttled back pending further investigation.
- **Carbon Monoxide Readings** – Air ingress can give rise to combustion (Hot Spot) within the waste mass. Aerobic activity by nature increases the temperature, together with fuel (waste) and a complex array of reactions, the conditions are right for combustion. An early indicator of a Hot Spot is an increase in Carbon Monoxide (CO) which is only produced by incomplete combustion. This can be measured using a GA Gas Meter. Other indicators include a burning odour, smoke, and/or heat damaged GCS. A CO reading using the gas meter can be affected by the presence of Hydrogen (H₂) and Hydrogen Sulphide (H₂S) so cannot be taken as accurate or a reliable indicator of combustion. A reading of 100ppm should however be used as a precautionary indicator and WI 001A – Hot Spot Procedure followed. Bag samples should be taken to confirm CO, H & H₂S levels.

5.6 The table below details the operational criteria that will be adhered to when balancing gas collection systems, together with the monitoring requirements for each location.

Determinants	Units & Accuracies	Trigger Levels
Methane	% by volume (+/- 0.5%)	< 20% & >50%
Carbon Dioxide	% by volume (+/- 0.5%)	No specific level – see relationship with CH ₄ and CO ₂ below
Methane to Carbon Dioxide Ratio	% by volume (+/- 0.5%)	The level of CO ₂ within an individual point shall be at least 2% less than the volume of CH ₄ . If CH ₄ & CO ₂ added together are less than 80% in volume, air investigation is required.
Oxygen	% by volume (+/- 0.5%)	> 2 to 5%
Gas Balance	% by volume (+/- 0.5%)	>20%
Free Nitrogen	% by volume (+/- 0.5%)	>18%
Carbon Monoxide	ppm	>100 ppm
Valve Position	% Open	No level set
Flow rate	m ³ /hr	No level set
Suction	Mbar	No level set

5.7 Landfill gas balancing must always be carried out using both gas quality and suction data. Valve position should be recorded with adjustments of individual control valves made relative to the vacuum applied.

5.8 Minimal adjustments will be needed if the field is balanced. This may change if site operational activities have changed dynamics. To assist in assessing if an adjustment is required, gas reads should be copied into Summarised Format helping to review historic data. During evaluation, adjustments should be made with the aim of avoiding repeated opening and closing of wells.

5.9 Adjustments should progressively be made to control aerobic activity and optimise gas yield.

5.10 If trigger levels are exceeded, the site operator must be informed. Use of a notebook is recommended to record observations and remediation works carried out.

5.11 The GA gas meter has the facility to record gas collector/well conditions. This can be inputted in code form:

Code	Fault	Explanation
1	No faults	Normal reading
2	Atmospheric leak suspected	High O ₂ is indicated but no immediate reason identified. Further works required.
3	Atmospheric leak found/repared	A leak is found, repaired and verified by a further gas read.
4	Aerobic activity	Free nitrogen is over 20% and/or CO ₂ levels are within 2% or higher than CH ₄ .
5	Migration control	Valve left open as the well is in the vicinity of a known odour or migration issue.
6	Cross suction	When the control valve is closed and yet shows signs of influence from other wells. (Not to be confused with blocked collector line).
7	Condensate detected	Slugging can be clearly heard or is drained manually on a regular basis.
8	Further maintenance required	Repairs that require additional parts or materials. A works notice should then be raised to carry out remedial works.
9	Frozen	Well cannot be tested due to frozen sample or control valve.

5.12 Adjustments to gas well and manifold mix valves should only be carried out when a manifold has been fully checked. When making individual adjustments to wells, decisions should be made following history, gas quality and suction applied. Adjustments should never be made using valve positions.

5.13 When an adjustment has been made, the gas well position should be recorded with the gas quality and vacuum applied. Ensure the correct suction level following adjustment is recorded.

5.14 All GCS should be checked at least once a week to ensure integrity is maintained. This includes well heads, collector lines, manifolds, gas main, KOP's and condensate discharging lines.

5.15 Following balancing, all reads should be downloaded and reviewed to remove any rouge results inadvertently recorded.

5.16 A review of results and adjustments should then take place before forwarding the report to his supervisor.

5.17 The Area Supervisor is to check the balance and confirm correct actions have been taken before forwarding for file at Head Office or to site operators as locally agreed.

5.18 Load adjustment may be required post balance to control the rate of gas extraction:

- As a guideline, if site vacuum increases as a direct result of the balance, load reduction is evaluated to prevent over extraction.
- If site vacuum decreases, it is recommended that the field is allowed to stabilise for at least 24hrs before evaluating load adjustment.

5.19 Managers, supervisors and operatives are to be made aware of any site/engine parameter changes. Engine Parameter Sheets must be updated at least monthly to reflect currently site/engine conditions.

6. Gas Field Maintenance/Damage

To ensure a gas collection system is optimised, high standards of maintenance practices are required.

6.1 Formal gas field audits are carried out six monthly. These are copied to the Area Supervisor, the site with a central copy stored on the Head Office drive.

6.2 Any damage found or reported should be recorded and whenever possible photographic records maintained. Repairs are to be carried out immediate. If this is not possible the Area Supervisor must be informed.

6.3 Weekly maintenance checks are carried out by the site operative.

6.4 Any problems or defects found should be addressed as soon as practical.

6.5 Minor works should be carried out by the operative such as:

- Gas leaks.
- Valve maintenance.
- Drainage of condensate in collectors if not self de-watering.
- Loose connections/hose clips.
- Putting surface gas collectors back onto supports
- Dry bentonite seals.
- Leaks of condensate.
- Atmospheric ingress.
- Dips in gas collector lines.

6.6 More in depth works should be planned ahead with assistance within the area or with assistance of the Projects Department.

6.7 Records of all works should be maintained on site with duplicates sent to Head Office as a central record.

7. Gas Field Reviews

Periodic reviews are carried out to assess individual GCS performance.

7.1 To fully assess the performance of wells and collection efficiency, the following data is required:

- Flow checks – to determine any restrictions.
- Well dips – to determine blocked, collapsing or submerged wells from site leachate.
- Gas Field Trending Data – to long term analyse data to assess performance.

- Camera surveys – visual verification within well liners.
 - Image maps or similar – to identify areas on the gas field where aerobic activity or other changes are taking place.
- 7.2 Further works may be required following review of the above data. These could include:
- Replacement wells.
 - Replacement collectors.
 - Remediation to well heads
 - Replacement of GCS.
 - Additional de-watering facilities.
- 7.3 Reviews highlight areas within the waste mass of aerobic activity, under/over extraction, localised atmospheric ingress and potential hot spots.
- 7.4 Recommended data parameters are:
- >50% CH₄
 - <40% CH₄
 - >20% Balance gases
 - >18% Free N₂
 - >2% O₂
 - >100ppm CO
 - >100mb vacuum
 - Any positive pressure in the waste mass area.
- 7.4 Following the Gas Field Review a report is presented to the Area Manager and Area Supervisor to assess areas where any additional works are required.

At Golder Associates we strive to be the most respected global group of companies specialising in ground engineering and environmental services. Employee owned since our formation in 1960, we have created a unique culture with pride in ownership, resulting in long-term organisational stability. Golder professionals take the time to build an understanding of client needs and of the specific environments in which they operate. We continue to expand our technical capabilities and have experienced steady growth with employees now operating from offices located throughout Africa, Asia, Australasia, Europe, North America and South America.

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