LANDFILL MANUALS

LANDFILL MONITORING

2nd Edition

Office of Environmental Enforcement, Environmental Protection Agency
P.O. Box 3000, Johnstown Castle Estate, Co. Wexford, Ireland.
Telephone: +353-53-60600 Fax: +353-53-60699
E-mail: info@epa.ie   Website: www.epa.ie

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The Agency personnel involved in the preparation of this manual were Ms. Regina Campbell (principal author), Dr. Brian Donlon, Mr. Peter Webster, Mr. Dara Lynott & Mr. Gerry Carty.

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Dr. Michael Henry	Environmental Protection Agency
Ms. Margaret Keegan	Environmental Protection Agency
Dr. Ciaran O' Donnell	Environmental Protection Agency
Mr. Michael O' Neill	Environmental Protection Agency
Ms. Maeve Quinn	Environmental Protection Agency
Mr. David Shannon	Environmental Protection Agency
Mr. Tony Dolan	Environmental Protection Agency
Ms. Jean Smith	Environmental Protection Agency
Ms. Anne Butler	formerly Environmental Protection Agency

PREFACE

The Environmental Protection Agency was established in 1993 to licence, regulate and control activities for the purpose of protecting the environment. Section 62 of the Environmental Protection Agency Act, 1992 states that "*the Agency shall, as soon as practicable, specify and publish criteria and procedures for the selection, management, operation and termination of use of landfill sites for the purpose of environmental protection*". A number of manuals have been published under the general heading of LANDFILL MANUALS.

The first Landfill Monitoring manual was published in 1995 to assist in meeting the statutory obligations of Section 62 of the EPA, 1992. This document revises the original manual and also takes into account the additional requirements of the Council Directive on the landfill of waste (99/31/EC).

The manual provides guidance on the design and implementation of a monitoring programme in order to accurately assess the impact of a landfill on the surrounding environment and is intended for use by those involved in the monitoring of landfills. It provides guidance on monitoring of licensed landfill sites and will also be of value to new landfill developments that require monitoring for a waste licence application and an environmental impact statement. The manual outlines minimum requirements for the location of monitoring points, the frequency of monitoring, the parameters to be analysed and the minimum reporting values of those parameters. Many of the principles will also have relevance for the monitoring of landfill sites which are closed or unlicensed.

Other manuals on landfill site design, investigations for landfills, operational practices, restoration and aftercare have also been published and it is important that this manual is read in conjunction with them.

LIST OF ABBREVIATIONS

BAT	Best Available Techniques
BOD	Biochemical oxygen demand
BS	British Standard
CBOD	Carbonaceous biochemical oxygen demand
CEN	Comité Europén de Normalization
COD	Chemical oxygen demand
FID	Flame Ionisation Detector
GC-MS	Gas Chromatography-Mass Spectrometry
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectrometry
ISO	International Standards Organisation
LEL	Lower explosive limit
LFG	Landfill gas
NDIR	Non-dispersive infrared
NSAI	National Standards Authority of Ireland
QA	Quality assurance
QC	Quality control
TOC	Total organic carbon
UEL	Upper explosive limit
WMA	Waste Management Act, 1996

1. INTRODUCTION

1.1 General

The Environmental Protection Agency (EPA) is required, under the Environmental Protection Agency Act, 1992 to specify and publish criteria and procedures for the selection, management, operation and termination of use of landfill sites. This document replaces the original *'Landfill Monitoring'* manual, and is one of a series of manuals on landfilling which have been published to fulfill the Agency's statutory requirements.

This manual, along with the others in the series, is designed to assist landfill operators to conform to the standards required, including the BAT (Best Available Techniques) principle, and to ensure that the long-term environmental risks posed by landfills (including closed landfills) are minimised through effective monitoring and control.

There are many potential environmental problems associated with the landfilling of waste. These problems include possible contamination of the groundwater and surface water regimes, the uncontrolled migration of landfill gas and the generation of odour, noise, dust and other nuisances.

In the past, landfill sites in Ireland were rarely engineered and the absence of an environmental monitoring programme, meant that the impact of the landfill on the surrounding environment was not assessed. However, over the past decade standards and practices have been steadily improving and many new technologies have been adapted or specifically designed to control and monitor the processes within a landfill. Henceforth, it is expected that landfill sites will be selected, designed, managed and monitored using BAT to comply with the Waste Management Act, 1996**,** the Council Directive on the landfill of waste (99/31/EC) and Council Directive concerning integrated pollution prevention and control (96/61/EC).

1.2 Legislation

Regulation of waste management in Ireland is through the Environmental Protection Agency Act, 1992, the Waste Management Act, 1996 and the Protection of the Environment Act, 2003.

The Waste Management Act, 1996 provides for the introduction of:

- measures to improve national performance in relation to the prevention, reduction and recovery of waste; and
- a regulatory framework for the application of higher environmental standards, particularly in relation to waste disposal.

These measures include for example, the Waste Management Plans, which Local Authorities are responsible for preparing under Section 22 of the Waste Management Act, 1996 and the Waste Management (Planning) Regulations, 1997; and which must have particular regard to waste prevention and waste recovery. Section 26 of the Waste Management Act, 1996 requires the Environmental Protection Agency to prepare a national hazardous waste management plan. This must also have particular regard to prevention and minimisation of the production of hazardous waste and to the recovery of hazardous waste.

The Waste Management Act, 1996 designates the Agency as the licensing authority for landfills. The Waste Management (Licensing) Regulations, (1997 – 2002) provide for the licensing by the Agency of waste recovery and disposal activities.

1.2.1 LANDFILL DIRECTIVE

The Council Directive on the landfill of waste (99/31/EC) came into force on the 16th July 2001. The Directive sets stringent operational and technical requirements for waste and landfills, and provides for measures, procedures and guidance to prevent or reduce negative impacts on the environment and on human health.

The Directive categorises landfill sites into three types; inert, non-hazardous and hazardous, with varying controls on their design and operation depending on the perceived hazard they pose to the environment. The monitoring requirements for a landfill accepting inert waste will be different from one accepting non-hazardous waste, which will in turn be different from a facility accepting hazardous waste.

The Directive requires that landfill sites be monitored at specified minimum frequencies during their operational and aftercare phases.

Certain categories of landfills may, subject to certain conditions, be exempt from the monitoring requirements of the Directive such as landfill sites for non-hazardous or inert waste in isolated settlements if the landfill site is destined for the disposal of waste generated only in that isolated settlement.

1.2.2 OTHER LEGISLATION

The requirements of all legislation relevant to a particular aspect of the environment should be borne in mind when developing and undertaking monitoring programmes. The primary reasons for monitoring are to meet the requirements of legislation and to meet the specific requirements of the waste licence.

Legislation is open to change and therefore this document does not attempt to go into details on all the legislation relevant to different aspects of the environment. However it is important to mention some legislative requirements in relation to groundwater and surface water.

The primary legislation governing groundwater is the Directive on the protection of groundwater against pollution caused by certain dangerous substances (80/68/EEC). The Directive is transposed into national legislation by the Local Government (Water Pollution) Regulations 1977-1999. The objective of the Directive is to ensure the effective protection of groundwater by preventing the discharge of List I substances and limiting the discharge of List II substances into groundwater by a system of authorisation or licensing. The Groundwater Directive seeks to control groundwater pollution by halting or limiting List I and List II discharges to an aquifer; it does not actually set standards for water quality in an aquifer.

In December 2000 the Water Framework Directive (2000/60/EC) came into force and it established a strategic framework for managing the water environment and sets out a common approach to protecting and setting environmental objectives for all groundwaters and surface waters in the European Community. The Directive is intended to replace many pieces of current water quality legislation and to provide a comprehensive system of environmental protection for surface water and groundwater.

1.3 Landfill Monitoring

The landfilling of waste poses a potential long-term threat to the environment. It is important therefore that landfills are located, designed, operated and monitored to ensure that they do not to any significant extent:

- harm the environment,
- endanger human health,
- create an unacceptable risk to water, soil, atmosphere, plants or animals,
- create nuisances through noise or odours, or
- adversely affect the countryside or places of special interest.

The purpose of this revised manual on landfill monitoring is to provide guidance on the design and implementation of an effective and efficient monitoring programme which will allow an accurate assessment of the impact of the landfill on the surrounding environment. A well designed monitoring programme will in turn allow for the early recognition of adverse environmental effects and facilitate rapid corrective action.

2. MONITORING PROGRAMME

2.1 Purpose of the Programme

The monitoring programme is an essential component of the management plan for a landfill site. It provides operators with information to assess the effect of the landfill on the surrounding environment and assists in ensuring that the landfill is operated and controlled to the specified standards. There are three key phases of monitoring at a landfill and these are summarised in Table 2.1.

TABLE 2.1 KEY PHASES OF MONITORING AT A LANDFILL

Phase	Type of monitoring	Reason
Prior to landfill operation	Baseline	Site investigation, environmental impact assessment, preparation of a waste licence application.
During the operation of the landfill	Compliance/Assessment	Comply with waste licence.
Aftercare and restoration of the landfill	Compliance/Assessment	Comply with waste licence, preparation of licence review application, surrender of licence.

The objectives of a monitoring programme are:

- to establish baseline environmental conditions;
- to detect adverse environmental impacts from the landfilling of waste;
- to provide information for the assessment of an application for a waste licence, review of a waste licence or surrender of a waste licence;
- to demonstrate that the environmental control measures are operating as designed;
- to assist in the evaluation of the processes occurring within the waste body;
- to demonstrate compliance with the licence conditions;
- to provide data for emission inventories;
- to provide data to inform the public;
- to provide data for the improvement and updating of monitoring programmes;
- to assist in an investigation in the event of a trigger level or emission limit value being breached.

Landfill monitoring is an interactive process incorporating the findings of the site investigation, the environmental impact assessment, environmental monitoring results, risk assessment and the conclusions reached in the investigations.

The following are common terms used in monitoring programmes.

Emission Limit Values
These are values, including concentration limits and deposition levels established in the licence. No specified emission from the facility can exceed these emission limit values. In addition, the licence requires that no emissions should result in significant impairment of, or significant interference with the environment beyond the facility boundary.

Trigger Levels
These are values that would require certain actions to be taken by the site operator should they be attained or exceeded. A breach of a trigger level may indicate a significant increase of a contaminant concentration in an environmental medium. These values are generally set by the Agency in the licence or else may be set by the operator. They may be site specific and be established from the baseline monitoring results.

Baseline Monitoring is monitoring in and around the location of a proposed facility so as to establish background environmental conditions prior to any development of the proposed facility. In the case of existing facilities, baseline monitoring serves as a reference point to which later monitoring results are compared. The information gathered can be used to evaluate the future compliance monitoring data and to identify potential impacts of the landfill on the environment.

Compliance Monitoring is periodic monitoring undertaken by either the licensee or the Agency at specified frequencies to determine if there has been a release of contaminants to the environment and to demonstrate compliance with the licence conditions. It includes taking measurements of process conditions, process emissions and levels in receiving environments and the reporting of the results of such measurements to demonstrate compliance with limits specified in the licence or other legislation.

The information provided by compliance monitoring is also valuable for other environmental and management activities (e.g. for optimising processes, protecting sensitive ecosystems and informing the public of the effectiveness of environmental protection measures).

Assessment Monitoring is investigative monitoring which is initiated after the detection of a release of a contaminant to the environment or on attaining a trigger level. The purpose of the assessment programme is:

- to identify the source of release;

- to characterise the nature, extent and rate of release;

- to evaluate the risk to the environment and to human health;

- to evaluate measures to prevent or minimise further releases; and

- to provide information for the design and implementation of corrective measures.

2.2 Scope of Programme

Monitoring is required throughout the life of a landfill. It extends from the pre-operational phase (baseline monitoring) through to the operational and aftercare phases (compliance and assessment monitoring) of the landfill. The scope of the programme should initially be identified from the investigation process, the environmental impact assessment and the nature of the waste being deposited. It should include all environmental media likely to be significantly impacted through the operation of the landfill**.** For a non-hazardous waste landfill provision for the monitoring of the following, as a minimum, should be made:

- surface water,
- groundwater,
- leachate,
- landfill gas and landfill gas combustion products,
- odours,
- noise,
- meteorological conditions,
- dust/particulate matter,
- topography and stability,
- ecology, and

- archaeology.

Table C.1 in Appendix C outlines the minimum monitoring requirements for a non-hazardous landfill.

2.3 Monitoring Programme Design

The steps to be taken in designing a monitoring programme are shown in Figure 2.1. The design of the monitoring programme will, to a large extent, depend on site conditions identified during the site selection and investigation processes. Such conditions may include:

- the degree of isolation of the site;
- the geological, hydrogeological and hydrological regimes;
- the containment measures proposed;
- the characteristics of the waste to be deposited; and
- the risk of adverse impacts on the various aspects of the environment.

It is desirable that the monitoring programme be developed using an integrated approach. Such an approach requires an understanding of the interaction and inter-relationship of the different environmental media. For example, it is important to understand how a discharge to the aquatic environment impacts on the biological quality of a river. An integrated approach would assist in the location of monitoring points and permit a greater understanding of the overall impact of the site on the environment.

The monitoring programme should address the following topics:

General & site specific objectives
These should be identified at an early stage and include:

- establishment of a reference database from baseline monitoring results;
- identification of areas and receptors vulnerable to contamination;
- compliance with licence conditions; and
- adherence to guidance issued by the Agency.

Selection of suitable monitoring points
The selection of suitable, *representative* monitoring points is essential in the collection of valid data. The number and location of monitoring points is site specific and depends on:

- geological, hydrogeological and hydrological regimes of the area;
- the topography of the site;
- the proximity of people and building developments; and
- the location of sensitive ecological habitats.

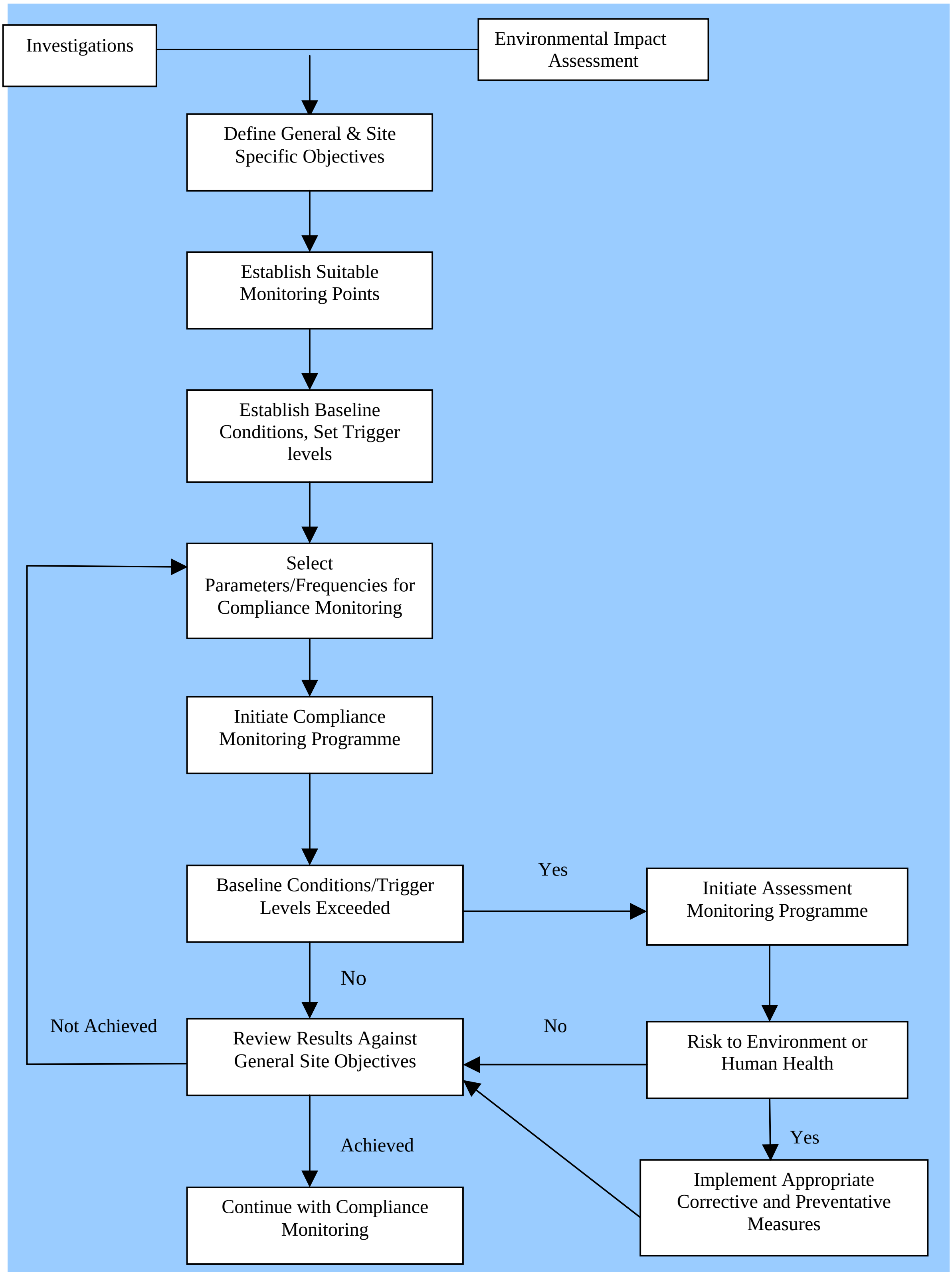

FIGURE 2.1 DESIGN OF A LANDFILL MONITORING PROGRAMME

Ease of access by sampling personnel and safety issues also need to be taken into account when selecting suitable monitoring locations. Monitoring for parameters such as surface water, groundwater, noise and odours will usually include monitoring points that are not located within the boundary of the facility. Permission from the respective owners may be necessary in some cases.

Consideration should also be given to the potential for dual use of monitoring points. For example, the use of groundwater boreholes for monitoring off-site landfill gas migration should be considered.

Possible monitoring locations can be grouped into the following: source, pathway and receptor positions.

- ***Source positions.*** These are positions within or at the exit from a process such as:
  - before and after abatement equipment,
  - within a flue for emissions to air,
  - at an outlet from an effluent pipe for wastewater emissions.

- ***Pathway positions.*** These are positions in the receiving environments (e.g. air or water) where the flow and dispersion require monitoring because they affect compliance with ambient limits such as:
  - in a river, for monitoring of river flow,
  - in the air, for monitoring of atmospheric dispersion conditions.

- ***Receptor positions.*** These are the sensitive positions in receiving environments where pollutants after emission, or impacts (e.g. noise, odour) from sources and dispersion along pathways are, e.g.:
  - at point of maximum ground-level concentration or deposition,
  - at a position occupied by the most exposed person(s),
  - across a local ecosystem, e.g. a catchment, or an area of forest or farmland.

Identification of Monitoring Points

All monitoring locations should be marked on a drawing or map so that they are readily identifiable during subsequent visits. An up to date drawing of all monitoring points should also be held at the facility office.

The monitoring programme must state clearly the positions (e.g. River A at grid reference 'xxx yyy'), a local description of the monitoring location, how it can be accessed and where samples and measurements are to be taken. Reference to a GPS based location citing the datum used would also be useful (e.g. WGS 84).

Standardisation of the names of monitoring points is recommended, e.g. surface water - SW, groundwater – GW, etc. All permanent sampling locations should have a marker detailing the location name and type of sample. The location marker should be easily visible from a distance. Different colour coding for the different types of samples, e.g. surface water, groundwater, leachate, etc. can improve efficiency in locating monitoring points. Access to points should be kept clear where possible. Locating monitoring points may be particularly difficult during the spring/summer months due to prolific plant and weed growth.

Monitoring parameters

Within this document parameters are suggested for baseline monitoring of surface water, groundwater and characterisation of leachate. Depending on the baseline monitoring data, the type of waste deposited and the level of containment at the site, it may be necessary to review the monitoring parameters and adapt them to reflect accurately the contaminants most likely to arise and adversely affect the environment.

Monitoring frequencies

The monitoring frequencies for a landfill may vary according to the age of the site, the type of waste accepted for disposal and the location of the site. Increased monitoring above the minimum requirements may be necessary to ensure that sensitive environmental media are adequately monitored. Some factors that would indicate the need for increased monitoring include:

- evidence of negative impacts or a decrease in environmental quality when compared with baseline conditions or the results of previous monitoring;
- non-compliance with a licence condition, e.g. if an emission limit value or a trigger level is

breached;

- change in site operations;
- increased extraction of surface waters or groundwater in the vicinity of the landfill;
- change in adjacent land use; or
- building developments adjacent to the site.

Monitoring Equipment

There are numerous instruments commercially available for sampling and monitoring at landfill sites. Limitations are inherent in all types of monitoring equipment and the conditions of use may also give rise to difficulties in obtaining reliable results. Sampling and monitoring equipment must therefore be chosen carefully to ensure that the objectives of the monitoring programme are achieved.

Some factors that may need to be considered when assessing the equipment are:

- suitability of the equipment for measuring the required parameters,
- equipment conforming to recognised standards,
- sensitivity/detection level,
- calibration requirements,
- maintenance requirements,
- ability to be decontaminated after being in contact with pollutants and toxins
- ease and safety of operation,
- portability of equipment where required,
- type of power source required,
- durability,
- cost, and
- intrinsically safe.

Sampling and Analytical Methods

The monitoring programme should detail the sampling and analytical protocols to be employed to ensure that the measurements obtained are valid and reliable. Further information on the design of sampling protocols is given in Appendix A. Analytical procedures for surface water, groundwater and leachate should be capable of meeting the requirements of Tables D.1 and D.2 in Appendix D.

Quality Assurance and Quality Control Procedures

Quality assurance is an integral component of any monitoring programme. Operators should develop a quality assurance plan as part of the programme to ensure that data obtained are accurate, precise and representative of the medium being investigated. Further information on quality assurance is given in Chapter 3.

2.4 Review of Programme

The monitoring programme should be reviewed periodically by the operator, assessed against its objectives and updated as necessary. Such reviews are essential to ensure the quality, effectiveness and continued suitability of the programme. This review could be carried out during the preparation of the yearly Annual Environmental Report or as part of a licence review application.

2.5 On-site Records

All monitoring results have to be interpreted and reported to the Agency at the frequencies outlined in the licence and must be available for inspection if requested by Agency personnel during site inspections or audits. A summary report of emissions and results and an interpretation of environmental monitoring must be included in the Annual Environmental Report of the facility. As part of the requirements of a waste licence, environmental information relating to the facility must be available to the public.

It is desirable that a Data Management System is established for the collation, archiving, assessing and graphically presenting the environmental data generated.

2.6 On-site Laboratory Facilities

It is recommended that in the case of larger facilities that an on-site laboratory is provided and maintained. This could provide basic laboratory equipment and apparatus necessary for process control testing such as balances, ovens, distilled water and proprietary test kits and a designated storage area for monitoring equipment such as pH and conductivity meters and sampling apparatus.
This would allow the quality of surface waters or the efficiency of an on-site leachate treatment plant to be checked if a problem was suspected. Adequate equipment maintenance and quality control is also necessary.

2.7 Safety Precautions

Safety must be carefully considered before monitoring begins and appropriate precautions followed. It is recommended that every monitoring programme should include a requirement that a risk assessment based on a safety audit be used to develop a safe working-plan covering the following points:

- confirmation that the equipment and facilities which will be used are safe and adequate (e.g. electrical and sampling equipment, walkways, ladders);
- guidance or briefing on how to safely access locations where monitoring is to be done;
- availability of an appropriate number of qualified personnel;
- reminders concerning risks and precautions in relation to physical, chemical and biological dangers;
- availability of personal protective equipment (PPE); and
- safety training of staff, including training in emergency and evacuation procedures (e.g. by site induction and safety course). FÁS run a Safe Pass Health and Safety Awareness Training Programme that aims to ensure that all construction site and local authority personnel have a basic knowledge of health and safety issues.

3. QUALITY ASSURANCE/QUALITY CONTROL

3.1 Purpose

A monitoring programme for a landfill is a substantial undertaking in terms of both time and money and will generate substantial quantities of data over the lifetime of a landfill. It is important that the data produced is representative, necessary and valid and that it allows the accurate assessment of the impact of the landfill on the environment.

Errors within the sampling or analysis processes may prejudice the analytical results and invalidate the interpretations and conclusions drawn from them. The selection of and adherence to the principles of quality assurance and quality control should provide the necessary controls to minimise potential sources of error by ensuring that:

- the entire process, including field and laboratory operations, are adequately documented;
- adequate training is given to all field and laboratory staff involved;
- the integrity of the samples is maintained during sampling, transportation and storage; and
- the appropriate analytical techniques are used.

3.2 Definitions

A Quality Assurance (QA) system is a set of operating principles which, if strictly followed during sample collection, transportation and analysis, will produce reliable data.

Quality Control (QC) is an integral aspect of Quality Assurance and focuses on ensuring that the data produced are inherently accurate and precise. The QC programme should specify the techniques used to measure and assess data quality, sample replication requirements and the remedial actions to be taken when quality objectives are not realised.

3.3 Quality Assurance Plan

The Quality Assurance (QA) Plan is a document that outlines the quality assurance principles under which the monitoring programme will be conducted. The plan should be prepared in advance of the monitoring programme and should define the overall management strategy designed to ensure the quality of the implementation of the programme. It should include documented lines of decision making, sampling and analysis conventions and procedures for sample handling, transport and preservation.

The QA Plan can be broadly divided into three sections: general quality issues, quality during field operations and the quality during laboratory operations. A selection of topics to be addressed under each of these headings is outlined below.

3.3.1 GENERAL QUALITY MANAGEMENT

- Overall objectives of the monitoring programme,
- Standard Operating Procedures for laboratory and field activities,
- Responsibilities and qualifications defined for each staff member involved,
- Designation of a Quality Assurance Officer (with authority for corrective action),
- Training (field & laboratory),
- Maintenance of Training Records,

- Quality Assurance reports,
- Report approval mechanisms,
- Document control procedures,
- Auditing procedures.

3.3.2 FIELD OPERATIONS

- Sampling programme design,
- Sampling protocols (further information is given in Appendix A),
- Documentation such as field data forms and chain of custody forms (further information is given in Appendix B),
- Instrument calibration,
- Sampling equipment (appropriateness, cleaning, maintenance records),
- Procedures for collection & preservation of samples,
- Procedures for transport & storage of samples (methods, labelling).

3.3.3 LABORATORY OPERATIONS

- Laboratory documentation,
- Standard methods of analysis such as National/International standards (NSAI/ISO/CEN methods), *'Standard Methods for the Examination of Waters & Wastewater'* (Eaton *et al.*, 1998), UK Standing Committee of Analysts "Blue Book" series, or similar,
- Validation of method performance to include detection/reporting limits, recovery, uncertainty of measurement,
- Laboratory instrument calibration and maintenance,
- Performance evaluation utilising in-house QC samples and/or Certified Reference Materials (CRMs),
- Control charts (or tables) to monitor precision and accuracy of data,
- Review of QC sample results (permanent record, replicates, verifications),
- Procedures for data evaluation (comparison with previous results, statistical methods) and notification of exceedances of emission limit values to the client,
- The structure, compilation, certification and verification of monitoring reports forwarded to the Agency,
- Retention of samples until such time as results are reported to the client.

3.4 Quality Schemes

3.4.1 LABORATORY ACCREDITATION

It is desirable that laboratories undertaking analyses be accredited to ISO/IEC 17025 (1999). It is important that consideration is given to the Scope of Accreditation of the laboratory to ensure that it is relevant to the test(s) required.

Non-accredited laboratories may require to be verified by the site operator to ensure the application of documented quality controlled practices.

3.4.2 INTERLABORATORY TESTING SCHEMES

In accordance with Section 66 of the Environmental Protection Agency Act 1992, the Agency operates an intercalibration programme for the purpose of assessing analytical performance and ensuring the validity and comparability of environmental data from laboratories that submit data to the Agency. It also provides for the establishment of a register of Quality Approved laboratories that would normally be expected to send data to the Agency. The register lists, on a parameter by parameter basis, those laboratories that performed satisfactorily in the EPA intercalibration programme for the previous year. The register is updated annually and may be viewed on the Agency's web site at www.epa.ie. At present this register is limited to water and wastewater.

Laboratories analysing leachate and complex wastewaters should assess the need for additional participation in inter-laboratory proficiency schemes more suited to these matrices as a supplement to internal quality control programmes.

Where practicable, other parameters such as landfill gas, noise, dust and odour monitoring should be undertaken by laboratories that participate in appropriate quality schemes. The Source Testing Association (STA) provides guidance on best practice for sampling of stacks and this may be applicable to flares and utilisation plants. Further information may be found at www.S-T-A.org.

Details of proficiency schemes within the EU may be found at the European Information System of Proficiency Testing Schemes (EPTIS) website at www.eptis.bam.de.

3.4.3 OTHER SOURCES OF INFORMATION ON DATA QUALITY

- *'Handbook on the Design and Interpretation of Monitoring Programmes'* Technical Report NS29 (WRc, 1989a).
- *'A Manual on Analytical Quality Control for the Water Industry'* Technical Report NS30 (WRc, 1989b).
- ISO/IEC (1999) 17025 *'General requirements for the competence of testing and calibration laboratories'*. This publication sets out the criteria required to enable laboratories to meet current accreditation requirements.
- ENV/ISO (1997) 13530 *'Water Quality - Guide to Analytical Quality Control for Water Analysis'* available from the NSAI.
- ISO (1991a) 8258 *'Shewhart Control Charts'*.
- Certified reference materials and other reference standards are widely available from a number of commercial sources many of whom also provide technical information
- Valid Analytical Measurement (VAM) Programme. This programme is coordinated by the Laboratory of the Government Chemist (UK) and is aimed at improving the quality of analytical information.

3.5 Sub-contracting of Analyses

It is not uncommon to find site operators sub-contracting the sampling and/or analysis of waste facilities to third party consultancy or laboratory services. The commercial sector for such work is expanding and there are now several companies with experience of such work.

In such cases it is necessary to ensure that the Quality Plan and any subsequent contract documentation makes full reference to the detail of all aspects of the monitoring process including such aspects as borehole purging techniques, sample filtration/preservation, storage, transport and analysis turnaround. This can be especially important in respect of some parameters such as those for microbiology, metals, and organics.

While many companies will apply the principles set out above it is important that operators satisfy themselves as to the technical and analytical competence of third parties before reporting of such analytical data. It is important when comparing contract details to ensure the comparability of service delivery and, most importantly analytical performance. In this regard the range of parameters covered and their practical reporting limits can vary significantly between one service provider and another. This is particularly true in the case of organic analysis where lower reporting concentrations are often closely linked to the complexity of sample pre-treatment and concentration procedures

Procedures should be put in place so that any exceedance of an emission limit value or a trigger level is communicated by the laboratory to the licensee as soon as possible so that further measures can be implemented.

4. Surface Water

4.1 Introduction

The Landfill Directive requires that surface water, if present, be monitored at representative points. The surface water environment on and off a landfill site may comprise of:

- streams, rivers, canals and ditches,
- lakes, reservoirs and lagoons,
- wetlands,
- estuaries, and
- coastal waters.

The purpose of a surface water monitoring programme is to verify the quantity and quality of the surface water on a periodic basis and to detect any significantly adverse environmental impacts resulting from landfill activities or resulting from construction activities at the landfill.

Contamination of the surface water regime by a landfill site may arise due to:

- intentional discharges (e.g. discharge of treated leachate); or
- unintentional discharges (e.g. leachate escape, contaminated surface water run-off, accidental spillages).

The design of the surface water monitoring programme should be site specific, and should take into account such factors as the nature of the drainage system, water levels, flow characteristics and the groundwater/surface water inter-relationship

4.2 Monitoring Locations

The location of surface water monitoring points will be site specific and will depend on the nature of the drainage system around the landfill site. Table C.1 in Appendix C outlines minimum baseline surface water monitoring requirements for a non-hazardous landfill. The monitoring points should allow information to be collected on the quantity and quality of the water both upstream and downstream of the landfill and should be representative of the particular site conditions. The investigation process will identify those surface water bodies at risk and the location of the monitoring points should reflect the results of the investigation.

The following guidelines should be observed when assessing suitable locations for monitoring points:

- for flowing water bodies (e.g. rivers and streams), monitoring should be undertaken at not less than two locations, one upstream and one downstream of the landfill. The downstream monitoring point should be located immediately downstream of the mixing zone. More than one monitoring point should be chosen downstream of the discharge if information on the extent of impact or recovery is required;
- for static freshwater bodies (e.g. lakes), a minimum of two monitoring points should be located radiating away from the landfill site and should be in an area that is representative of the water body as a whole;
- surface water draining from the landfill site should be monitored before discharge to the receiving surface waters;
- the inlet and outlet points of any surface water holding and settlement ponds at the landfill should be monitored so that their efficiency can be determined and so that any potential sources of

contaminants can be identified;

- if applicable, any effluent discharge points from the landfill should be identified and monitored before discharge to the receiving surface waters;
- the accessibility of the monitoring location and the safety of personnel when sampling should be assessed;
- the measurements to be made and the sampling method to be used at each location should be considered;
- conflict with other potential pollution sources and pathways should be avoided, e.g. cattle drinking or crossing points, farmyard run-off, tributary streams.

4.3 Monitoring Frequency and Parameters for Analysis

For baseline monitoring, each monitoring point should be monitored quarterly for a minimum of one year prior to the commencement of activities at the site.

The frequency of compliance monitoring during the operational and aftercare phase is site specific and will be governed by the waste licence and should take into consideration the characteristics of the surface water regime and its vulnerability to contamination.

For baseline monitoring, the parameters listed in Table C.2 in Appendix C should be included in the determination of the surface water quantity and quality. Tables D.1 and D.2 in Appendix D outline the guideline minimum reporting values for those parameters required to be analysed.

Where contamination of the surface waters is suspected, then surface water flow will have a large bearing on the extent of the contamination. Surface water flow may be:

- rapid, with the result that contaminants can be spread to receptors in a matter of minutes or hours rather than days or longer;
- of high volume, offering large dilution of contaminants; or
- seasonally variable and liable to rapid fluctuations over short time periods resulting in large variations in dilution potential.

Therefore risk assessment should be cautious and take account of the lowest flows in surface watercourses. At least one sample over the course of a year should be taken at a time of low flow conditions.

4.4 Biological Assessment of Surface Water Quality

Chemical analyses of surface waters are essential both in identifying possible contaminants and in quantifying their concentrations. However, chemical analyses only provide an instantaneous picture of water quality. Since contaminants often interact and occur in complex mixtures, such analyses alone will frequently give little indication of the potential biological impacts. Therefore, as part of the integrated approach to monitoring at a landfill, operators should undertake periodic biological assessments of the quality of the surface waters surrounding the landfill. Ideally, all the components of the aquatic biota (the micro- and macrofauna and flora) should be utilised but in practice macroinvertebrate community analysis is found to be satisfactory for routine biological water quality monitoring purposes.

One of the most common methods employed to assess surface water quality is monitoring changes in the diversity and density of macroinvertebrates that inhabit the substrata. With increasing pollution there is often a decrease in faunal diversity and an increase in numbers of specific tolerant forms. The sensitivity and tolerance to pollution varies considerably from species to species and it is possible to relate certain faunal groups to particular pollution levels.

The biological information gathered by this method can be presented as a biotic index, which is a system that relates the benthic community composition and water quality. A five-point scale of numerical values has been in use in Ireland since the 1970's with the intermediate indices Q1-2, 2-3, 3-4 and 4-5 used to denote transitional conditions. The Q scheme, as it is known, is related to water quality as shown in Table 4.1.

TABLE 4.1 Q VALUES AND QUALITY CLASS

Biotic Index (Q value)	Quality Status	Quality Class
Q5, Q4-5, Q4	Unpolluted	Class A
Q3-4	Slight pollution	Class B
Q3, Q2-3	Moderate pollution	Class C
Q2, Q1-2, Q1	Serious pollution	Class D

(Source: McGarrigle *et al.*, 2002)

Details of the classification system used in the Q scheme may be found in the Agency's report on *'Water Quality in Ireland 1998-2000'*, (McGarrigle *et al.*, 2002).

Fisheries Assessment

An assessment of the fisheries status of a river may be necessary in some cases. This may be of particular importance where treated leachate is discharged directly into a river or to provide baseline data of the status of a river adjacent to a proposed landfill. The relevant Regional Fisheries Board should be contacted to ascertain if there is any current information on the fish species or fish populations present in the river or if any electrofish surveys have been undertaken. The Fisheries Board should also be able to provide information on whether the river is a designated salmonid or coarse fishery.

4.5 Sediment Sampling

Occasionally there may be a requirement to take samples of bottom sediment deposits, e.g. at a landfill that is located beside an estuary. Sediment samples can provide a very sensitive means of identifying impacts on surface water by contaminants such as trace metals that are readily adsorbed onto sediment from flowing water. This can sometimes provide an indicator of the long-term accumulation of pollutants carried by a watercourse. It is important that sampling locations are depositional in nature, that comparable upstream and downstream sites are used and that sampling depth is chosen to reflect recently deposited sediment. It is important that cross-contamination is avoided between sites when sampling.

4.6 Trigger Levels

The licensee may need to determine normal levels and trigger levels for parameters such as TOC and conductivity for the water entering surface water management features such as settling and holding ponds. If these trigger levels are breached, then it may be necessary to close off the outlet from the ponds to the receiving waters, investigate the source of the contamination and implement measures to treat the contaminated surface water.

4.7 Sampling Guidelines

4.7.1 INTRODUCTION

Monitoring of surface waters may involve obtaining samples for physical, chemical or biological analysis. There is a variety of sampling equipment available for these purposes, but its suitability will depend on the nature of the investigation and the intended use of the sample. Sampling of sediments may also be required from time to time.

The principal purpose behind a sampling programme is to collect samples that accurately reflect the quality of the medium being investigated. The analytical data from these samples will be used in the interpretation of the environmental impact of the landfill and therefore it is important that the composition of the samples remains unaltered before analysis. All types of sampling and monitoring equipment have inherent limitations which may cause difficulties in obtaining sufficiently reliable results.

4.7.2 GENERAL SAMPLING GUIDELINES

The general procedure for taking a representative sample of leachate, groundwater or surface water is illustrated in Figure 4.1. General sampling guidelines are outlined below.

- All staff involved in the taking of samples should receive appropriate training and be familiar with the sampling procedure and equipment to be used.
- Appropriate protective clothing should be worn which may include the use of high visibility vests, hard hats, eye protection, gloves and protective footwear.
- Appropriate vaccinations should be received by sampling personnel.
- Before sampling, arrangements should be made with the relevant laboratories for the analysis of the samples taken.
- Only sampling containers supplied or recommended by the laboratory carrying out the analysis should be used. Further information may be found in ISO 5667-3 (1994).
- Sampling personnel should be familiar with any preservatives and/or storage temperatures required for the parameters to be analysed.
- In general, containers should be filled to the brim to avoid the inclusion of air in the sample, unless there is a ‘fill-to’ mark, for example in pre-preserved bottles.
- All equipment should be checked to ensure that it is in working order and if necessary is calibrated.
- All samples should be put into appropriately labelled containers and detailed fieldsheets should be used (e.g. site, time, date, sample code, personnel, weather etc).
- The chain of custody for all samples should be documented (Appendix B.2 provides an example of a Chain of Custody Form).
- Samples should be stored in a cool box or similar environment, out of direct sunlight and delivered to the laboratory with minimum delay, ideally on the same day and preferably within 24 hours of sampling.

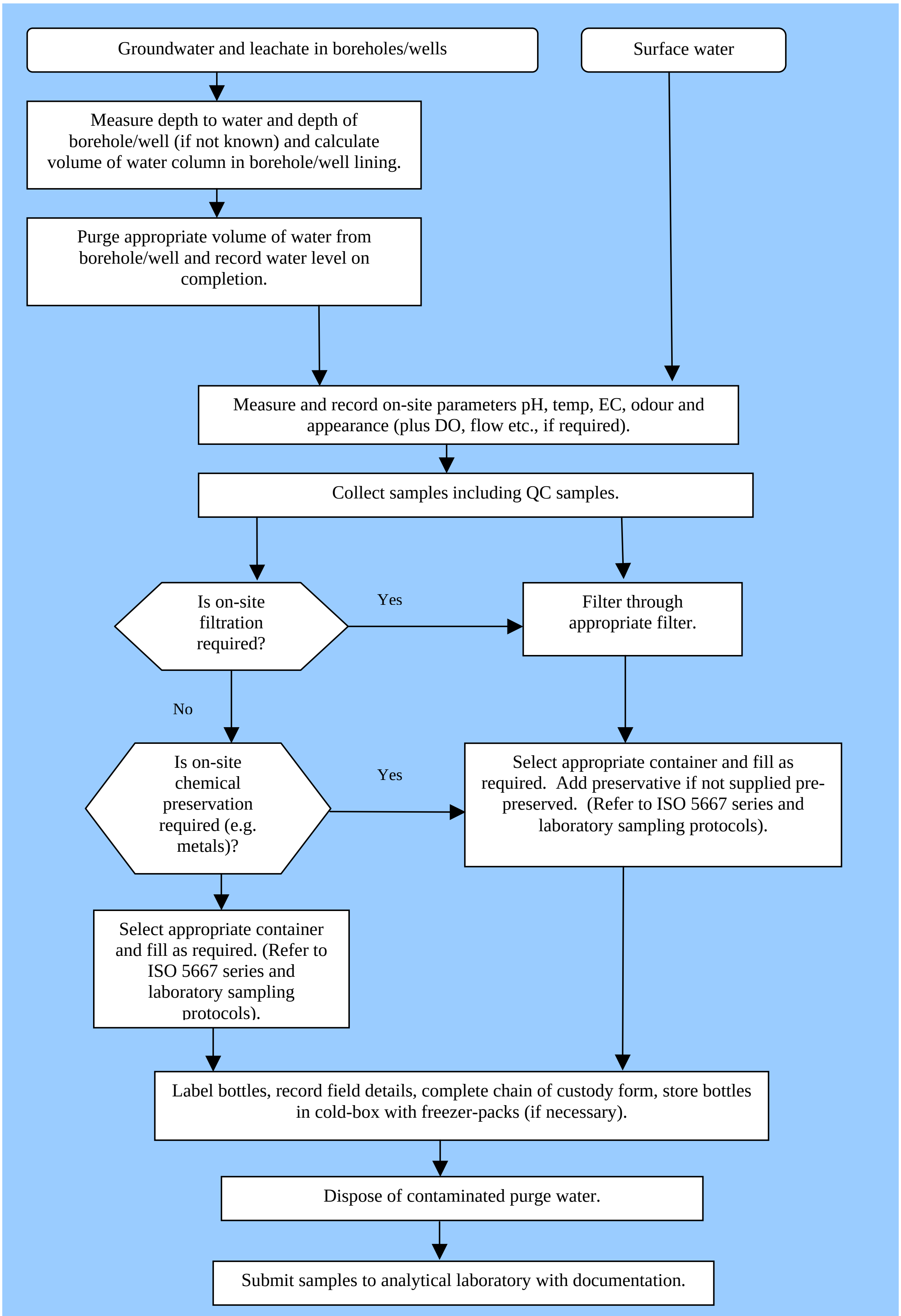

FIGURE 4.1 PROCEDURE FOR COLLECTING A REPRESENTATIVE WATER SAMPLE

4.7.3 SAMPLING EQUIPMENT

Flow/Volume
Water movement plays an important role in the dilution and dispersion of contaminants and physical parameters such as surface water speed and flow may be measured in a number of ways. These include:

- floats, timed over a specified distance,
- velocity tubes,
- current meters,
- and weirs.

The choice of appropriate method depends on the dimensions of the water course (e.g. profile, gradient) and flow rate as well as other factors.

Further guidance on measuring surface water flow is provided by ISO 8363 (1986).

The volume from a discharge point (or outfall) may be measured by fitting the discharge point with an integrated flow meter, in which flow measurement consists of timed readings of the meter. Flow-meters should be fitted and calibrated to the manufacturer's instructions. Pipe diameter, gradient, effluent chemical characteristics and flow volumes must be considered in the specification and installation of flow meters.

Flow emerging from a pipe can sometimes be measured by the timed filling of a container (e.g. volume collected in 10 seconds flow). However, health and safety considerations, particularly for contaminated discharges may preclude use of this method. Discharge measurements should be timed to take account of cyclic (e.g. daily) or rainfall dependent variations in flow.

Chemical parameters
For the analysis of chemical parameters in the field such as pH, temperature, dissolved oxygen and electrical conductivity, a variety of instruments and kits are commercially available which are calibrated and relatively easy to operate.

The simplest equipment for taking spot surface water samples is a bucket or a wide-mouthed bottle dropped into a body of water and hauled out after filling. The use of extendible rod bucket samplers allows improved access to mid-stream samples compared with bankside sampling. Discrete depth samplers are used where sampling at selected depths is needed.

Automatic sampling equipment may also be required. These are portable and are often highly automated. There are two general types of automatic samplers. Time-dependent samplers collect discrete, composite or continuous samples but ignore variations in flow whereas volume-dependent samplers also collect these sample types and take into account variations in flow. In the case of fixed locations, the storage of composite samples under refrigeration or the sampler itself under refrigeration is desirable.

When sampling surface waters, the following guidelines should be followed:

- Special care should be taken to avoid cross contamination of samples. New or decontaminated sampling devices should be used for each sampling location. Sampling devices should be adequately cleaned before reuse.
- Sampling of surface water should commence at the least contaminated location first and then end at the most contaminated location.
- When sampling flowing watercourses, avoid disturbing water upstream of the sample location. If possible stand downstream of the sample point and collect water into sample containers in the flow of the water.
- The sampling location should be chosen with care. Safe and permanent access to all on-site

sampling points should be provided. Common sense should be used at all times.

- Where possible a representative sample should be taken such as in the middle of a stream at mid-depth. Samples should be taken from the fastest flowing part of the watercourse, where possible, and stagnant areas should be avoided. Sediment in the sample should also be avoided.
- Other observations of the water quality should be noted such as presence of litter, sewage fungus, surface scum, oil, weeds, algae, presence of aquatic life, odour, river or tidal condition, e.g. river in flood, ebb tide.

Further guidance on surface water sampling may be found in ISO 5667 Parts 4 (1987) and 6 (1990).

Biological sampling of macroinvertebrates
For macroinvertebrate biological assessment, there should be a minimum of two sampling sites, one upstream (background site) and one downstream (impact site) of the likely discharge point from the landfill. Monitoring should be undertaken annually as a minimum and should usually be undertaken in the summer-autumn period (June-September) when flows are likely to be relatively low and water temperatures highest. Surveys during this period are likely, therefore, to coincide with the worst conditions to be expected in those sites affected by discharges.

The simplest and most commonly used method for taking samples for biological analysis is the ‘kick’ sample. For this technique, the substratum of the water body is vigorously disturbed with the foot and the dislodged macroinvertebrates are collected in a pond net. In shallow waters stones can also be turned over by hand in front of the net.

Measurements of dissolved oxygen saturation and water temperature, as well as observations on macrophyte and algal abundance, substratum type, water appearance and other biological and physical features are also recorded, in addition to the specific information on the nature of the macroinvertebrate fauna. An example of a Rivers Ecological Assessment Fieldsheet is provided in Appendix B.4 and it is recommended that this be used.

Biological sampling techniques are rapid and inexpensive. However there are potential problems in comparing results between sites with different flow regimes, substratum types and so on, and also between individual operators in the case of extensive survey programmes (Mason, 1996).

Other types of invertebrate sampling equipment include:

- Surber samplers– this combines a quadrat with a net and is designed to give a quantitative collection of macroinvertebrates;
- Cylinder samplers – these are suitable for shallow, still waters such as ponds or shallow, coastal lagoons;
- Grabs and corers – these are suitable for sampling deeper waters such as lakes and rivers.

Further guidance on sampling methodology is outlined in McGarrigle and Lucey (1983).

Sampling of bottom sediment deposits
Bottom sediment deposits may be sampled by grabs or dredges designed to penetrate the substrate as a result of their own mass or leverage. These are devices with spring loaded or gravity activated jaws which enclose a defined surface area and allow sampling of unconsolidated sediment. In selecting the type of dredge to be used, the habitat, water movement, area of sample and boat equipment available need to be considered.

A core sampler is used when information concerning the vertical profile of a sediment is of interest.

Further guidance on sediment sampling may be found in ISO 5667 Part 12 (1995).

5. Groundwater

5.1 Introduction

Groundwater is that part of the subsurface water which is in the saturated zone. The saturated zone is the subsurface zone in which all interstices are filled with water. The top of the saturated zone is called the water table and can be identified by measuring the water level in a borehole which extends into the saturated zone. Groundwater is a major natural resource of both ecological and economic value and its protection is of prime importance.

The fundamental objectives of a groundwater monitoring programme at a landfill are to assess groundwater quality and quantity and to determine the effectiveness of the environmental control systems in order to ensure the continued integrity of the groundwater quality and quantity. These objectives are achieved through the collection and analysis of representative groundwater samples.

The efficiency of a monitoring programme is dependent on a thorough understanding of the hydrogeological conditions of the site, coupled with the appropriate location and construction of monitoring boreholes.

5.2 Monitoring Locations

Monitoring boreholes should be installed at appropriate locations and depths to:

- provide samples representative of the quality of groundwater upgradient of the site,
- provide samples representative of the quality of groundwater downgradient of the site,
- permit an accurate water level or pressure (piezometric) level of groundwater to be measured and recorded to an elevation expressed as metres above ordnance datum, and
- provide data to show the direction of groundwater flow (minimum of three monitoring boreholes necessary).

For groundwater monitoring at a landfill, the Landfill Directive specifies a minimum of one upgradient and two downgradient boreholes. Table C.1 in Appendix C outlines minimum baseline groundwater monitoring requirements for a non-hazardous landfill.

In reality, a number of site specific factors will determine the actual number and locations of the boreholes required. Such factors may include:

- the area of the landfill,
- heterogeneity of the aquifer(s),
- permeability of the aquifer(s),
- groundwater abstraction,
- groundwater flow velocities,
- anticipated composition of leachate (based on expected wastes types),
- baseline water quality,
- proximity of potential external influences such as contaminated lands,
- proposed containment system,
- licence requirements,
- ease of access to the borehole by sampling personnel; and

- safety issues.

The location for groundwater boreholes should be based on the information derived from the site investigation. Monitoring locations may include:

- existing groundwater discharges and abstractions, e.g. springs, water supply boreholes or wells;
- existing monitoring points, e.g. those installed for other monitoring purposes by adjacent landowners or for site investigations;
- construction of new boreholes. This allows the monitoring points to be located and designed specifically to meet monitoring objectives.

Existing structures should only be used if they are capable of fulfilling the monitoring objectives of the site. Borehole logs and design details are essential to evaluate the usefulness of existing monitoring points. This is because boreholes could be screened at different intervals or screened into a different aquifer to the one that is required to be monitored. The use of trial pits is generally not acceptable for groundwater monitoring.

The groundwater monitoring programme at a landfill site should contain the following information:

- number and location of boreholes – the precise location of the boreholes should be recorded on the logs using a grid reference and marked on a drawing or a map,
- depth of boreholes,
- screen area/level,
- pump tests, yield information etc,
- information on soils,
- borehole construction material,
- nested borehole configurations,
- direction of groundwater flow,
- groundwater recharge and discharge areas, and
- groundwater abstraction points in the vicinity of the landfill.

5.3 Design and Construction of Boreholes

Detailed construction drawings or borehole logs for each monitoring point should be produced. When constructing new boreholes, the method of drilling, lining materials, screen design and sealing method should all be given careful consideration to ensure the monitoring objectives are met. Following installation, each monitoring borehole should be cleaned out and developed to remove silt and other fine materials from the lining, gravel pack and surrounding strata.

Further information on the construction of new boreholes is available from the Geological Survey of Ireland (GSI). Details of all borehole logs including precise location should be submitted to the GSI to contribute to the knowledge pool of the national groundwater database.

Until guidelines are developed in Ireland, subsoils should be logged using standard procedures outlined in the British Standards Institution publication BS 5930 (1999). The GSI have prepared decision-making fieldsheets on the basis of these standards and can supply them on request.

In order to facilitate groundwater sampling and protect boreholes the following is recommended:

- each borehole should have standpipes that are approximately half a metre above the ground, cased in metal, set in concrete, and surrounded by protective poles. These measures will help to avoid accidental burial of boreholes during landslides and also protect against accidental damage from plant and machinery.

- the borehole should be capped to avoid damage or blockage to the tubing and the casing should be padlocked so that there is no access to the borehole other than by authorised personnel.
- the borehole should be at least 50mm in diameter so that a representative sample can be obtained. However, boreholes with diameters wider than 50mm can be very time-consuming to purge and thus can reduce the number of samples that can be taken in a day.
- the borehole should have a marker detailing the location name and type of sample and this should be visible from a distance. It is useful if all groundwater monitoring points are coded a particular colour.

Most groundwater monitoring boreholes will require periodic maintenance. Any boreholes that become damaged should be repaired or replaced as soon as possible. Boreholes and wells that are no longer required need to be made safe, structurally stable, backfilled or sealed (e.g. with bentonite) to prevent groundwater pollution and flow of water between aquifer units and to prevent confusion with active monitoring points.

5.4 Monitoring Frequency and Parameters for Analysis

Baseline data are those that are characteristic of conditions in the absence of any impacts arising from landfill operations. For the determination of baseline water quality, each monitoring location should be monitored at quarterly intervals for a minimum of one year prior to the operation of the site. A groundwater contour plan with flow direction should also be produced to provide baseline information.

The frequency of compliance monitoring during the operational and aftercare phase is site specific and will be governed by the waste licence and should take into consideration the hydrogeology of the site and the landfill design.

Table C.2 in Appendix C lists the parameters to be used in baseline monitoring of groundwater quality. Tables D.1 and D.2 in Appendix D outline guideline minimum reporting values for those parameters required to be analysed. Parameters for baseline monitoring should include specific indicators to ensure early recognition of changes in water quality (Section 5.5 provides further information). Throughout the life of the landfill the baseline monitoring parameters chosen should be re-analysed at intervals not exceeding twelve months.

Monitoring of groundwater levels will be required on a more frequent basis. The Landfill Directive requires level monitoring to be undertaken every six months as a minimum during the operational and aftercare phases of the landfill.

5.5 Trigger Levels

The Landfill Directive states that significant adverse environmental effects should be considered to have occurred in the case of groundwater when an analysis of a groundwater sample shows a significant change in water quality. A trigger level must be determined taking account of the specific hydrogeological formations and groundwater quality in the location of the landfill and must be laid down in the waste licence where possible.

To determine trigger levels, a review of the baseline monitoring results should be undertaken including a statistical summary of all data on certain specific indicators. Trigger levels should be evaluated by control charts with established control rules and levels for each downgradient well.

When setting trigger levels it is important to consider the following:

- the substances for which the trigger levels should be set – this may depend on the type of waste which will be accepted in the landfill and the subsequent type of leachate which will be formed.
- the levels at which they should be set – typical groundwater quality in the area needs to be assessed.
- the monitoring locations for which they should be set - the specific hydrogeological formations in

the location of the landfill should be identified and trigger levels should be set for each of the downgradient monitoring points that are included in the overall groundwater monitoring programme.

The Landfill Directive recommends setting trigger levels for certain parameters such as pH, TOC, phenols, heavy metals and fluoride.

For a typical non-hazardous landfill accepting biodegradable wastes, trigger levels should be set for substances such as ammonia, TOC and chloride as a minimum. Other appropriate substances for determining trigger levels for non-hazardous landfills may include some volatile/semi-volatile organic compounds.

Further guidance on setting environmental quality objectives and standards for groundwater may be found in the Agency's Interim Report *'Towards Setting Guideline Values for the Protection of Groundwater in Ireland'* (2003a).

An assessment monitoring programme should be implemented after the detection of a release of a contaminant to the groundwater or on attaining a trigger level. When a trigger level is reached, verification is necessary by repeating the sampling. If repeat sampling shows that the trigger level has been breached then a contingency plan including possible remedial actions must be prepared and implemented. The assessment programme may require an increase in monitoring frequencies, installation of extra monitoring boreholes and/or additional analyses of the contaminant transport patterns.

A number of computer based contaminant transport models are available. These require data regarding the location and concentration of contaminant sources, the distribution of effective porosity, fluid density variations and natural concentrations of solutes distributed through the groundwater regime. Contaminant transport may be estimated by using the model to compute the direction and rate of fluid movement. Contaminant loading on the groundwater system may then be estimated from solute-transport equations and flow model predictions.

Following the completion of the assessment monitoring programme, the appropriate corrective measures should be implemented to reduce the impact of releases on the environment and to minimise further contaminant releases from the landfill.

5.6 Sampling Guidelines

A variety of devices may be used for both groundwater and leachate sampling. The equipment used ranges from simple bailing devices to sophisticated multilevel samplers. Sampling devices should be chosen based on the parameters that are to be monitored, the compatibility of the rate of borehole purging with borehole yield (for groundwater), the diameter of the groundwater borehole or leachate well and the depth from which the sample must be collected.

Bailers are commonly used sampling devices and theoretically do not cause alteration to the sample as no suction or pressure is applied. They are used to collect discrete samples from specific depths or to collect average samples from the water they pass through. Pumps can be used for both purging of boreholes as well as for sampling. They can be used to obtain samples from specific depths and generally have adjustable flow rates to minimise agitation or aeration of the samples. The advantages and disadvantages of some of the equipment more commonly used in groundwater and leachate sampling are outlined in Table E.1 of Appendix E.

Liquid levels in boreholes or wells can be measured by a variety of devices of which the most commonly used are electric tapes fitted with a liquid sensor.

General guidelines for sampling were previously outlined in Section 4.7.2. In addition, when sampling groundwater, the following guidelines should be followed:

- It is recommended that sampling commences with upgradient boreholes.
- In order to obtain a representative sample of groundwater, stagnant water must be removed from the borehole. A purging trial should be undertaken to observe the behaviour of field determinands (e.g. conductivity, pH, temperature) continuously or at intervals during purging. A sufficient volume (normally at least 3 borehole volumes) should be pumped during the trial to demonstrate genuine stabilisation of the pumped water chemistry. The results of the trial may then be used to determine the standard purge volume for the borehole. Generally, purging of three times the borehole volume is sufficient to allow a representative sample to be taken.
- For a borehole that becomes dewatered before three volumes is purged, then the sample should be taken as soon as sufficient water is in the borehole. If the recharge is slow it may be possible to carry out other monitoring on site and return later to take a sample.
- Purged water should be disposed of away from the borehole to prevent its recirculation.
- Any odours from the borehole should be noted on a fieldsheet.
- Special care should be taken to avoid cross-contamination of samples. Equipment used to sample leachate wells should never be used to sample groundwater boreholes as it can lead to a risk of cross-contamination. New or decontaminated tubing, valves, bailers or water level measurement devices must be used for each groundwater borehole.
- All reusable equipment should be thoroughly cleaned after use using a non-phosphate laboratory detergent and then fully rinsed with distilled water.
- Sometimes there may be dedicated borehole tubing already located in the groundwater borehole and this may be used provided that it is clean. Tubing can be left in the groundwater borehole between sampling. If removed, the lengths of tubing used should be rinsed out with clean tap water or distilled water and labelled with the location and borehole where they were used. Care must be taken to ensure that tubing is not contaminated by contact with soil or other contaminated materials during storage. Before reuse, any tubing should be thoroughly rinsed as above before reinsertion into the borehole.
- Separate samples should be taken for chemical and bacteriological examination.
- Samples for bacteriological examination must be taken using sterile techniques. Contamination may occur from dirty tubing or poor sampling technique. Removal of *in-situ* tubing is not desirable for microbiological sampling unless contamination by the tubing is expected. It is essential that the delivery end of the tubing be thoroughly cleaned using a disinfectant medium and rinsed before commencement of purging or sampling. Samples for bacteriological examination should be transported in a coolbox or similar refrigerated environment to the laboratory preferably within 6 hours of sampling.
- Samples for chemical analysis should be transferred to appropriately labelled sample containers being careful to avoid agitation or turbulence or any air spaces or bubbles that could result in the loss of volatile organic compounds or excessive oxygenation of the samples. For VOC analysis low flow sampling or diffusion samplers may be more suitable.
- Samples for metal analysis should be filtered through a 0.45μm membrane filter and acid preserved. It is recommended that samples for metal analysis be filtered as soon as possible after sampling and preferably within 24 hours to minimise compositional changes. On-site filtration and preservation is recommended for samples where precipitation of metals may occur in transit. However, for most sample types it may be more practical to filter the sample as soon as possible on return to the laboratory.
- Special care and attention is required when sampling groundwater used as drinking water for private dwellings.

Monitoring of groundwater when used as drinking water for private dwellings in the vicinity of a landfill facility.

In this case the following procedure is recommended:

- When sampling from a tap, it is important that all fittings are removed and that the sample comes directly from the tap itself. Mixer style taps should be avoided if possible.
- Check that the water is coming directly from the borehole and not via a storage tank.
- It is important that any water within the system be purged before sampling. This may be done by running the tap before taking a sample (about 2-3 minutes for a tap in regular service and up to 10 minutes for a tap that is out of service).
- When taking a bacteriological sample, the tap should first be purged as above. The tap should then be turned off and sterilised by either gently flaming or wiping with a solution of 1% v/v Sodium Hypochlorite. Anti-bacterial wipes based on quaternary ammonium salts or similar substances may be equally effective, and often more practical, for sterilising surfaces. Attention should be paid to the manufacturer's recommended contact times. Allow the tap to run for a few minutes at moderate flow after sterilising before taking the sample. The bottle should then be filled directly from a low flowing water stream avoiding any contact with the bottle cap.
- It is generally helpful to take samples for chemical analysis before disinfecting the tap to minimise the potential for cross-contamination.

6. Leachate

6.1 Introduction

Leachate may be defined as any liquid percolating through the deposited waste and emitted from or contained within a landfill. This leachate picks up suspended and soluble materials that originate from or are products of the degradation of the waste. If this leachate is allowed to migrate from the site it may pose a severe threat to the surrounding environment and in particular to the groundwater and surface water regimes.

Effective environmental protection requires an understanding of the composition and volumes of leachate being generated and the implementation of control measures. The composition of leachate within a landfill is unique as the characteristics of the leachate will vary depending on the wastes deposited. The main factors that influence the generation of leachate include:

- meteorological conditions at the site,
- waste composition,
- waste density,
- waste age,
- depth of landfill,
- moisture content,
- rate of water movement, and
- lining system (if any).

Further information on leachate management systems is available in the Agency's manual *'Landfill Site Design'* (2000).

The purposes of a leachate monitoring programme are:

- to confirm that the leachate management systems are operating as designed;
- to provide information on the progress of decomposition of the waste; and
- to provide information for the potential revision of groundwater and surface water monitoring parameters.

6.2 Monitoring Locations

The Landfill Directive requires that sampling and measurement of leachate (both volume and composition) must be performed separately at each point at which leachate is discharged from the site. Each cell in a landfill should be treated as a separate unit for the purpose of determining the number and location of leachate monitoring points.

Table C.3 in Appendix C summarises typical leachate monitoring requirements for a non-hazardous landfill. The precise location of these monitoring points will be decided on a site specific basis, but they should be located taking into account the likely flow-paths of the leachate within the cell, so as to provide samples representative of the leachate composition.

On-site processes such as leachate treatment plants or other leachate management schemes should also be monitored, e.g. treated leachate discharged from a site and leachate storage lagoons.

6.3 Monitoring Frequency and Parameters for Analysis

The frequency of leachate monitoring at a landfill site will be site specific and governed by the waste licence. It should be reviewed on a regular basis to reflect changes in:

- quantity and types of waste deposited,
- operational practice,
- size of operational cell, and
- the effectiveness of the leachate drainage and collection system.

The Landfill Directive specifies minimum monitoring frequencies for leachate volume and composition during the operational and aftercare phases of a landfill. Monitoring of leachate levels within the waste body is important to ensure that the leachate head is successfully controlled. The volume of leachate discharged or transported from a landfill should be recorded on an ongoing basis.

A representative sample of leachate from each monitoring location should be taken for analysis. Table C.2 in Appendix C lists the parameters to be analysed for characterisation. Tables D.1 and D.2 in Appendix D outline guideline minimum reporting values for these parameters.

The composition of leachate is variable and depends on a number of factors including:

- age of the landfill,
- composition of the waste,
- the rate of decomposition within the landfill,
- the amount of rainwater infiltration, and
- temperature.

Therefore, the parameters to be analysed should reflect these influences and should provide for the anticipated characteristics of the leachate.

6.4 Toxicity Testing

Occasionally toxicity limits may be set in a waste licence or toxicity testing of a substance may be required, e.g. if treated leachate is discharged to surface water. These toxicity limits are equivalent to emission limit values for chemical and physical parameters. The tests are not intended to replace assessments of the biological impacts of discharges in the natural environment. Test species may range from bacteria and algae through to invertebrates and fish. The use of systems based on luminescence measurement is useful for assessment of toxicity patterns (ISO, 1998).

When setting an emission toxicity limit, it is important to consider the effluent mixing conditions within the receiving waterbody or otherwise toxicity limits may not give adequate protection to aquatic life downstream. Information is therefore needed on the receiving waters (e.g. the minimum flow of a river) and the number of dilutions of the discharge available.

Further information on Aquatic Toxicity Testing is available in the Agency's Wastewater Treatment Manual '*Characterisation of Industrial Wastewaters*' (1998a).

6.5 Sampling Guidelines

As mentioned previously, a variety of devices may be used for both groundwater and leachate sampling and the techniques used for the sampling of leachate wells are similar to that used for groundwater boreholes (Section 5.6 provides further information). General sampling guidelines were previously outlined in Section 4.7.2. In addition, when sampling leachate, the following guidelines should be followed:

- It is preferable to sample from a collection point to where leachate from the landfill is pumped.
- Extreme care should be taken when sampling from leachate lagoons or manholes. Site safety precautions should be observed at all times.
- Leachate and leachate contaminated groundwaters are chemically unstable in comparison with clean groundwaters. Their composition is generally complex and particularly liable to change if allowed to remain in contact with air for any substantial time between collection and analysis.
- In order to obtain a representative sample of leachate from small diameter wells any stagnant water must be removed from the well. A purging trial should be undertaken to observe the behaviour of field determinands (e.g. conductivity, pH, temperature) continuously or at intervals during purging. A sufficient volume (normally at least 3 well volumes) should be pumped during the trial to demonstrate genuine stabilisation of the pumped water chemistry.
- Purged leachate or contaminated groundwater should be disposed of in a manner that will minimise any health risks to monitoring or other personnel, risk of cross-contamination of samples or risk to the environment. Disposal routes can include the removal of the leachate to the leachate collection system or disposal directly onto open areas of waste.
- Sampling without purging may be feasible where trials have shown that there are no significant differences between purged and non-purged samples or where there are no safe options for disposal of purge water.
- In the case of leachate wells in highly compacted or dry waste, recovery to an adequate sample volume for sampling may not occur during a practical timeframe. Such an incident should be recorded as “no sample available” as pumping a nearly dry well will result in high solids content in the sample and inaccurate, elevated concentrations of many chemical parameters.
- Where it is necessary to sample leachate from large diameter chambers, sumps or combined collection systems, it is generally impractical to purge. In such circumstances discrete grab or pumped samples should be obtained by subsurface sampling. In the case of grab samples, efforts should be made to ensure that individual subsamples are taken at differing locations and depths across and within the sump chamber. Field records and laboratory test reports should make reference to the sampling procedure used.
- Any odours from the well should be noted on a fieldsheet.
- Samples for chemical analysis should be transferred to appropriately labelled sample containers being careful to avoid agitation or turbulence or any air spaces or bubbles that could result in the loss of volatile organic compounds or excessive oxygenation of the samples.
- Samples for microbiological examination should be taken using sterile bailers.
- Samples for metal analysis should be filtered through a 0.45μm membrane filter and acid preserved. It is recommended that samples for metal analysis be filtered as soon as possible after sampling and preferably within 24 hours to minimise compositional changes. On-site filtration and preservation is recommended for samples where precipitation of metals may occur in transit. However, for most sample types it may be more practical to filter the sample as soon as possible on return to the laboratory. Note: acidification may cause release of hydrogen sulphide (H_2S) or other harmful gases.
- Equipment used to sample leachate wells should never be used to sample groundwater boreholes as it can lead to a risk of cross-contamination.
- All reusable equipment should be thoroughly cleaned after use using a non-phosphate laboratory detergent and then fully rinsed with distilled water.

7. Landfill Gas

7.1 Introduction

Landfill gas is generated by the decomposition of organic materials in waste deposited at the landfill. Typically, the gas is a mixture of methane (up to 65% by volume) and carbon dioxide (up to 35% by volume). It also contains many minor constituents at low concentrations (typically less than 1% volume contains 120-150 trace constituents).

The rate of gas generation at a landfill site varies throughout the life of a landfill and is dependent on several factors such as waste types, depths, moisture content, degree of compaction, landfill pH, temperature and the length of time since the waste was deposited.

The Landfill Directive requires the following:

- that appropriate measures are taken in order to control the accumulation and migration of landfill gas;
- that landfill gas should be collected from all landfills receiving biodegradable waste and the landfill gas should be treated and used. If the gas collected cannot be used to produce energy, then it should be flared; and
- that the collection, treatment and use of landfill gas should be carried on in a manner which minimises damage to or deterioration of the environment and risk to human health.

Landfill Gas Risks
Landfill gas poses various risks including:

- flammability and explosion risks;
- asphyxiation risks;
- potential health impacts due to many minor constituents present at low concentrations;
- odour impacts from trace constituents, e.g. hydrogen sulphide and mercaptans;
- environmental impacts due to global warming potential of methane and carbon dioxide; and
- vegetation dieback.

It is important therefore that landfill gas is properly monitored and controlled.

Why monitor for landfill gas?
The reasons for monitoring landfill gas may be summarised as follows:

- To ensure the facility is compliant with its waste licence;
- To ensure the facility is not causing environmental pollution;
- To ensure the facility is not posing a risk to human health;
- To compare actual site behaviour with expected/modelled behaviour;
- To assess the effectiveness of any gas control measures installed at the site; and
- To establish a reliable database of information for the landfill throughout its life.

Further details on landfill gas management systems including design details are given in the Agency's Manual *'Landfill Site Design'* (2000).

7.2 Landfill Gas Safety

The flammability, toxicity and asphyxiate characteristics of landfill gas requires personnel involved in the monitoring, operation, construction or any other aspect of a gas management system to be adequately trained. A safe system of work with rehearsed emergency procedures should be developed and undertaken before any monitoring of landfill gas is carried out.

Stringent safety measures should be incorporated into equipment for landfill gas monitoring and all electrical equipment should comply with appropriate relevant standards.

7.3 Landfill Gas Within and Outside the Waste Body

7.3.1 INTRODUCTION

Monitoring should take place both within the waste to identify both the quantity and quality of gas generated and outside of the waste to assess whether gas is escaping in an uncontrolled manner. The methane content of landfill gas is flammable, forming potentially explosive mixtures in certain conditions, resulting in concern about its uncontrolled migration and release.

The Lower Explosive Limit (LEL) and the Upper Explosive Limit (UEL) of methane are approximately 5% v/v and 15% v/v respectively.

Landfill gas can move in any direction within the waste body and may migrate from a site. The potential for gas migration will depend on the gas quality and volume, the site engineering works, geological characteristics of the surrounding strata and on man-made pathways such as sewers, drains, mine shafts or service ducts.

The monitoring programme should commence prior to waste disposal and should continue until the biodegradation process has ceased. It is important in the case of new sites to get naturally occurring background levels of methane and carbon dioxide which may vary depending on local geology. These levels should be established prior to the commencement of landfilling at the site.

7.3.2 MONITORING LOCATIONS

Within the waste body
The Landfill Directive requires that gas monitoring be representative for each section of the landfill. It is recommended that the locations for gas monitoring within the waste body should be at a density of at least one monitoring point per cell in lined landfills and one monitoring point per hectare of filled area in unlined landfills.

Monitoring wells constructed within the waste body are for the purpose of monitoring landfill gas concentrations and fluxes within the waste. These wells should be independent of the gas collection and extraction system and used as dedicated monitoring points for the purpose of ascertaining the state of degradation within the waste body and how it responds to environmental conditions.

The monitoring of collection wells and associated manifolds is undertaken to determine the effectiveness of the gas extraction and collection system and to facilitate the balancing of the extraction and collection system. Collection well monitoring is necessary for the efficient management of an extraction system

Outside the waste body
The monitoring of boreholes outside the waste body is essential to detect any gas migrating from the waste body and to demonstrate the efficient management of gas within the site. Boreholes for monitoring gas outside the waste body may be located both on-site and off-site.

The spacing and location of gas monitoring points outside the deposited wastes should be determined on a site specific basis. A detailed exposure and risk assessment should be undertaken with potential pathways and receptors identified. Some factors which need to be taken into account when selecting monitoring locations include:

- quality and volume of gas being generated;
- geology of the site;
- type of waste;
- containment measures adopted, e.g. landfill lining or capping;
- proximity of buildings and developments to the site; and
- permeability of the waste.

The spacing of the monitoring locations is unlikely to be uniform around the site. It is probable that more monitoring points would be needed near building developments, where there are changes in the site geology and where there is no containment.

It is recommended that monitoring boreholes are located a minimum of 20m from the waste body and should be installed at least to the depth of the maximum depth of waste within the waste body. Where appropriate, groundwater monitoring boreholes may also be used for gas monitoring.

Landfill gas monitoring should also be undertaken in any buildings on the site (e.g. site offices). For some sites this may take the form of a permanent monitoring system.

Pressure monitoring
Atmospheric pressure should be measured regularly in order to aid understanding of gas pressure readings within the waste body. Rapid drops in atmospheric pressure can cause the pressure of landfill gas to rise significantly above that of ambient atmospheric pressure, resulting in possible migration. The monitoring of pressures within the waste body may give an indication of the likelihood of gas migration occurring.

Inversely, a sudden rise in atmospheric pressure after a prolonged low pressure period can lead to an artificial depression of the monitored methane concentration. At some landfills very frequent recordings of barometric pressure trends (e.g. hourly intervals from the nearest meteorological station) may be necessary so that fluctuating methane concentrations can be related to barometric pressure conditions.

7.3.3 MONITORING FREQUENCY AND PARAMETERS FOR ANALYSIS

The frequency of monitoring required is site specific and should be established from the results of the investigations. The frequency will depend on a number of factors, such as:

- the age of the site;
- the type and mix of waste;
- the possible hazard or nuisance from gas escaping from the site;
- the results of previous monitoring;
- the control measures that have been installed;
- the development surrounding the site; and
- the geology of the site and its environs.

Table C.4 in Appendix C summarises typical landfill gas monitoring requirements for a non-hazardous landfill. In the case of a licensed landfill, frequencies and parameters will be governed by the waste licence.

Monitoring should be increased when:

- increases in gas quantity or changes in gas quality are observed during monitoring;
- control systems are altered by landfill operations;
- capping of part, or all, of the site takes place;

- pumping of leachate ceases or leachate levels rise within the wastes; or
- buildings or services are constructed within 250 m of the boundary of the waste.

Monitoring should continue until either:

a) the maximum concentration of methane from the landfill remains less than 1% by volume (20% LEL) and the concentration of carbon dioxide from the landfill remains less than 1.5% by volume measured at all monitoring points within the wastes over a 24 month period taken on at least four separate occasions, including two occasions when atmospheric pressure was falling and was below 1,000 mb; or

b) an examination of the waste using an appropriate sampling method provides a 95% level of confidence that the biodegradation process has ceased.

7.3.4 TRIGGER LEVELS

Unless otherwise determined from baseline monitoring results, the trigger levels for emissions of methane and carbon dioxide in boreholes outside the waste body are shown in Table 7.1. These trigger levels for landfill gas emissions also apply to measurements in any service duct or manhole on, at or immediately adjacent to the landfill.

TABLE 7.1 LANDFILL GAS TRIGGER LEVELS FOR BOREHOLES OUTSIDE OF THE WASTE BODY

Parameter	Trigger concentration
Methane	Greater than or equal to 1% v/v or
Carbon dioxide	Greater than or equal to 1.5% v/v

If either of these trigger levels are attained within buildings then the affected areas should be evacuated and the emergency services notified. Monitoring should be undertaken to identify the point of gas ingress and control measures should be implemented to prevent further ingress.

Methane has explosive and flammability risks and carbon dioxide is an asphyxiant.

7.3.5 MONITORING SURFACE EMISSIONS

The surface methane emissions of landfill gas from a site cap and from other parts of a landfill should also be monitored from time to time. This gives a measure of the methane escaping to atmosphere and checks the integrity of the gas management system and the capping system.

A walkover survey may be undertaken using a portable flame ionisation detector (FID) held as close to the surface of the landfill as possible. More detailed measurements of changes in methane concentrations above a specific small area of the landfill surface may be undertaken using a flux box. These flux boxes are most suitable for use on completed areas of a landfill site. They will produce high flux measurements if used on waste that is not capped or covered by an intermediate layer of soil or other inert material.

It has been established that on a capped landfill with active landfill gas abstraction that a limit value of 1 x 10^{-3} mg/m^2/s of methane surface emissions or better can be achieved (Environment Agency, 2002a). Monitoring of other surface emissions such as hydrogen sulphide or non-methane volatile organic compounds (NMVOCs) should also be undertaken if required.

7.4 Landfill Gas Combustion Plants (Enclosed Flares & Utilisation Plants)

7.4.1 INTRODUCTION

Methane is estimated to be 20 – 30 times more damaging (per molecule) than carbon dioxide to the global climate due to its greenhouse effect. Landfill gas should therefore, where practicable, be collected from all landfills receiving biodegradable waste and converted to energy or flared.

Methane has a high calorific value and hence can be used for power generation and process heating. Typically some 600 – 700m^3 of landfill gas (containing approximately 50% methane) is required to generate 1 MW of electricity. If the gas cannot be utilised for energy, then it should be flared. Combustion disposes of the flammable constituents of landfill gas safely and also controls odour nuisance, health risks and other adverse environmental risks.

Whilst the combustion of landfill gas reduces the risk of uncontrolled landfill gas emissions and explosion, the potential health and environmental impact of emissions from flares and utilisation plants also have to be taken into account. Therefore monitoring of these emissions is necessary.

It should be noted that the guidance in this document only relates to the monitoring of enclosed flares. The use of open flares is generally not allowed as they do not represent BAT and cannot be tested accurately or safely.

7.4.2 MONITORING LOCATIONS

When identifying a suitable location for the siting of a flare and/or utilisation plant at a landfill, it is necessary to have an understanding of the environmental impact that the flare and/or utilisation plant will have on the surroundings. Screen modelling should be carried out on expected emissions and these should be compared with relevant air quality standards. Where a potential problem exists, full modelling should be undertaken to help in selecting a location for the flare or utilisation plant.

Other factors which must be considered when siting a combustion plant include explosion and fire risks, asphyxia, human health, odour nuisance, noise, heat, visual impact, ground type and operational requirements.

It is essential to monitor routinely both the inputs and outputs of the flare and/or utilisation plant. All emissions from landfill gas combustion processes will be variable in terms of flow-rate and composition due to the nature of the gas source. Variations may occur due to the aging of the waste, inconsistencies within the waste composition itself as well as changing meteorological conditions.

Health and safety is of great importance when sampling emissions from combustion plants. Easily accessible, safe and functional monitoring/sampling points should be fitted on all combustion plants. The dimension of the sampling platform and the positioning of the sampling ports should be in accordance with guidelines issued for stack testing by the Source Testing Association (STA). Guidelines on hazards and risks relating to source testing are also provided by the STA (2001).

7.4.3 MONITORING FREQUENCY AND PARAMETERS FOR ANALYSIS

Table C.5 in Appendix C contains a typical monitoring regime for landfill gas flares and utilisation plants. The exact parameters and emission limit values will be set in the waste licence and may be dependent on the specification of the equipment.

The species and composition of emissions from the combustion of landfill gas is determined by a number of factors. These include:

- compounds present in the fuel gas;
- type and design of the equipment used;
- operation of the equipment; and
- combustion conditions, temperatures, excess air, etc.

Flares and utilisation plants (such as engines) differ in the mechanism of combustion. The reaction in an engine involves a short-lived explosive reaction occurring under pressure, whereas, the combustion process in a flare occurs over a comparatively long period.

Carbon monoxide is a product of incomplete combustion of carbon and is a good indication of the combustion efficiency of the process. All flares should be fitted with continuous combustion temperature and carbon monoxide monitors and utilisation plants fitted with continuous carbon monoxide monitors connected to a datalogger with visible display panel at ground level.

In the case of enclosed flares, a minimum combustion temperature of 1000°C and a retention time of 0.3 seconds is recommended as an indicative standard that is likely to achieve required emission standards.

Incomplete combustion of halogenated organic compounds may occur due to a combination of low turbulence, temperature and oxygen content. These conditions may be found at the periphery of an open flare or in the cooler zones around the walls of enclosed flares. This is one of the key reasons why all flares are required to be enclosed and to operate at a minimum combustion temperature and retention time.

7.4.4 DESIGN CERTIFICATION OF FLARES

Design certification of enclosed flares is an approach that has been adopted in Germany where manufacturers design, build and test flares at the factory to meet the TA Luft emissions standards. The advantages of this system is that it is safe, easily automated, provides accurate data, is relatively inexpensive and allows for random spot verification. The Agency may consider the design certification approach as an alternative to emissions testing.

7.5 Sampling Guidelines

7.5.1 INTRODUCTION

There is a variety of equipment available for the detection and quantification of landfill gas. The choice of instrument will depend on the circumstances of the monitoring as shown in Table E.2 in Appendix E. The instrument to be used may be fixed where continuous monitoring is required (e.g. in a building or combustion plant) or portable where periodic monitoring is required (e.g. boreholes outside the waste).

The most important part of the instrument will be the sensor. Table E.3 in Appendix E presents the characteristics of the most common types of sensors used. In the selection of equipment, particular attention should be given to the safety features of the instrument and to its intended use.

Attention needs to be paid to the quality of monitoring being carried out and standards can vary greatly between consultants. The Source Testing Association (STA) provides information on best practice for stack sampling. Further information may be found on www.S-T-A.org. Interpretation of the results obtained from monitoring equipment requires a full understanding of the method of detection employed and of the environment which is being sampled. The wide variation in gas mixtures which can occur in and around landfills can lead to misinterpretation of readings.

7.5.2 LANDFILL GAS WITHIN AND OUTSIDE THE WASTE BODY

When monitoring landfill gas from boreholes or wells, the following guidelines should be followed:

- Health and safety precautions should be adhered to at all times. There should be no smoking while sampling for landfill gas. Direct inhalation of the landfill gas and entry into confined spaces should be avoided. Chemical resistant gloves should be worn to avoid contact with landfill gas condensate.
- All equipment should be operated, calibrated and serviced according to the manufacturers instructions.
- All boreholes or wells should be fitted with sealable gas sampling valves to isolate the borehole/well from the atmosphere, to prevent air ingress and to enable equilibrium with the area to be monitored.

In order to prevent atmospheric dilution of the sample the gas sampling valve should be closed at all times other than when the gas sampling equipment is attached to the monitoring structure. The borehole or well should be resealed after sampling. Monitoring boreholes should also have a security cover to ensure that the valves cannot be tampered with.

- Most portable gas monitoring instruments are susceptible to interference by water vapour or water entering the equipment. To check the borehole for flooding, it may be necessary to remove the seal and therefore open the borehole to the atmosphere. Care should be taken to ensure that liquid is not sucked into the gas sampling equipment during monitoring.
- Where groundwater boreholes are also used to monitor off-site landfill gas migration, then screw on caps and a control valve need to be fitted. Gas monitoring should be undertaken before groundwater monitoring. It should be noted that the specific construction of a groundwater monitoring borehole could sometimes render it ineffective for gas monitoring and the construction details should be assessed to determine if it is also suitable for gas monitoring.
- The atmospheric pressure should be measured during each sampling round and the details noted on the fieldsheet, e.g. 1001-1003 millibar (rising). The monitoring of gas pressure in wells within the waste body may also be noted and this may give an indication of the likelihood of gas migration occurring.
- Any unusual observations should be noted while monitoring at the facility such as any vegetation die-back, any hissing sounds or bubbling occurring, description of any odours occurring and if the ground is warm.
- Leachate monitoring or abstraction wells are inappropriate for gas monitoring purposes within the waste body. If such monitoring points are used, then the results cannot be regarded as comparable with, or a substitute for specifically designed monitoring points within the waste body.
- Monitoring of bulk gases and flow rates of the gas collection wells and manifolds should be undertaken in order to achieve sufficient control over the gas extraction and treatment systems. These wells are not appropriate for the monitoring of landfill gas concentrations and fluxes within the waste body.

An example of a landfill gas monitoring form is given in Appendix B.1

Further guidance on routine monitoring of landfill gas may be found in the *'The Monitoring of Landfill Gas'*, IWM (1998).

7.5.3 FLARES AND UTILISATION PLANTS

There is a wide range of instrumentation available for monitoring landfill gas flares and utilisation plants. Monitoring will usually take the form of either *in-situ* techniques or extractive monitoring. *In-situ* or in-stack techniques are where the sensing device is in the stack and the results are conveyed as an electronic signal. Extractive monitoring involves the collection of a sample of combusted gas and transport away to an analyser.

Stack testing of flares generally cannot meet the same standardised monitoring procedures required of industrial stack testing. By using certified and experienced specialists, monitoring standards will be adhered to as closely as possible and the interpretation of sampling results will be based on a thorough understanding of the variabilities involved.

When monitoring emissions from landfill gas flares/utilisation plants the following points should be noted:

- A full health and safety risk assessment should be undertaken before commencement of monitoring. This should identify any hazards that may be encountered and put in place potential control measures.
- Stack testing personnel or consultants should be certified under a professional competency scheme specific to landfill gas flares, where available, or alternatively should provide company certification of flare emission testing experience gained.
- Monitoring conditions are severe with high temperatures and corrosive gases present. Flares may have flames exiting at the top and as a result are extremely dangerous to personnel working near the

top of the flare. Adequate personal protective equipment should be worn at all times.

- An adequate sampling platform may need to be constructed so that sampling can be undertaken safely. Ladders and small mobile platforms such as cherry-pickers should not be used to access monitoring points.
- Easily accessible, safe and functional monitoring/sampling points should be provided at all plants. Provision for these should where possible be provided at the design and construction stage. These sampling ports allow much safer and more frequent on-site testing of the flare or utilisation plant.
- Sampling of emissions should take place after combustion is completed.
- Special high temperature resistant (>1,100°C) monitoring equipment is required and may have to be manufactured specifically for flare emission monitoring.
- Representative sampling points need to be determined in the ducts through which the landfill gas flows. Multi-point sampling may be necessary to obtain a more representative sample.
- *In-situ* probes should be fitted where continuous monitoring is required (e.g. carbon monoxide emission monitoring).
- Recognised standard methods (e.g. ISO, CEN) should be used.
- All relevant on-site sampling and laboratory analytical methods should be accredited.
- There may be variation in gas composition across the stack due to poor mixing and variable flow rates. Combustion is an unsteady process. Thus, 'single-shot' measurements may be misleading. Time averaged readings are essential. In practice measurement intervals of less than 30 minutes are of little value.
- Some flare designs operate at extremely high excess air values. This needs to be accounted for when measuring and correcting data.

Table E.4 in Appendix E outlines recommended monitoring techniques for flares and utilisation plants. Monitoring protocols for flares and utilisation plants have also recently been developed by the UK Environment Agency (2002b, 2002c).

8. Odour

8.1 Introduction

Odour may be defined as that characteristic property of a substance which makes it *perceptible* to the sense of smell. The perception of odour as a nuisance will depend on a number of factors, such as the concentration of that substance in the atmosphere, the frequency of releases, the form of the release (intermittent or continuous) and the sensitivity of the individuals impacted. For each substance there is a limiting concentration in air below which its odour is not perceptible. This is generally referred to the odour threshold of that substance.

Over one hundred trace constituents have been identified in landfill gas and similarly for leachate. Unpleasant odours are usually associated with the sulphur-containing compounds, primarily mercaptans and sulphides. These compounds also have the lowest odour threshold concentrations making them the most likely source of unpleasant odours detected in landfill gas. Organic acids and aldehydes may also be significant contributors to odours at landfills.

Odours from landfills may be caused by:

- arriving and queuing refuse vehicles;
- depositing odorous wastes (e.g. decomposing household waste or sewage sludge);
- working face;
- landfill gas emissions from temporary covered areas;
- landfill gas emissions from cracks and vents in capped cells;
- excavating old waste;
- landfill gas vented without combustion;
- gas well construction;
- leaking gas wells and collection piping;
- malfunctioning flares and utilisation plants;
- leachate collection and treatment systems (e.g. uncovered lagoons or wells);
- associated landfill activities (e.g. composting); and
- odour masking agents.

Landfill gas generated at landfills accepting municipal waste has a characteristic odour caused by trace chemical constituents. Gas is produced shortly after waste is landfilled. If there is a delay in capping an area and constructing a suitable landfill gas control system, then gas emissions will occur.

Generally, good landfill management practice such as daily cover, minimising the area of the active tipping area, covering odorous wastes immediately and the provision of proper landfill gas and leachate control systems are the most effective ways of reducing odours at source, thus minimising the need to undertake such monitoring.

Further information on landfill management may be found in the Agency's manual *'Landfill Operational Practices'* (1997).

8.2 Odour Assessment

Proposed Landfill
An odour assessment study for a proposed landfill should take into consideration potential sources of odour, what actions can be taken to minimise or eliminate odour, the proximity, direction and sensitivity of likely receptors, factors such as prevailing winds and weather conditions and any other pathways which may exist. Although odours are generally localised, they may under certain meteorological conditions travel long distances.

Existing Landfills
For existing landfills, an odour assessment study may include the following:

- olfactometric or chemical measurements of all significant odour releases and appropriate air dispersion modelling of measurements;
- on-site and off-site odour monitoring;
- complaints analysis, e.g. location of complainants, time and weather conditions to which complaints relate;
- public questionnaire on odour complaints; and
- details on the efficiency of any control and treatment systems for leachate and landfill gas.

Many atmospheric conditions, such as high pressure, calm wind conditions, fog or temperature inversion, can exacerbate, prolong or increase the range of any odour present as a result of operational conditions on any site.

8.3 Frequency of Monitoring

A waste licence for a landfill may require that activities be carried out in a manner such that odours do not result in significant impairment of, or significant interference with amenities or the environment beyond the facility boundary. The licensee may also be required to inspect the facility and its immediate surrounds for nuisances caused by odour and to maintain a record of those inspections.

The level of monitoring required around a facility will depend on the risk from that site. For example, sites accepting a high proportion of putrescible waste would need more odour monitoring than sites accepting inert waste. The need to monitor odours may also arise in response to complaints.

Table 8.1 links some commonly used descriptors of odours around landfill facilities with the most likely chemical cause.

TABLE 8.1 ODOUR DESCRIPTORS AND POSSIBLE CHEMICAL CAUSE

Odour Descriptor	Chemical cause
Rotten eggs	Hydrogen sulphide
Rotten cabbages	Methyl mercaptan – landfill gas
Gassy, pungent	Sulphur compounds – landfill gas
Faecal	Indole, scatole - leachate
Sharp, acidic, e.g. vinegar, sour milk, cheesy, sweaty feet.	Volatile organic acids - landfill gas/leachate

(Source: *'Odour Guidance –Internal Guidance for the Regulation of Odour at Waste Management Facilities, Version 3.0'*, Environment Agency, 2002d.)

8.4 Analysis Techniques

Techniques that are generally used for monitoring odours and their impacts include:

- **Field observations:** This may involve monitoring by landfill staff and/or residents. Odours can be monitored throughout the day and observations can be made of specific activities such as any odorous materials arriving, the working face, gas wells, leachate collection and treatment systems. Observations can also be made at predetermined locations such as at the facility boundary and at sensitive receptors. Any observations should be recorded along with date, time, prevailing winds, temperature, etc. All this information can help to pinpoint likely causes of odour complaints.

  It should be recognised that there is the possibility that staff working at an odorous site could suffer from odour fatigue, i.e. the inability to detect relevant odours due to constant exposure to them. Monitoring should be undertaken by staff prior to them arriving onto the site.

- **Olfactory methods**: This technique is best used for point source sampling of potentially odorous sources such as gas vents or leachate treatment plants.

  Olfactory methods involve the assessment of odour by a panel of selected persons under controlled conditions. Odour samples must be sampled and analysed in accordance with the standard EN13725 (CEN, 2003) '*Odour concentration measurement by dynamic olfactometry*'. This standard sets down rigorous procedures for determining the odour strength of a gaseous sample. It covers field sampling and laboratory analysis of air samples. Odour strength is measured in European Odour Units per cubic metre (ou_E/m^3). An odour that is just detectable by 50% of selected panel members is described as having an odour concentration of 1 ou_E/m^3. It must be noted that the relation between perceived intensity and odour concentration is not linear but logarithmic. Use of this standard means that it is now possible to quantify the odour strength of releases from landfill sites and allows the perception of odour as a nuisance to be assessed.

  In view of the varying background odour concentrations in ambient air, it is difficult if not impossible to reliably interpret the results of ambient olfactometric monitoring results. Ambient olfactometric measurements should not be featured routinely in odour assessment other than when verifying the extent of an identified nuisance. It is recommended that the odour assessment should be based on measurements *at source* with modelling to predict off-site odour impact.

- **Chemical analysis**: If odour levels in landfill gas can be accounted for by the chemicals in the gas, sampling and analysis of these chemicals can be used to determine odour levels in addition to direct olfactometric measurements. An attempt can be made to actually measure a multitude of odourants in the mixture, using advanced analytical methods such as GC-MS or 'electronic nose' devices. The results obtained can be compared with, where available, World Health Organisation (WHO) guideline values, published odour thresholds and Occupational Exposure Limits (OELs) to allow an assessment of the odour problem at the site. Substances which may be analysed include mercaptans, organic acids and hydrogen sulphide.

  The sensitivity of the analytical methods is rarely as great as that of the human nose (e.g. the adopted odour threshold of hydrogen sulphide is as low as 0.1 $\mu g/m^3$) and the capability to predict or model the actual odour perception in humans on the basis of measured parameters is poor.

  Emissions from surfaces may also be determined using a flux box. Landfill surfaces are by nature heterogenous with surface cracks and variations in cover material thickness producing wide variations in the emissions of landfill gases. Section 7.3.5 provides further information.

- **Dispersion Modelling**: Where the odour emission rate from a source is known by measurement or can be estimated, the odour concentration in the vicinity can be predicted by dispersion modelling. The model attempts to describe the effects of atmospheric turbulence on the emission(s) as they undergo dilution and dispersion in the surrounding environment. The effects of buildings, terrain and coastlines can be taken into account in some dispersion models. This allows the effects of specific features such as landfill phases, bunds, walls, etc. on odour dispersion to be modelled.

  Air dispersion modelling is also a useful tool that can be used both as a development aid for site location and design (e.g. cell/phasing plan) and for determining the optimum location of a specific site feature, e.g.

gas flare, gas engine, leachate storage lagoon and composting area.

The output from the modelling process can be compared with an odour exposure criterion (in odour units) or a guideline value for avoiding annoyance (in ppb or $\mu g/m^3$). For the purpose of predicting odour impact, models and input data with the following characteristics are preferred:

- gaussian plume and new generation models, e.g. ISCST3, AERMOD and ADMS.
- to represent conditions for an ‘average year’, hourly meteorological data for at least 3 years should be used.
- one-hour average concentrations should be calculated for all hours in the meteorological data-set.
- exposure to be expressed as the concentration corresponding with the 98th percentile of the distribution of hourly values.
- to incorporate critical receptors as discrete receptors.
- the ability to account for the effects of buildings and topography on the plumes from point sources.

Further information may be found in the Agency’s R & D Report Series No. 14 *‘Odour Impacts and Odour Emission Control Measures for Intensive Agriculture’* (2001) and in the *‘IPPC Technical Guidance Note H4: Draft Horizontal Guidance for Odour: Part 1- Regulation and Permitting and Part 2 – Assessment and Control’* (Environment Agency, 2002e).

9. Noise

9.1 Introduction

Noise may be defined as unwanted sound. The generation of noise at a landfill is an inevitable consequence of the activities being carried out on site. However, excessive noise may become a problem if potential noise sources are not properly monitored and controlled. Noise impacts on the environment will be influenced by a number of site specific factors relating to the site operations and the location of the landfill. The primary sources of noise at a landfill include:

- mobile plant used in the construction of the facility prior to waste acceptance;
- mobile plant used in the construction and restoration of cells;
- mobile plant used in day to day operations (e.g. compactors);
- throughput of vehicles such as refuse collection vehicles and other heavy goods vehicles (e.g. loading/unloading waste from vehicles);
- fixed plant, such as gas flares, wheel cleaners, generators, leachate treatment equipment; and
- audible bird-scaring equipment.

9.2 Monitoring Locations

Proposed Landfill

Where a landfill is proposed for a greenfield site, a baseline noise survey should be conducted initially. This will provide useful information on existing noise levels in the vicinity of the proposed site before it is developed. Noise levels prior to the development of the proposed facility may vary considerably. For instance, sites adjacent to primary roads and built up areas will tend to have higher noise levels than sites in rural locations.

A noise impact assessment should be undertaken by the developer in order to predict the likely impacts of the proposed development on the existing noise environment. Depending on the predicted impact, appropriate mitigation measures can then be incorporated into the design and included as part of the application for a waste licence.

The applicant should refer to BS 4142:1997 *'Rating industrial noise affecting mixed residential and industrial areas'* and BS 5228: 1997 Part 1 - *'Noise and Vibration Control on Construction and Open Sites'* when assessing the potential noise impacts of a new landfill development.

Selection of Monitoring Locations

The factors to take into consideration when selecting monitoring locations for assessing noise levels are:

- proximity of the landfill to noise sensitive locations;
- existing background noise levels;
- the topography of the surrounding area; and
- the prevailing wind direction.

Noise Sensitive Location

A noise sensitive location may be defined as any dwelling house, hotel or hostel, health building, educational establishment, places of worship or entertainment, or any other facility or area of high amenity which for its proper enjoyment requires the absence of noise at nuisance levels.

Activities or types of land use which could be specifically sensitive to noise pollution should be identified and noise levels at these locations measured. This provides a baseline for these locations prior to the development of the facility against which future monitoring measurements can be compared when, and if, the facility is operational. Measurements should also be made at the boundary of the proposed facility.

9.3 Frequency of Monitoring and Parameters for Analysis

During the baseline noise survey, monitoring should be undertaken during the day, at night and at weekends at the various monitoring locations. The frequency of noise monitoring for a licensed landfill will be governed by the waste licence.

Noise is usually measured on the decibel (dB) scale which is a logarithmic scale of sound intensity. The most common scale used for the measurement of environmental noise is the dB(A) scale. This scale incorporates a frequency weighting (A-weighting) which differentiates between sound of different frequency (pitch) in a similar way to the human ear. Measurements in dB(A) broadly agree with peoples assessment of loudness. A 10 dB increase in noise level will produce a perception of about a doubling of the loudness. Thus a noise measured at 50 dB(A) will sound twice as loud as one at 40 dB(A).

Some common descriptors of noise are:

- L_{AeqT} - this is the equivalent continuous steady sound level in dB(A) containing the same acoustic energy as the actual fluctuating sound level over the given period T. T may be as short as 1 second when used to describe a single event, or as long as 24 hours when used to describe the noise climate at a specified location. L_{AeqT} can be measured directly with an integrating sound level meter. It is referred to as the ambient noise which is the whole noise climate including the site specific noise under consideration
- $L_{A10\ T}$ - the dB(A) level exceeded for 10% of the measurement period. Used to give an indication of the higher noise levels (or peak levels) measured.
- $L_{A90\ T}$ - the dB(A) level exceeded for 90% of the measurement time. This is generally used to estimate background levels.
- Frequency Analysis (1/3 Octave band analysis) – this is the frequency analysis of sound such that the frequency spectrum is subdivided into bands of one third of an octave each. This technique can objectively assess the presence of prominent tonal components.
- Narrow band analysis – is used to identify tonal components in recorded sound where 1/3 octave band frequency cannot. The 1/3 octave band analysis may fail to detect a tone because the energy of the tone may not be sufficient (i.e. not loud enough against ambient noise) or the frequency of the tone may lie on the band edge between two 1/3 octave bands.
- $L_{Ar\ T}$ - the equivalent continuous A-weighted sound pressure level measured over a specified time interval period and adjusted for tonal or impulsive character.
- Impulsive noise - this is noise of a short duration (typically less than one second), the sound pressure level of which is significantly higher than the background (e.g. reversing alarms).
- Tonal noise – this is noise which contains a clearly audible tone, i.e. a distinguishable, discrete or continuous note such as a whine, hiss, screech or hum. Examples of tonal noise would be noise from flares, pumps or some fans.

Due to its intermittent nature impulsive noise may pose a particular nuisance at noise sensitive locations and operators should ensure that all noise surveys conducted adequately reflect the characteristics of the noise generated. Some factors to be considered in assessing the impact of impulsive noise include the peak level and repetition of the event.

Landfill gas flares emit noise of distinctive tonal characteristics at one or two 1/3 octave band frequencies (commonly at 25Hz and 800Hz) and should be positioned in order to prevent noise disturbance, particularly at night-time.

It is always beneficial to record statistical parameters (e.g. L_{A90}, L_{A10}, L_{A1}) in different types of noise climate. If such parameters are recorded then they should be reported and interpreted in the report. Where noise monitoring at a landfill is complicated by the proximity of the site and/or the monitoring points to major roadways, it may be useful to measure over very short time intervals when traffic is not present.

The methods used to measure noise should be described with reference to the equipment used, calibration procedures, duration of monitoring and time of monitoring. It is recommended that monitoring personnel obtain certification from a suitably accredited body.

All monitoring of noise should be in accordance with ISO 1996: *'Acoustics – Description and measurement of Environmental noise, Parts 1, 2 and 3'* or another method approved by the Agency.

9.4 Emission Limits

Noise emission limits may apply to individual sources of noise on-site, at the site boundary of the landfill, or at the nearest noise sensitive location(s) that requires protection from disturbance. Higher limit values may be set at the boundary than at noise sensitive locations to reflect the closer relative proximity to the source of noise.

Setting a noise emission limit at a particular source of noise has the advantage of providing a control on key noisy equipment at the facility.

A boundary limit has the advantage of allowing guaranteed access to the monitoring location, observation of site activities and easier exclusion of extraneous noise. However it has the disadvantage of requiring calculation and assumptions with regard to noise reduction through distance and barriers. A limit at a sensitive location has the advantages of direct measurements without calculations but has the disadvantages of uncertain access, the possibility of poor observation of site activity and difficulty of exclusion of extraneous noise or the possibility that the site cannot in fact be measured above the residual noise.

When limits are being established for noise emissions from landfills, regard will be had to factors such as location of the activity (rural/urban, residential/industrial), ambient noise levels (L_{Aeq}), background noise levels (L_{A90}), proximity to noise sensitive locations as well as other factors. Sensitivity to noise is usually greater at night-time than it is during the day, by about 10 dB(A).

General guidelines are that noise emissions monitored at noise sensitive locations should not: - contain any tonal component or impulsive component; and - should not exceed the L_{AeqT} value of 55 dB(A) by daytime or the L_{AeqT} value of 45 dB(A) by night.

9.5 Noise Monitoring Equipment

Environmental noise is generally measured on a Sound Level Meter. These instruments may perform a variety of functions and are designed to be used either as portable devices or as permanent outdoor units. A number of different types of noise measurement equipment are commercially available with various levels of sophistication. The range includes instruments that are capable of measuring basic time varying sound pressure level and those that are capable of calculating statistical noise indices over time. Integrating or integrating averaging sound level meters will measure the 'A'-weighted equivalent sound level (L_{Aeq}). Statistical sound level meters will calculate the statistical noise measurement parameters such as L_{A90}, L_{A10} as well as L_{Aeq}.

Many instruments also contain integral frequency filters which are used in 1/3 octave frequency analysis.

In some circumstances, tape recorders provide a useful means of recording noise or a noise event for later analysis, which is useful when the event is rare, short lived, or when it is expensive to repeat a certain operation for measurement purposes. Digital audio tape (DAT) recorders have now replaced traditional tape recorders.

The sound level meter should be calibrated in the field with its specific acoustic calibrator before and after each series of measurements. All the calibration levels should be recorded. If they vary significantly before and after the monitoring the results may have to be disregarded or treated with caution. In addition to the field calibration, an accredited laboratory should calibrate microphones and calibrators periodically in accordance with the manufacturers instructions.

Further information on noise may be found in the Agency's Guidance Document *'Environmental Noise Survey'* (2003b).

Revision of the Agency's *'Guidance Note for Noise in Relation to Scheduled Activities'* (1995) is currently being revised to encompass IPPC and waste disposal and recovery activities as set out in the Protection of the Environment Act, 2003.

10. Other Aspects

10.1 Meteorological Data

The measurement of the meteorological conditions at a landfill site is an integral part of the overall monitoring programme. Precipitation, temperature, evaporation, atmospheric pressure and humidity are important influences in leachate and landfill gas generation. Water balance calculations are often used to design the optimum cell sizes for a landfill site with the intention of minimising leachate build up within the waste body. Such calculations cannot effectively be undertaken without valid, representative data on the actual meteorological conditions experienced at the site.

Wind speed and direction can be important factors in causing litter or odour nuisance.

The meteorological data can be collected from a number of sources:

- an *in situ* weather station at the landfill site;
- a nearby meteorological station; or
- a combination of both.

Table C.6 in Appendix C outlines typical meteorological monitoring requirements for a landfill.

10.2 Dust/Particulate Matter

10.2.1 INTRODUCTION

The generation of airborne dust at landfill sites is primarily related to construction activities at the site and to the transportation and deposition of waste. The movement of dust is determined by a number of parameters including prevailing wind direction, wind speed, vehicle movement and type of waste deposited.

Dust emissions can present a soiling or visibility nuisance or may pose a hazard to human health depending on the particle size and chemical composition of the dust.

During the design stage it is important to identify sensitive receptors in the event of dust generation. Any existing dust sources such as nearby industries or quarries should be identified as well as areas of the proposed landfill such as site roads and activities such as the acceptance of particular waste types that may give rise to dust generation.

For a licensed landfill, dust monitoring requirements will be set by the waste licence. Daily or weekly site inspections are generally required as a minimum. A more comprehensive monitoring programme may be required to demonstrate the effectiveness of control systems or in response to complaints by the public.

Some commonly used parameters for monitoring dust emissions include dust deposition and PM_{10}.

10.2.2 DUST DEPOSITION

The term dust deposition refers to the coarse fraction of particulates that fall out due to gravity and that causes dust annoyance. In general, particulates with diameters >50 µm tend to be deposited quickly.

The standard method used for monitoring dust deposition is VDI 2119 *'Measurement of Dustfall, Determination of Dustfall using Bergerhoff Instrument (Standard Method)'*, German Engineering Institute.

A waste licence typically contains a dust deposition emission limit value of 350 $mg/m^2/day$ when the Bergerhoff method is used.

Using the above method, samples are collected in a collecting bottle mounted on a 2m pole and protected by a bird guard. Analysis employs evaporation to dryness which produces a result for Total Deposited Dust (both dissolved and undissolved).

The monitoring period should be for 30 $\pm$ 2 days unless biological growth is evident in which case shorter or more frequent analysis may be desirable. Algal growth may be hindered by sterilising the sampling container (e.g. with dilute sodium hypochlorite) or by using a blacked-out sample container to minimise light ingress and thus minimise algal growth. Any modifications to eliminate interference due to algal growth in the gauge should be reported with the results. A typical monitoring regime may require a minimum of three monitoring periods per year, with two of the sampling periods occurring between May and September. Monitoring may be required at the facility boundary, near sensitive receptors and potential sources.

Ideally the gauges should be positioned at a minimum of four locations surrounding the site of interest. It is preferable to monitor upwind and downwind of the prevailing wind. The gauges should be positioned away from interfering objects such as trees to minimise the risk of interference from birds, falling leaves, etc.

Directional dust deposition gauges can be used alongside the Bergerhoff gauge if the source of the dust is in dispute. A relevant wind rose for each sampling period also provides additional information on wind direction.

10.2.3 PM_{10}

PM_{10} may be defined as particles with a diameter of less than 10 µm which can be inhaled beyond the larynx. These fine particles may present a health hazard. The requirement to monitor PM_{10} will be site specific. The frequency of monitoring will be dependent on the size of the site, the wastes accepted at the site and any history of dust problems at the site. Monitoring may be required at the facility boundary, upwind and downwind of potential sources and near sensitive receptors.

The standard method for the measurement of PM_{10} is EN12341 (CEN, 1998) *'Determination of the PM_{10} fraction of suspended particulate matter. Reference Method and field test procedure to demonstrate reference equivalence to measurement methods'*.

A typical trigger level in a waste licence is PM_{10} > 50 µg/m^3 for a daily sample measured at any location on the boundary of the facility. This trigger level is a 24-hour average and therefore the monitoring interval must be over a 24-hour period.

PM_{10} sampling equipment generally consists of an automatic pump sampler which draws air in through a fine filter. The sampler is set up at each monitoring point for a 24-hour period and should be located away from road traffic or other non-site specific PM_{10} sources. The internal filters collect the fine particulates contained in the ambient air. After sampling, the filters are gravimetrically analysed in a laboratory.

10.3 Topography & Stability

10.3.1 INTRODUCTION

Monitoring of topography provides data on the landfill body and is a specific requirement of the Landfill Directive. Monitoring of landfill settlement and investigating the structure and composition of the landfill body is required.

Stability monitoring ensures that the emplacement of waste takes place in such a way as to ensure stability of the mass of waste and associated structures particularly in respect of avoidance of slippages.

10.3.2 TOPOGRAHICAL SURVEYS

The information gained through topographical monitoring can provide the following:

- a definitive drawing which indicates the extent of landfill activities at a given date,

- a record of construction activities at the site and the location of key elements of environmental control infrastructure,
- information to calculate the void space remaining in a landfill, and
- information to determine whether the desirable level of compaction is being achieved.

The following points should be borne in mind when undertaking topographical surveys:

- The survey drawing should be based on one or more temporary benchmarks at the facility. These in turn should be related to local permanent Ordnance Survey benchmarks. Temporary benchmarks should be selected on the criteria that they are unlikely to ever be affected by site development works, waste settlement, that they are accessible and that they will be able to provide effective reference points from which subsequent surveys should be carried out.
- The drawing should be of a consistent scale to any final contour/restoration drawing referred to in the waste licence.
- The drawing should be consistent in its methods of presentation to earlier drawings (captioning, methods of portraying site contours, etc.).
- The drawing should have a unique identification number, be dated, captioned and any revision clearly identified.

Settlement

Settlement within landfills is due primarily to compaction and volume changes during the waste decomposition process and a reduction in void spaces due to the placement of the waste. The amount of settlement is difficult to predict and will depend on a number of site specific factors such as moisture content, waste composition and waste density.

Settlement values of up to 25% can be expected for municipal waste landfills with most settlement occurring over the first five years. The settlement process may cause damage to the cap, any components of the leachate collection system constructed within the waste body and gas collection and drainage systems.

Regular monitoring to observe settling behaviour should be carried out throughout the life of a landfill and if necessary, corrective measures should be put in place. The assessment of settlement should be undertaken by an appropriately qualified person (e.g. Chartered Civil Engineer). It should be carried out at intervals not exceeding twelve months.

10.3.3 STABILITY

The monitoring of stability is important in assessing the structural integrity of a landfill. Slope failure may pose a potential hazard to the environment and to human health and therefore the slopes of landfilled waste should be monitored at regular intervals to ensure they remain within acceptable limits. Landfill stability should be assessed annually by an appropriately qualified person (e.g. Chartered Civil Engineer).

Slope stability should be analysed using conventional limit state analysis. These include Fellenius method and Bishops method. Computer programs (e.g. Slope) are usually used to analyse the data.

Further information on stability and settlement is available in the Agency's manual *'Landfill Site Design'* (2000).

10.4 Ecology

It is important that the operation of a landfill site does not have a significant adverse impact on ecosystems. A baseline assessment of the ecology surrounding the site and the identification of any significant species or habitats should be undertaken as part of the waste licence application process. Any designated areas such as Special Protection Areas (SPAs) or Special Areas of Conservation (SACs) should be identified. The advice of the appropriate authority should be sought. The implications that the development of the landfill will have on the biological diversity and the ecology of the area should be addressed.

Ecological monitoring of a particular species or habitat may also be required as part of the waste licence. An appropriately qualified professional ecologist should be employed to undertake any studies and standard survey techniques should be employed where possible.

Further information is available in the Agency's Manual – *'Investigations for Landfills'* (1995). A good overview of Ireland's biodiversity is provided in *'Biodiversity in Ireland – A Review of Habitats and Species'* (Lucey & Doris, 2001).

10.5 Archaeology

The operation of a landfill should not have a significant adverse impact on the archaeological importance of a site. The potential impact of a landfill would be to disturb and in some instances to cover archaeological remains.

Before the development of any undisturbed area, the advice of the appropriate authority should be sought. A desk study should be undertaken to establish the proximity and relative archaeological importance of any sites. A check should also be carried out by walking the site and noting any item of potential archaeological significance.

Further information is available in the Agency's Manual *'Investigations for landfills'* (1995).

11. Reporting of Monitoring

11.1 Routine Reporting

Routine monitoring reports submitted to the Agency should be set out in a format that allows for the ready assessment of the data. All monitoring reports should contain the following information:

- A cover letter detailing the waste licence register number, the licensee name and the period to which the contents relate.
- An interpretation of all monitoring data.
- Any exceedance of an emission limit value or trigger level should be highlighted and actions taken as a result outlined.
- The monitoring point reference number and details.
- A drawing showing all the monitoring locations.
- Sample date, analysis date, analytical method together with its detection limits.
- The parameter, measurement unit and where contained in the licence, the emission limit value. The measurement uncertainty should also be estimated and reported with the result.
- For continuous monitoring, the average, minimum and maximum result in addition to percentage compliance should be calculated for each parameter. Results should, if possible, be shown in graphical format.

11.2 Annual Environmental Report

Under the waste licence, a landfill operator is required to submit an Annual Environmental Report (AER) to the Agency. The purpose of the AER is to give a concise overview of the activities undertaken and the operational and monitoring performance of the facility in the year being reported on. The AER should be produced on a calendar year basis unless otherwise stated in the licence. This is so that figures presented in the document may be used to update the National Waste Database or provide information for EPER (European Pollutant Emissions Register) reporting.

The following information should be included in the AER:

- **Summary report on emissions**: the licensee should provide a brief outline on the emissions monitoring carried out during the year and the trends of the results should be given. An up to date drawing of monitoring points should be included.
- **Summary of results and interpretation of environmental monitoring**: this information may be presented as a series of graphs of the key parameters with an interpretation of the trends from the past year and a discussion on predicted future trends. For example, key parameters in groundwater may be pH, TOC, ammonia and conductivity. An example of a graphical presentation of groundwater results over a year is shown in Figure 11.1.
- **Surface water:** trends in key parameters (e.g. pH, BOD, COD, suspended solids, ammonia) should be compared between upgradient and downgradient monitoring locations. Any change in the Q-value of the surface water should be highlighted.
- **Groundwater**: estimated annual and cumulative quantity of indirect emissions to groundwater may be calculated. Guidance is provided in the Agency's manual '*Landfill Site Design*' (2000).
- **Leachate**: the volume of leachate produced and volume of leachate transported/discharged off-site should be calculated. An annual water balance calculation and interpretation should be included. This

should include a comparison of predicted leachate versus actual leachate generated during the reporting period.

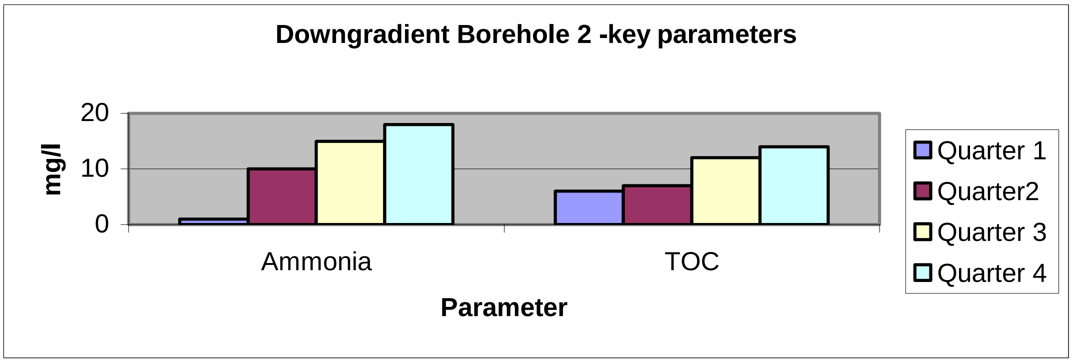

FIGURE 11.1 GRAPHICAL PRESENTATION OF RESULTS AT A GROUNDWATER BOREHOLE

- **Landfill gas**: the estimated annual and cumulative quantities of landfill gas emitted from the facility should be calculated by use of models such as the US EPA's LandGEM or GasSim (Environment Agency, 2002f). Information from pumping trials or from flares may be included here. Guidance is provided in the Agency's manual '*Landfill Site Design*' (2000). The amount of landfill gas flared and quantities of electricity or heat generated (if applicable) and the amount of flare or engine downtime should be included.

- **Topography**: site survey showing existing levels of the facility and the areas in which it is proposed to fill in the next year should be provided. A comparison with the previous years estimated levels should be made. The remaining capacity of the facility and the year in which the final capacity is expected to be reached should be calculated.

GLOSSARY

Aerobic	A condition in which elementary oxygen is available and utilised in the free form by bacteria.
Aftercare	Any measures that are necessary to be taken in relation to the facility for the purposes of preventing environmental pollution following the cessation of the activity in question at a facility.
Anaerobic	A condition in which oxygen is not available in the form of dissolved oxygen or nitrate/nitrite.
Annually	At approximately twelve monthly intervals.
Aquifer	A formation (e.g. body of rock, gravel or sand stratum) that is capable of storing significant quantities of water and through which groundwater moves.
Baseline monitoring	Monitoring in and around the location of a proposed facility so as to establish background environmental conditions prior to any development of the proposed facility.
Benthic	Bottom dwelling. Benthic organisms may crawl, burrow or remain attached to a substrate.
Biodegradable waste	Any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, paper and paperboard.
Biotic index	An index derived from observations of the responses to water quality of indicator species or higher taxa designed primarily to indicate organic pollution.
Borehole	A shaft installed outside a waste area for the monitoring of and/or extraction of landfill gas/groundwater. Established by placing a casing and well screen into the boring. If installed within the waste area, it is called a well.
Bunding/berm	A dike or mound usually of clay or other inert material used to define limits of cells or phases or roadways; or to screen the operation of a landfill from adjacent properties; reducing noise, visibility, dust and litter impacts.
Capping	The covering of a landfill, usually with low permeability material (landfill cap).
Condensate	The liquid which forms within gas pipework due to the condensation of water vapour from landfill gas.
Detection Limit	That concentration of the determinand for which there is a 95% probability of detection when a single analytical result is obtained, detection being defined as obtaining a result which is significantly greater ($p=0.05$) than zero. Also referred to as Limit of Detection.
Direct discharge	The introduction into groundwater of List I or II substances without percolation through the ground or subsoil.
Downgradient	The direction towards which groundwater or surface water flows.
Emission	Meaning assigned by the EPA Act of 1992.
Flare unit	A device used for the combustion of landfill gas thereby converting its methane content to carbon dioxide.
Gas wells	Wells installed during filling or retrofitted later within the waste area for the monitoring of and/or removal of landfill gas either actively through an extraction system or passively by venting.
Greenhouse effect	The accumulation of gases in the upper atmosphere which absorbs heat re-radiated from the earth's surface, resulting in an increase in global temperature.
Groundwater	Groundwater is that part of the subsurface water which is in the saturated zone.
Hazardous landfill	A landfill that accepts only hazardous waste that fulfils criteria set out in the Agency's draft manual 'Waste Acceptance' and that set out in Article 6 of Council Directive 99/31/EC on the landfill of waste.

Hydrogeology	The study of the interrelationships of the geology of soils and rocks with groundwater.
Indirect discharge	The introduction into groundwater of List I or II substances after percolation through the ground or subsoil.
Inert landfill	A landfill that accepts only inert waste that fulfils the criteria set out in the Agency's draft manual *'Waste Acceptance'*.
Lagoon	A land area used to contain liquid, e.g. leachate collected from landfill.
Landfill	Waste disposal facility used for the deposit of waste on to or into land.
Landfill gas (LFG)	All gases generated from the landfilled waste.
Leachate	Any liquid percolating through the deposited waste and emitted from or contained within a landfill as defined in Section 5(1) of the WMA.
Leachate well	Well installed within the waste area for the monitoring and/or extraction of leachate as opposed to borehole which is the term used when located outside the waste deposition area.
List I/II substances	Substances referred to in the EU Directives on Dangerous Substances (76/464/EEC) and Groundwater (80/68/EC).
Lower explosive limit (LEL)	The lowest percentage concentration by volume of a mixture of flammable gas with air which will propagate a flame at 25°C and atmospheric pressure.
Macroinvertebrate	Larger invertebrate animals visible to the eye. Usually defined as those that are retained by a net or sieve of mesh size 0.6mm.
Minimum Reporting Value	This is the lowest concentration of a substance that can be determined with a known degree of confidence. It is matrix dependent and not necessarily equivalent to the Limit of Detection of the analytical system but is generally a multiple of that value which reflects the robustness and reproducibility of the test method as applied to the specific matrix. Also referred to as the Limit of Quantitation or Practical Reporting Limit.
Noise Sensitive Location (NSL)	Any dwelling-house, hotel or hostel, health building, educational establishment, place of worship or entertainment, or any other facility or area of high amenity which for its proper enjoyment requires the absence of noise at nuisance levels.
Quarterly	At approximately three monthly intervals.
Receiving Water	A body of water, flowing or otherwise, such as a stream, river, lake, estuary or sea, into which water or wastewater is discharged.
Restoration	Works carried on a landfill site to allow planned afteruse.
Substrata	River bed or bottom on or in which invertebrates live.
Taxa	Named taxonomic groups. Usually family or species level in biotic indices.
Trigger level	A parameter value specified in the licence, the achievement or exceedance of which requires certain actions to be taken by the licensee.
Upper explosive limit (UEL)	The highest percentage concentration by volume of a mixture of flammable gas with air which will propagate a flame at 25°C and atmospheric pressure.
Void space	Space available to deposit waste.
Water balance	A calculation to estimate a volume of liquid generated. In the case of landfills, water balance normally refers to leachate generation volumes.

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APPENDIX A SAMPLING PROTOCOLS

A SAMPLING PROTOCOLS

A protocol is a set of instructions that must be executed in performing a specific task. They are designed to give credibility to data by ensuring that the same procedures are followed each time a task is performed. Protocols for analytical techniques are generally well documented. However, protocols for sampling are often less well documented. Procedures detailed within such protocols will be task specific since they depend on the type of medium being sampled, the proposed method of sampling, the equipment used, the intended use of the sample and the data recording procedures. For example, protocols for groundwater sampling may include:

- sampling of groundwater from boreholes by depth sampler;
- sampling of groundwater from boreholes by pumping;
- sampling of groundwater from nested boreholes by pumping;
- sampling of groundwater from boreholes fitted with a permanent pump;
- multilevel groundwater samples from a borehole; or
- sampling of groundwater by depth sampler for volatile organic analysis.

The validity and reliability of the analytical results generated will depend largely on the quality of the samples obtained and on the procedures carried out to maintain the integrity of the samples before their analysis. Operators are therefore encouraged to develop or adapt protocols for each relevant aspect of their monitoring programme to ensure that a consistent and logical approach is taken to sampling. Guidelines on the information to be contained in a typical sampling protocol are given in Table A.1.

TABLE A.1 DESIGN OF A SAMPLING PROTOCOL

Page 1 of ___

Sampling Protocol For: (groundwater/surface water/leachate/landfill gas)	
Compiled By:	Authorised By:
Protocol Number:	Version Number:
Issue Date:	Supersedes Version:
Reason for update:	

Background

This should briefly outline the following:

- the location of the site;
- the purpose of the sampling exercise (e.g. to check compliance with licence conditions); and
- the type of sample to be obtained (e.g. surface water sample for the assessment of water quality).

Responsibilities

This should outline the responsibilities of the designated quality assurance officer in relation to the protocol. Such responsibilities may include:

- overseeing all technical aspects of the sampling exercise;
- undertaking periodic checks and audits to ensure the sampling procedures have been carried out in accordance with the protocol requirements; and
- authorising deviations from the protocol.

Materials

Instrumentation and Equipment:
This would list all equipment required to obtain a valid and representative sample of the medium being investigated and may also include equipment for field analysis of particular parameters. For example, in groundwater sampling the equipment required may include bailers or discrete depth samplers, purging devices, dip meters and instruments for chemical analysis of conductivity, dissolved oxygen, pH and temperature.

Ancillary Material:
This would list the supplementary equipment and materials required and would typically include:

- sample containers (appropriate for the type of sample required and including any preservative if required);
- sample bags, tags and labels;
- field record sheets;
- chain of custody documentation;

- indelible markers;
- site maps showing monitoring points; and
- health & safety accessories (first aid kit, safety clothing).

Methods

This section should outline stepwise the procedures to be followed in the sampling exercise. Within the text, references should be made, where appropriate, to methods developed in-house or to recognised standard methods. For example, one of the steps in a groundwater sampling protocol will require the purging of the borehole before sampling. However, it may not be necessary to detail in each protocol the set of instructions to be followed for purging, but instead to refer to recognised standard procedures.

The methods section should also outline procedures for on-site chemical analyses and for the labelling, tagging, transport of samples and cleaning of equipment.

Sample Plan

The sampling plan should outline:

- the number and location (including grid references) of the monitoring points to be sampled;
- the frequency of sampling of each monitoring point;
- the depths from which the samples are to be obtained;
- the number and type of samples required (e.g. for chemical or biological analysis); and
- QA/QC sample requirements.

Records

The records maintained at the site should be sufficient to demonstrate that the sampling protocol has been strictly adhered to. This section should outline the records to be maintained and the field sheets to be completed during the sampling exercise. Such records would include:

- date & time of sampling;
- name of sampling personnel;
- weather conditions;
- amount of sample obtained;
- tag numbers and description of samples;
- precise location of monitoring point;
- details of preservatives used;
- analytical results obtained from field determinations;
- completion of appropriate standard forms;
- deviations from the protocol; and
- difficulties encountered during sampling.

APPENDIX B STANDARD FORMS

B STANDARD FORMS

This appendix provides examples of suggested forms which operators are encouraged to use in order to standardise monitoring and reporting formats. Although actual formats may vary, the report should contain the key components as shown in the suggested forms. The documents included are:

- Example of a Landfill Gas Monitoring Form,
- Example of a Chain of Custody Document,
- Example of a Sample Analysis Report Form, and
- Example of a Rivers Ecological Assessment Fieldsheet.

B.1 Example of a Landfill Gas Monitoring Form

LANDFILL GAS MONITORING FORM

Facility Name: **Waste Licence no.**:	**Facility Address:**	
Licensee:		
Date of licensing:	**Date of sampling:**	**Time of sampling:**
Instrument used:	**Date Next Full Calibration:** **Last Field Calibration:** (include date and gases)	
Monitoring Personnel:	**Weather:**	**Barometric pressure:** (e.g. 1001-1003 mbar rising) **Mean temperature:**

Results [1]

Sample Station Number	CH_4 (%v/v)	CO_2 (% v/v)	O_2 (% v/v)	CO ppm	H_2S ppm	Comments
e.g. GS1	0.0	0.5	20.7			Perimeter borehole.
e.g. GS2	59.6	34.8	0.0			Borehole within body of waste.

<u>**General Comments**</u>

Note:

1. Monitoring for other gases such as hydrogen (H_2) may be required also.

B.2 Example of a Chain of Custody Form

CHAIN OF CUSTODY FORM				
Facility Name			**Waste Licence no.**	
Facility Address			Grid Reference	
Operator/Site Manager				
Telephone		Fax		
Sample Ref. No.	Sample Type	Sample Description	Sampled by	Date
Potential Hazards Associated with Sample:				
TRANSPORTATION Samples Dispatched by: *Signature* Date/Time			**RECEIVING LABORATORY** Laboratory Name & Address:	
Received by: *Signature* Date/Time			**Samples Received by:** *Signature* Date/Time	
Received by: *Signature* Date/Time			Condition of Samples:	

B.3 Example of a Sample Analysis Report Form

SAMPLE ANALYSIS REPORT FORM	
Facility Name:	**Waste Licence No.:**
Report to:	**Date of report:**
Sampling Location & grid reference: Sampling Date: Sampled by:	Sample Type (e.g. groundwater/surface water/leachate) Weather: Other Remarks:

Received at (laboratory): By: (Signature)	Date: Time:	

Sample Reference Number:		Date of analysis:

Parameter	Units	Results	ELV (if relevant)	Limit of Detection	Analytical Technique/Method	Accreditation
e.g. Ammonia (as N)	mg/l	0.058		<0.001	Colorimetry or method reference	Y

Comments:

e.g. sampling method such as grab for surface water, bailer/pump for groundwater

e.g. details of any pre-treatment of samples should be included here such as filtration, acid preservation, etc.

Report Compiled by:	
Signature:	Date:
Position:	

Report Certified by:	
Signature:	Date:
Position:	

B.4 Example of a Rivers Ecological Assessment Fieldsheet

Facility Name:	**Waste Licence No.**	**Date & Time of Sampling:**	**Weather:**
River:	**Sample Station No.:** **Grid Ref.:**	**Sampling Personnel:**	

DO %			**Sampled in:** Cascades
DO mg/l		**Modifications: Canalised – Widened – Bank Erosion – Arterial Drainage**	
Temp		**Dominant Types:** **Substratum Condition:**	
Conductivity		Bedrock Calcareous – Compacted – Loose	Riffles
pH		Boulder (>128mm) **Degree of Siltation:**	Glides
Bank Width		Cobble (32-128mm) Clean - Slight - Moderate - Heavy	Pools
Wet Width		Fine Gravel (2-8mm) Gravel (8-32mm)	Deeps
Avg Depth		Sand (0.25-2mm) **Cattle Access:** u/s – d/s	Margins
Staff Gauge		Silt (<0.25mm) **Litter:** NO - P - M – A [1]	Vegetation

Velocity:	**Coloured:**	Photo: Video:	
Torrential	None	**Macrophytes** (A - M - P - NO)	**Shading** H - M - L–N[2]
Fast	Slightly	Submerged Emergent Bankside	**Tree Species:**
Moderate	Highly		
Slow			
Very Slow			
Clarity:			**Main Land Use upstream**
Very Clear Clear Slightly Turbid Highly Turbid			Pasture Bog Forestry Urban
Discharge:		**Filamentous Algae:** A - M - P – NO	Tillage
Flood		Gelatinous Complexes A - M - P – NO Other:	Other:
Normal	V. Low	Sewage Fungus: A - M - P – NO	
Low	Dry	**Overall Macroinvertebrate Abundance and Diversity**	**Sample in Minutes:**

Recent Flood	**Density**	**Diversity**	**No. Taxa**	Pond Net x
Fish species: (where known)	High Average Low	High Average Low		Stone Wash x Weed Sweep x **Sample Retained** Y - N

	Macroinvertebrate Composition - Taxa		
Protected species: (where known)	Excessive (>75%)	Dominant (51-75)	Numerous (21-50)

Common (6-20)	Few (1-5)
Remarks:	
Q-Value:	Previous Qs:
Access Point:	

Notes:

1. NO-P-M-A indicates: Not observed – Present – Moderate – Abundant.

2. H-M-L-N indicates: High-Medium-Low-None.

APPENDIX C MINIMUM MONITORING REQUIREMENTS

TABLE C.1 MINIMUM BASELINE MONITORING REQUIREMENTS FOR A NON-HAZARDOUS LANDFILL

Monitoring Medium	Parameters	Monitoring Points	Frequency of Monitoring
Surface water	Flow/level and composition. See Table C.2 for further details.	At least two monitoring points in each watercourse – one upstream and one downstream of the proposed landfill.	Quarterly intervals over a one year period (pre-operational).
	Biological assessment.	At least two monitoring points in the main watercourse adjacent to the landfill – one upstream and one downstream of the proposed landfill.	At least once between June & September.
	Sediment assessment.	Site specific.	Site specific.
Groundwater	Level and composition. See Table C.2 for further details.	Minimum of three boreholes, one upgradient and two downgradient of the proposed landfill.	Quarterly intervals over a one year period (pre-operational).
Landfill Gas	Gas composition (methane, carbon dioxide, oxygen).	Three perimeter boreholes.	Two readings over a year prior to waste deposition to establish background gas concentrations.
Meteorological Data	See Table C.6.	Historical data from nearby meteorological station.	Sufficient data required to be able to predict leachate generation and to undertake air dispersion modelling of e.g. odour or emissions from flare/utilisation plant.
Other Aspects	Noise, dust, PM_{10} and odours.	Sensitive receptors. Potential sources. Perimeter locations.	Site specific.
	Topography, ecology, archaeology.	Assessment of facility and surrounding locality needed.	Site specific.

TABLE C.2 PARAMETERS FOR MONITORING OF GROUNDWATER, SURFACE WATER & LEACHATE

	Surface Water	Groundwater	Leachate
Monitoring / Parameter [1]	**Baseline (pre-operational)**	**Baseline [2] (pre-operational)**	**Characterisation (when site is operational)**
Fluid Level	●	●	●
Flow rate [3]	●		
Temperature	●	●	●
Dissolved oxygen	●		
pH	●	●	●
Electrical conductivity [4]	●	●	●
Total suspended solids	●		
Total dissolved solids		●	
Ammonia (as N)	●	●	●
Total oxidised nitrogen (as N)	●	●	●
Total organic carbon		●	
Biochemical oxygen demand	●		●
Chemical oxygen demand	●		●
Metals [5]	●	●	●
Total alkalinity (as $CaCO_3$)	●	●	
Sulphate	●	●	●
Chloride	●	●	●
Molybdate Reactive Phosphorus [6]	●	●	●
Cyanide (Total)	●	●	●
Fluoride	●	●	●
Trace organic substances [7]	●	●	●
Faecal & Total Coliforms [8]		●	
Biological assessment [9]	●		

Notes:
1. Tables D.1 and D.2 recommend guideline minimum reporting values for parameters.
2. For landfills accepting biodegradable wastes, it is recommended that trigger levels are set for ammonia, TOC and chloride as a minimum. Section 5.5 contains further details.
3. Range of flow measurements required, i.e. high and low flow.
4. Where saline influences are suspected, a salinity measurement should also be taken.
5. Metals for analysis should include: calcium, magnesium, sodium, potassium, iron, manganese, cadmium, chromium (total), copper, nickel, lead, zinc, arsenic, boron and mercury.
6. Total Phosphorus should be measured in leachate samples where colorimetric interference is likely.
7. Table D.2 recommends trace organic substances that should be included in the determination. Surface water should be analysed for the pesticides and solvents listed in the Water Quality (Dangerous Substances) Regulations (S.I. No. 12 of 2001).
8. Required for drinking water supplies within 500m of the landfill.
9. Site specific and twice between June and September.

TABLE C.3 TYPICAL LEACHATE MONITORING REQUIREMENTS FOR A NON-HAZARDOUS LANDFILL

Parameter	Monitoring Points	Monitoring Frequency (operational and aftercare)
Leachate levels	• For lined landfills, at the leachate collection point and at two other points per cell. • For unlined landfills, three points per five hectares of filled area. • Leachate lagoon.	As required by waste licence.
Leachate composition See Table C.2 for details.	• Sampling point representative of the landfill body. • Leachate lagoon. • Treated leachate before discharge.	As required by waste licence.
Leachate discharge volume	• Treated leachate discharge point.	As required by waste licence.

TABLE C.4 TYPICAL LANDFILL GAS MONITORING REQUIREMENTS FOR A NON-HAZARDOUS LANDFILL

Monitoring Points	Parameter	Monitoring Frequency (operational and aftercare)
Perimeter boreholes (outside the waste body)[1], site office/buildings	Methane, carbon dioxide, oxygen[2], atmospheric pressure[3], temperature.	As required by licence.
Boreholes/Vents/Wells [4] (within the waste mass)	Methane, carbon dioxide, oxygen[2], atmospheric pressure[3], temperature.	As required by waste licence.
Collection wells and associated manifolds	Bulk gas concentration, flow-rate.	As required by waste licence.
Surface emissions	Methane, flow-rate.	As required by waste licence.
Inputs and outputs of each flare/utilisation plant	See Table C.5 for details.	See Table C.5 for details.

Notes:
1. Number and location depends on the site risk assessment.
2. Other gases, e.g. H_2S, CO and H_2 as required.
3. Falling atmospheric pressure may cause increased migration of gas out of the waste body.
4. The locations for gas monitoring within the waste body should be at a density of at least one monitoring point per cell in lined landfills and one monitoring point per hectare of filled area in unlined landfills.

TABLE C.5 TYPICAL LANDFILL GAS FLARE AND UTILISATION PLANT MONITORING REGIME

Parameter	Flare Monitoring Frequency	Utilisation Plant Monitoring Frequency
Inlet		
Gas flow rate	Continuous	Continuous
Methane (CH_4) % v/v	Continuous	Continuous
Carbon dioxide (CO_2) % v/v	Continuous	Weekly
Oxygen (O_2) % v/v	Continuous	Weekly
Total Sulphur [1]	Annually	Annually
Total Chlorine [1]	Annually	Annually
Total Fluorine [1]	Annually	Annually
Process Parameters		
Combustion temperature	Continuous	Not applicable
Retention time	Annually	Not applicable
Outlet		
Carbon monoxide (CO) [2]	Continuous	Continuous
Nitrogen oxides (NOx)	Annually	Annually
Sulphur dioxide (SO_2)	Annually	Annually
Total VOCs as carbon	Annually	Annually
Total non-methane VOCs	Not applicable	Annually
Particulates	Not applicable	Annually
Hydrochloric acid (HCl)	Annually	Annually
Hydrogen fluoride (HF)	Annually	Annually
Other parameters, e.g. heavy metals, halogenated organic compounds.	Site specific	Site specific

Notes:

1. If a high concentration of these substances is present in the gas (Cl > 160 mg/m^3, F > 25 mg/m^3, S > 1400 mg/m^3), purification treatment may be required in order to fulfill emission standards.
2. The presence of CO in the flue gases is indicative of incomplete combustion.

TABLE C.6 MINIMUM METEOROLOGICAL MONITORING REQUIREMENTS

Parameter [1]	Operational phase	Aftercare phase
Volume of precipitation	Daily	Daily, added to monthly values
Temperature min/max, 14.00h CET [2]	Daily	Monthly average
Direction and force of prevailing wind	Daily	Not required
Evaporation	Daily	Daily, added to monthly values
Atmospheric pressure	Daily	Monthly average
Atmospheric humidity, 14.00h CET [2]	Daily	Monthly average

Notes:

1. Data to be collected from an *in situ* weather station at the landfill site or from a nearby meteorological station.
2. CET is Central European Time and is specified in the Landfill Directive.

APPENDIX D MINIMUM REPORTING VALUES

TABLE D.1 GUIDELINE MINIMUM REPORTING VALUES

In general, the term 'clean' waters refers to surface waters, groundwaters and drinking waters whereas the term 'dirty' waters refers to leachates or similar matrices. All analysis should be carried out by a competent laboratory using standard or internationally accepted procedures capable of achieving, where practicable, the Minimum Reporting Value (MRV) for the matrix. The MRVs represent acceptable criteria for the sensitivity of test methods. Where procedures routinely employed are capable of producing measurements of greater resolution, then these should be reported in preference.

Determinand [1]	Units	Recommended Analytical method	MRV 'clean'	MRV 'dirty'
Temperature [2]	°C	Thermometry	± 1	± 1
pH [2]	pH units	Electrometry	± 0.2	± 0.2
Electrical conductivity [3]	µS/cm	Electrometry	10	50
Dissolved oxygen [2]	mg/l	Electrometry	± 0.1	± 5
Dissolved oxygen [2]	% saturation	Electrometry	± 1	± 5
Total suspended solids	mg/l	Gravimetry	5	10
Total dissolved solids	mg/l	Gravimetry	10	20
Ammonia (as N)	mg/l	Ion selective electrode/Colorimetry	0.05	1
Total oxidised nitrogen (as N) [4]	mg/l	Colorimetry/Ion chromatography/Ion selective electrode	1	1
Total organic carbon [5]	mg/l	TOC Analyser	2	10
Biochemical oxygen demand [6]	mg/l	Electrometry or Titrimetry	2	10
Chemical oxygen demand	mg/l	Digestion/Colorimetry	10	20
Calcium [7]	mg/l	Atomic spectroscopy/Ion chromatography	1	10
Magnesium [7]	mg/l	Atomic spectroscopy/Ion chromatography	1	10
Sodium [7]	mg/l	Atomic spectroscopy/Ion chromatography	1	10
Potassium [7]	mg/l	Atomic spectroscopy/Ion chromatography	1	10
Iron [7]	mg/l	Atomic spectroscopy/Colorimetry	0.05	0.2
Manganese [7]	mg/l	Atomic spectroscopy/Colorimetry	0.02	0.05
Cadmium [7]	mg/l	Atomic spectroscopy/Colorimetry	0.0005	0.005
Chromium (Total) [7]	mg/l	Atomic spectroscopy/Colorimetry	0.005	0.05
Copper [7]	mg/l	Atomic spectroscopy/Colorimetry	0.005	0.05
Lead [7]	mg/l	Atomic spectroscopy/Colorimetry	0.005	0.05
Nickel [7]	mg/l	Atomic spectroscopy/Colorimetry	0.005	0.05
Zinc [7]	mg/l	Atomic spectroscopy/Colorimetry	0.008	0.1
Arsenic [7]	mg/l	Atomic spectroscopy	0.005	0.05
Boron [7]	mg/l	Atomic spectroscopy/Colorimetry	0.2	2
Mercury [7]	mg/l	Atomic spectroscopy	0.0001	0.001
Cyanide (Total)	mg/l	Colorimetry/Ion chromatography/Ion selective electrode after distillation	0.01	0.05
Total alkalinity (as CaCO3)	mg/l	Potentiometric or Acidimetric titration	5	50
Sulphate	mg/l	Ion chromatography/Turbidimetry	20	50
Chloride	mg/l	Colorimetry/Ion chromatography/Ion selective electrode	2	25
Fluoride	mg/l	Ion chromatography/Ion selective electrode	0.1	1
Phosphorus [8]	mg/l	Atomic spectroscopy/Colorimetry	0.02	0.2
Trace organic substances	µg/l	See Table D.2	-	-
Dissolved methane	µg/l	Sensor/GCMS/GCFID	5	5
Total & Faecal coliforms [9]	No./100ml	Membrane filtration, MPN or Colilert™, dilution as required	<1	10

Notes:

1. The Water Quality (Dangerous Substances) Regulations (S.I. No. 12 of 2001) lists water quality standards for the following metals: arsenic, chromium, copper, cyanide, fluoride, lead, nickel and zinc as well as selected pesticides and solvents.
2. This is the typical instrumentation resolution required rather than reporting value.
3. The reference temperature at which the conductivity is measured should be specified.
4. Total oxidised nitrogen may be expressed as the sum of nitrate (NO_3) and nitrite (NO_2) analyses.
5. For waters high in inorganic carbon the preferred method for determination of TOC is measurement of an acid-purged sample where TOC is reported as Non-Purgeable Organic Carbon.
6. Carbonaceous BOD analysis may be required in certain situations, e.g. when analysing treated leachates. This is done by addition of a nitrification inhibitor and if undertaken, then should be specified in the sample analysis report form. Unless otherwise specified, BOD data should relate to non-inhibited measurements.
7. It is recommended that metal analysis on groundwater and leachate samples is undertaken on samples that have been filtered through a 0.45µm membrane filter and acid preserved.
8. Soluble molybdate reactive phosphorus (MRP) should be analysed in 'clean' waters and total phosphorus in 'dirty' waters where practicable. Total phosphorus is desirable where colorimetric interference in the measurement of MRP is likely.
9. Faecal Coliforms should be confirmed as *E. Coli*.

TABLE D.2 RECOMMENDED CORE DETERMINANDS FOR TRACE ORGANICS ANALYSIS & GUIDELINE MRVS

In general, the term 'clean' waters refers to surface waters, groundwaters and drinking waters whereas the term 'dirty' waters refers to leachates or similar matrices. All analysis should be carried out by a competent laboratory using standard or internationally accepted procedures capable of achieving, where practicable, the Minimum Reporting Values for the matrix. These represent acceptable criteria for the sensitivity of test methods. Where procedures routinely employed are capable of producing measurements of greater resolution, then these should be reported in preference.

Determinand [1] (include representative compounds from the following groups)	**MRV 'clean' μg/l**	**MRV 'dirty' μg/l**
VOCs		
e.g. trichloroethylene, tetrachloroethylene, 1,2-dichloroethane, 1,2-dichlorobenzene, toluene, xylenes, hexachlorobutadiene, trichlorobenzene, dichloromethane, chlorobenzene, benzene.	1.0 [2, 3]	1.0 [2]
SEMI-VOCs		
Organochlorine pesticides e.g. aldrin, γ-HCH (Lindane), dieldrin, endosulfan, trifluralin, hexachlorobenzene.	0.1 [2, 3]	1.0 [2]
Triazine herbicides e.g. atrazine, simazine.	0.1 [2, 3]	1.0 [2]
Organophosphorus pesticides e.g. dichlorvos.	0.1 [2, 3]	1.0 [2]
Herbicides e.g. dichlorprop, mecoprop, bromoxynil.	0.1 [2, 3]	1.0 [2]
Phenols e.g. 2-chlorophenol, pentachlorophenol, 2,4,6-trichlorophenol.	0.1 [2, 3]	1.0 [2]
Organotin compounds e.g. tributyltin	Note 4.	Note 4.
Polycyclic Aromatic Hydrocarbons (PAHs) e.g. benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, indeno(1,2,3-cd)pyrene, napthalene .	0.1 [2, 3]	1.0 [2]

Notes:

1. Inclusion of the above substance groups reflects legislation current at the time of preparation of this document. Studies being undertaken on behalf of the Department of the Environment and Local Government are expected to provide further guidance on priority substance monitoring. The above groupings are not exhaustive and this listing may be subject to change to reflect new information and/or legislation. The Water Quality (Dangerous Substances) Regulations (S.I. No. 12 of 2001) lists the following pesticides and solvents: atrazine, dichloromethane, simazine, toluene, tributyltin and xylenes.

2. Samples should be analysed by appropriate recognised standard methods such as US EPA, ISO, CEN, NSAI or equivalent which are capable of achieving the required degree of analytical performance.

3. Lower minimum reporting values may be necessary in some circumstances, e.g. where compounds are detected in drinking waters or where a trigger level is set for a particular substance.

4. This parameter only relates to tidal waters. Analytical techniques capable of meeting the requirements of relevant legislation should be used. Monitoring for biological effects such as reproductive impairment in gastropods may also be necessary.

APPENDIX E SAMPLING EQUIPMENT & ANALYTICAL TECHNIQUES

TABLE E.1 GROUNDWATER & LEACHATE SAMPLING EQUIPMENT

Equipment	Advantages	Disadvantages
Bailers	• Low cost • Simple to operate and reliable • Readily portable • External power source not required • Can be constructed in a wide variety of diameters and materials • Dedicated or disposable options • Suitable for VOC sampling	• Aeration of sample possible if operated too vigorously or when transferring water to the sample bottle • Can cause turbidity in sample medium • Possibility of cross contamination from the bailing cable • Labour intensive when used for purging • Can only sample top of water column
Discrete Depth Samplers	• Samples at specific levels in boreholes. • Low cost – can be dedicated • Easy to operate and portable	• Low abstraction rate makes purging slow • Causes agitation if operated too vigorously
Inertial pumps	• Low cost and can be used as a dedicated pump • Can be used for purging and sampling • Can be used in silty/sandy water • Can operate to c. 60m depth • Lightweight and portable mechanical unit available	• Potential mixing of water column • May cause disturbance of accumulated sediments • Causes agitation of sample.
Suction lift pumps (including peristaltic)	• Suitable for sampling most inorganic compounds • Relatively inexpensive and portable • Pump is at surface – dedicated tubing can be left in hole • Inertial pumps can be used as priming mechanism to avoid cross-contamination	• Only suitable for boreholes <9 m depth • Unsuitable for VOC determinations • Can cause degassing of samples • Possible contamination of samples from priming fluid • Causes pressure changes and agitation
Bladder Pumps/Gas driven pumps	• Easy to operate and reliable • Portable and easily cleaned • Can operate at very low flow rates • Suitable for sampling all major organic and inorganic parameters • Can operate to any depth	• Low discharge rate unsuitable for purging • Expensive • Gas source required • Large gas volumes and long cycles are necessary when pumping from deep wells
Diffusion samplers	• Only suitable for VOC • No purging required	• Dedicated • Expensive
Submersible pumps	• Flow rate variable, suitable for purging and sampling • Efficient for purging deep boreholes • Easy to operate and reliable	• Heat generated by pump may cause changes in chemical composition of sample • Possible pressure changes/agitation of sample
Multilevel samplers	• Can take samples from several discretely isolated zones within a single borehole • Useful in determining flow patterns and contaminant distribution	• Expensive and requires specialist knowledge • Installation difficult and if poorly done may lead to cross-contamination

TABLE E.2 THE RELATIONSHIP BETWEEN MEASURED GAS PARAMETERS & MONITORING PURPOSE

Purpose	Monitoring Location	Measured Parameters	Instrument Type(s)
Personal protection	Atmosphere around a person working in a confined space	Flammable gas concentration, oxygen deficiency. Other gases (e.g. H_2S) concentration if necessary.	Pocket size device with acoustic, optic or vibrating alarm
Building or development protection	Confined spaces, rooms, etc.	Flammable gas concentration, oxygen deficiency. Other gases (e.g. H_2S) concentration if necessary.	Fixed or transportable with acoustic or optic alarm with or without telemetry OR Portable instrument for surveys
Monitoring for gas during a surface survey	Ground surface, services, manholes, search bar holes	Flammable gas (methane), carbon dioxide and oxygen concentration. Pressure, temperature, flow.	Portable
Monitoring for gas outside the waste	Gas monitoring borehole or probe	As above.	Portable OR Fixed for continuous monitoring with telemetry (optional)
Monitoring the gas in the waste or within a gas collection system	Gas or leachate extraction well, Knock-Out-Pot (gas dewatering plant), gas collection pipes	As above. Carbon monoxide in case of suspected underground fires.	As above
Monitoring in a gas thermal destruction unit	Gas flare	Flammable gas (methane), carbon dioxide and oxygen concentration. Pressure, temperature and flow.	As above
Monitoring in a gas utilisation plant	Power station, kiln, boiler, etc.	As above and calorific value, moisture.	As above
Detailed gas analysis	Sample of gas	Gas composition, concentration of its components, moisture.	Fixed or transportable laboratory instruments (e.g. GC-MS)

(Source: *'Monitoring of Landfill Gas'*, IWM, 1998.)

TABLE E.3 CHARACTERISTICS OF VARIOUS GAS SENSORS

Sensor type	Gas	Advantages	Disadvantages
Infrared	CH_4 Other hydrocarbons, CO_2	Fast response and simple to use Can be used to measure specific gases in gas mixtures and cannot be 'poisoned' Wide detection range (ppmv – 100%) Less prone to cross-interference with other gases than other sensors Can be incorporated into intrinsically safe instruments Gas sample passes unchanged through the sensor	Prone to zero drift Pressure sensitive Temperature sensitive Moisture sensitive Majority instruments sensitive to hydrocarbon bond only, not specifically to CH_4 – in presence of specific organic compounds can cause interference Optics sensitive to contamination (condensate, particulates).
Flame ionisation	CH_4 Flammable gases Vapours	Highly sensitive (usual range (0.1 - 10,000ppmv) Fast response	Will not work in O_2 deficient environment Accuracy is affected by presence of other gases like CO_2, H_2, minor constituents of landfill gas, water vapour 'Blind test' – respond to any flammable gas Limited detection range Gas sample destroyed
Electrochemical	O_2, H_2S and CO_2.	Low cost Usual detection range 0-25% v/v, against various gases	Limited shelf-life and requires frequent calibration Can lose sensitivity due to moisture, corrosion and poisoning Poor performance against cross-contamination
Paramagnetic	O_2	Accurate and robust No interference from majority of other gases	Prone to drift and gas contaminants Expensive Respond to partial pressure and not concentration
Catalytic oxidation (Pellistor)	CH_4 Flammable gases and vapours	Fast response Low detection range (0.1–100% LEL) Respond to any flammable gas	Accuracy affected by presence of other flammable gases Readings inaccurate in O_2 deficient atmosphere (< 12% v/v) Prone to aging, poisoning and moisture Not possible to notice sensor deterioration Gas sample destroyed during measurement
Thermal conductivity	CH_4 Flammable gases and vapours	Fast response to any flammable gas Full detection range (0 – 100% v/v) Independent on oxygen fuel Can be combined with other detectors	Accuracy affected by presence of other flammable gases, CO_2 and other gases with the same thermal conductivity Sensitivity too poor for use in safety checks Errors at low concentrations
Semiconductor	Mainly toxic gases	Good selectivity for some toxic gases (e.g. H_2S) Less susceptible to poisoning High sensitivity to low concentration of gases Long-term stability	Lack of selectivity to combustible gases Not specific to any one material Accuracy and response depend upon humidity
Chemical (indicator tubes)	CO_2, CO, H_2S, water vapour, other gases	Simple in use and inexpensive	Crude identification of specific landfill gas constituents and prone to interference effects
Photo–ionisation detector	Most organic gases	Very sensitive	Susceptible to cross – contamination and expensive

(Source: *'Monitoring of Landfill Gas'*, IWM, 1998.)

TABLE E.4 MONITORING METHODS & TECHNIQUES FOR FLARES & UTILISATION PLANTS

PARAMETER	ANALYSIS METHOD /TECHNIQUE [1]
Temperature	Thermocouple/temperature probe/datalogger
Flow	Pitot tube
Methane	Infrared/flame ionisation/thermal conductivity
Carbon dioxide	Infrared/thermal conductivity
Oxygen	Non-dispersive infrared (NDIR)/paramagnetic/electrochemical/thermal conductivity
Total sulphur/total chlorine/total fluorine	Ion chromatography/ion selective electrode
Sulphur dioxide	NDIR/non-dispersive ultraviolet/electrochemical/chemical absorption
Nitrogen oxides	NDIR/chemiluminescence/electrochemical/chemical absorption
Carbon monoxide	NDIR/infrared/electrochemical/datalogger
Particulates	Isokinetic & gravimetric
VOCs	Adsorption/desorption & GC-FID/GC-MS
Hydrochloric acid, hydrogen fluoride & acid gases	Impinger & ion chromatography
Heavy metals	Isokinetic & ICP-AES

Note:

1. All equipment used for monitoring flares and utilisation plants must be capable of withstanding high temperatures and may have to be specifically manufactured or altered to be fit for the purpose.

User Comment Form

NOTE: Completed comments to be forwarded to: Office of Licensing and Guidance, EPA, P.O. Box 3000, Johnstown Castle Estate, Wexford.

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