LFTGN02

Landfill directive

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Guidance on Monitoring of Landfill Leachate, Groundwater and Surface Water

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Published by:

Environment Agency
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Waterside Drive, Aztec West
Almondsbury, Bristol BS32 4UD
Tel: 01454 624400 Fax: 01454 624409

ISBN:1-84432-159-2

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Dissemination Status
Internal: Released to Regions
External: Released to public domain

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Statement of Use
This technical guidance document presents generic guidance on the best practice for the monitoring of landfill leachate, groundwater and surface water at permitted landfill sites. It has been prepared for regulators and private industry concerned with the development, operation, management, aftercare and regulation of landfill sites. It sets out technical guidance on the requirements of the Landfill Directive within the regulatory framework under the Pollution Prevention and Control (PPC) Regime that implements the Directive. Some of the principles set out in this document are also relevant to both closed and/or unlicensed landfill sites. This document may be updated from time to time.

Research Contractor
The document was produced under Agency contract to the Environment Agency by SLR Consulting Ltd, with the main contributors being Dr Alan Edwards and John Leeson. The document updates (to take account of implementation of the Landfill Directive) guidance that was produced under R&D Project HOCO_232 by a team of independent consultants led by Peter Dumble and Charles Ruxton (joint principal authors). Additional input and debate on statistical / chemometric issues was provided by John Thompson. Ellen Pisolkar contributed to sections on surface water monitoring. Max Fuller produced the diagrams in the original guidance, several of which are reproduced here.

Foreword

The EU Landfill Directive (EEC/1999/31/EC), which came into force on 16 July 1999, aims to improve standards of landfilling across Europe, through setting specific requirements for the design and operation of landfills, and for the types of waste that can be accepted in landfills. All landfills, with a few exceptions for very small or remote sites, are required to comply with the Directive's requirements, although a transitional period is allowed for landfills existing at 16 July 2001. In the UK, the Directive is implemented through the Landfill Regulations (England and Wales) 2002, made under the Pollution Prevention and Control Act (England and Wales) 1999, and through equivalent legislation in Scotland and Northern Ireland.

The Environment Agency has produced a series of guidance documents to assist the waste management industry and regulators in complying with the Directive's requirements. This document is one of a linked series of technical guidance documents that support both landfill operators and their advisors in the development and management of landfills, and the Agency and local authorities in making regulatory decisions. This document is non-statutory, but represents guidance that the Agency will use and will expect others to use, except where there is adequate justification to do otherwise.

Readers of this guidance are expected to be familiar with the Landfill Regulations requirements and the national regulatory framework, including the Department for Environment, Food & Rural Affairs (DEFRA; formerly Department of the Environment, Transport and the Regions) guidance document IPPC: A Practical Guide (Edition 2, June 2002), which sets out how Government expects the PPC Regime to operate.

Acknowledgements

This document has been produced in consultation with the Contract's Project Board and issued for publication with the approval of the Landfill Directive Project.

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Part 1 Context

1.0 Introduction

1.1 Landfill leachate and its impact

Landfill leachate is a potentially polluting liquid, which unless managed and/or treated, and eventually returned to the environment in a carefully controlled manner, may cause harmful effects on the groundwater and surface water that surround a landfill site.

This applies to leachate from all types of landfill. Hazardous and non-hazardous landfills may produce leachate that has elevated concentrations of contaminants, such as ammoniacal nitrogen, heavy metals and organic compounds. These could, if not contained and managed, affect both surface and groundwater resources. However, some non-hazardous landfills accept waste with a relatively low pollution potential, so a risk-based approach to all aspects of landfill design and monitoring should be taken, including the monitoring of leachate, surface water and groundwater. Even inert waste landfills can, if not managed correctly, generate uncontrolled run-off, which could contain high loads of suspended solids that could affect surface water quality and therefore such sites still require some monitoring of surface and groundwater quality.

1.2 Reasons for monitoring

A waste management licence[1] or Pollution Prevention and Control (PPC) Permit[2] contains conditions to provide assurance that the landfill operation does not cause harm to human health or the environment. These conditions normally include requirements for environmental monitoring. This guidance is specifically concerned with the monitoring of leachate, groundwater and surface water within and around landfills. Separate guidance is provided with regard to monitoring other emissions from landfills, such as landfill gas, odour and noise.

Specific reasons for leachate, groundwater and surface water monitoring at landfills are:

- to demonstrate that the landfill is performing as designed;
- to provide reassurance that leachate controls are preventing pollution of the environment (by reference to a pre-established baseline);
- to meet the control and monitoring requirements of legislation and in particular Regulations 14 and 15, as well as Schedule III, of the Landfill Regulations, this includes the requirement for control monitoring;
- to demonstrate compliance with the Groundwater Control and Trigger level requirements of Schedule 3 of the Landfill Regulations;
- to indicate whether further investigation is required and, where the risks are unacceptable, the need for measures to prevent, reduce or remove pollution by leachate;
- to identify when a site no longer presents a significant risk of pollution or harm to human health (to enable an application for a certificate of completion to be made, and thereby formally end the licensing or permitting process and the legal duty to monitor).

1.3 The need for reliable long-term monitoring records

Monitoring is a long-term commitment that accompanies the development, operation and post-closure management of all landfill sites. Landfill sites that contain biodegradable or other polluting wastes may need to be monitored for periods of up to 50 years or more after completion of landfilling (Environment Agency, 2003a) during the site's aftercare period (as defined by the Landfill Regulations), as illustrated in Table 1.1.

[1] As granted under the Waste Management Licensing Regulations 1994.
[2] As granted under the Pollution Prevention and Control Regulations 2000.

Table 1.1 Phases in landfill-site life

Phase	Activity	Monitoring Required	Aftercare Period	
			Requirements of Planning Permission	Requirements of Landfill Regs
Phase 1	**Pre-planning, which is sub-divided into:** • Strategic planning • Site identification and preliminary assessment • Planning application and accompanying Environmental Impact Assessment • PPC authorisation	To support planning and PPC Permit applications		
Phase 2	**Operational period** (landfill construction, filling and restoration)	To demonstrate that the landfill is performing as predicted		
Phase 3	**Post closure and aftercare period** (final restoration, site closure until surrender of permit; not comparable to planning aftercare period)	To demonstrate that the landfill is performing as predicted		
Phase 4	**Site completion** (submission of permit surrender application)	To support and justify completion		
Phase 5	**Post site completion** (passive phase and potential after use)	None		

To ensure consistency and long-term reliability of monitoring records, monitoring programmes should be undertaken by competent personnel and should also be targeted and risk-based. However, the details of monitoring programmes should always be balanced against minimum statutory requirements, particularly where risk assessment has not been undertaken or is inadequate.This guidance explains the importance of monitoring throughout the first four phases of landfill development and management, the need for quality control (QC) and for recording, interpreting and presenting the data in a clear fashion that is fit for the purpose and also accessible to both specialists and non-specialists. In addition to this, monitoring data and interpretative reports form part of the public register and need to be supplied in a format that is compatible with this.

The monitoring programme for a landfill should evolve as both the site and its conceptual model, which describes how it interacts with its surrounding environment, develop. Monitoring programmes should, therefore, be both robust and flexible in order to be tailored to site-specific circumstances.

1.4 Aims of guidance

The principal aims of this guidance are:

- to provide technical guidance for the monitoring of leachate, groundwater and surface water for waste management licensing and PPC purposes so as to comply with the Landfill Regulations;
- to provide the methodology for determining monitoring schedules in accordance with the Landfill Regulations and the Agency's guidance on Hydrogeological Risk Assessment for Landfills and the Derivation of Groundwater Control and Trigger Levels (Environment Agency, 2003b), and for justifying any deviation from these;
- to provide guidance for England and Wales that conforms with the monitoring requirements of the EC Dangerous Substances Directive (Commission of the European Communities, 1976), the EC Groundwater Directive (Council of the European Communities, 1980) and the EU Integrated Pollution Prevention and Control (IPPC) Directive (Council of the European Communities, 1996)
- to provide guidance that places landfill monitoring within the context of an overall catchment-based water protection strategy, in accordance with the principles of the EU Water Framework Directive (Council of the European Communities, 2000).

1.5 Use of guidance

This guidance is written for landfill sites with a current waste management licence or PPC Permit; references to permits should be taken to include licences. It will be used by the Agency as a primary reference source for drafting PPC Permit conditions. This guidance should also be used by operators when preparing PPC applications.

The principles in this document are also of value to the promoters of proposed landfill developments that require monitoring as part of an environmental impact assessment that is being prepared to accompany a planning application. Some of the principles will also have relevance to the monitoring of landfill sites that are closed and unlicensed.

As with all technical guidance, issues are addressed that are the subject of ongoing research and development and that may be influenced by future legislation or policy. For this reason, it is intended to periodically update sections of this guidance and users should ensure that they refer to the latest version of the guidance.

This guidance is intended as a basis for ensuring that issues are addressed in proportion to risk. **Every site is different and the development of permit conditions and monitoring requirements should follow site-specific, risk-based techniques and should not slavishly follow every detail in this guidance. The examples within this document should be treated as such and not used prescriptively.**

1.6 Legislation, policy and responsibilities

The legal framework in England and Wales that provides for the disposal of waste to land has been formulated to comply with the Landfill, Groundwater and IPPC Directives. The Landfill Directive is implemented in England and Wales via the PPC Regulations 2000 and the Landfill (England and Wales) Regulations 2002. All new landfills are subject immediately to the requirements of the Directive, whereas existing landfills, as at 16 July 2001, will be phased into PPC through a timetable prioritised by the risk posed by the site. Accordingly, the current waste management licensing regime will run in parallel to the PPC regime, and will continue to be the relevant regime for sites that close prior to obtaining a PPC Permit.

The Regulations that implement the Landfill Directive in England and Wales will be enforced by the Environment Agency (referred to as 'the Agency' hereafter in this guidance).

The Groundwater Directive is implemented through the Groundwater Regulations 1998 for the PPC regime, and Regulation 15 of the Waste Management Licensing Regulations 1994.

1.7 Relationship to other guidance

This guidance represents what the Agency considers to be best practice with regard to the monitoring of leachate, groundwater and surface water at and around landfill sites. For landfills that contain biodegradable wastes, the evolution and migration of landfill gas is intimately associated with leachate-forming processes, and monitoring programmes for the aqueous and gaseous phases will overlap to some degree. When designing monitoring programmes, guidance in this document must be considered together with that on landfill gas monitoring (Environment Agency, 2002b).

It is emphasised that monitoring programmes should be designed to meet site-specific monitoring objectives. The parameters used and the frequency with which they are monitored will depend on the characteristics of the landfill, the vulnerability of controlled water in the vicinity and the need to demonstrate compliance with relevant legislation. The Agency will, however, expect proposals for monitoring programmes that depart significantly from model schedules in this guidance to be justified by risk assessment. This will be particularly necessary if the number of parameters and their monitoring frequency are reduced.

1.7.1 Relationship to Hydrogeological Risk Assessments for Landfills and the Derivation of Groundwater Control and Trigger Levels guidance

Separate guidance (Environment Agency, 2003b) is provided by the Agency on the interpretation and application of Groundwater Control and Trigger levels and hydrogeological risk assessment as required by the Landfill Regulations. This has replaced the original guidance on hydrogeological risk assessments (Regulation 15). The information to be gathered for a hydrogeological risk assessment of a landfill should be used to design a risk-based monitoring programme for groundwater once Control levels, Trigger levels and their compliance points have been derived and agreed. If a hydrogeological risk assessment indicates 'requisite surveillance' for List I and List II substances, these should be incorporated into the routine monitoring programme for the landfill.

1.7.2 Relationship to other sampling guidance

Standardised information and protocols (Environment Agency, 1998) for undertaking sampling programmes have been developed by the Agency and should be used in conjunction with this guidance.

Further guidance on sampling and measurement methodology is contained within the national and international standard documents developed by the Standing Committee of Analysts (1996) and the International Standards Organisation. Where appropriate, reference is made to these documents.

1.8 Structure of documentation

This guidance provides an overview of key issues relevant to the management and implementation of leachate, groundwater and surface water monitoring programmes at permitted landfill sites. Its main aim is to provide sufficient information to understand the purpose of monitoring programmes and the main elements of work required for PPC permitting. It is divided into three parts, as follows.

Part 1: Context (Chapters 1 to 2)

Introduction (Chapters 1 and 2).
Sets out the aims and content of the guidance and provides a brief review of the characteristics and origin of landfill leachate and how leachate can give rise to pollution of water.

Part 2: Monitoring philosophy (Chapters 3 to 7)

Monitoring principles (Chapter 3).
Outlines the principles that underpin the development of landfill monitoring guidance.

Reviewing risks (Chapter 4).
Describes how risks to groundwater and surface water receptors from landfill leachate should be evaluated to help define the aims of monitoring programmes and focus monitoring effort.

Design issues and monitoring schedules (Chapters 5 and 6).
Describes the objectives and the issues to be addressed in designing a monitoring programme based on an evaluation of risks. Examples of monitoring schedules for high or low risk settings are presented.

Assessment criteria (Chapter 7).
Describes the means by which monitoring results are assessed against agreed criteria, and how assessment investigations and contingency measures can be triggered.

Part 3: The practical aspects of monitoring (Chapters 8 to 10)

Design of monitoring points and monitoring methodology (Chapters 8 and 9).
Describes some of the practical issues associated with the design of monitoring points and the process of obtaining appropriate measurements and samples.

Data management and reporting (Chapter 10).
Describes the process of managing and reporting monitoring data with examples of reporting schedules and data presentation.

A series of supporting technical appendices are provided; these incorporate standard forms and additional supporting information on the design, construction and maintenance of monitoring points and monitoring methodology.

2.0 Landfill leachate and its effect on surrounding waters

2.1 Introduction

Every landfill is unique, in both the nature of its development and its environmental setting, so risk-based techniques should be used to design and tailor monitoring programmes. It is the task of those responsible for designing the monitoring programme to use these techniques.

Risk assessment should be a structured, practical aid to decision making that takes into account all of the site's unique features. The initial stage of any risk assessment involves the development of a conceptual site model, which defines the nature of the development and its hydrogeological setting, and incorporates all of the potential contaminative sources, pathways and receptors. The vulnerability of individual receptors should be evaluated against the hazard posed by a source (e.g. landfill leachate) and whether or not there are any migration pathways that could allow contaminants to migrate from the source to the receptor.

Harmful substances contained within a waste body represent the **hazard or source** of risk to groundwater and surface water receptors. This source is defined by:

- the amount of each substance present in the waste;
- the nature of each substance and the effects associated with it (e.g. toxicity);
- the mobility of each of these substances in the waste body and in water;
- the flow of water into and out of the waste body, controlled principally by the degree of containment offered by the landfill design and its geological setting.

The degree to which the source poses a risk depends on the presence of:

- a means of transport for the contaminants derived from the landfill (i.e. pathways). The potential **pathways** for contaminant migration include vertical percolation through the unsaturated zone, saturated and perched groundwater flows, as well as surface water flow;
- vulnerable water abstractions, resources or ecological systems, which could be affected by the contaminants (i.e. **receptors)** and for which quality standards may be available. For List I Substances, the receptor that should be considered is the groundwater directly beneath or adjacent to the landfill, without allowing any dilution in the receiving groundwater. For List II Substances, the primary groundwater receptor is the groundwater at the downstream site boundary. Secondary receptors for both List I and List II Substances could include adjacent surface water streams, public groundwater supply abstractions, ecological Sites of Special Scientific Interest (SSSI) and European Habitats sites etc.

It is important to realise that groundwater and surface water are both pathways and receptors.

Once the conceptual site model has been formulated, it is possible to determine both the hazards and the risks presented by the landfill to potential receptors. Monitoring programmes should be tailored to the site-specific conditions using the knowledge of the hazards and risks presented by the landfill. In cases of uncertainty, a precautionary approach to the scope of monitoring should always be followed until the uncertainty has been resolved.

The technical issues that underpin hydrogeological risk assessment and the development of the conceptual site model are presented in separate technical guidance (Environment Agency, 2000d, 2003b) that should be read in conjunction with this document. Notwithstanding this, a number of the key technical issues are discussed under the following headings:

Section 2.2 The landfill source term.

Section 2.3 The potential pathway terms.

Section 2.4 The potential receptor terms.

2.2 The landfill source term

2.2.1 Landfill classification

The Landfill Regulations require each landfill to be classified as being suitable for the disposal of hazardous, non-hazardous or inert wastes. The Regulations prohibit the disposal of hazardous and non-hazardous wastes in the same landfill except in specific circumstances (refer to Environment Agency, 2002e). Consequently, there are three separate classes of landfill, as follows:

- Hazardous Landfills;
- Non-Hazardous Landfills;
- Inert Landfills.

Associated with each of the above classifications is a series of the required minimum design and operational standards. Separate technical guidance that considers both site classification (Environment Agency, 2002c) and the associated design and operational standards (Environment Agency, 2003e) is available.

Historically, prior to the implementation of the Landfill Regulations, the nature of landfills has been more variable than the current classification. Consequently, for closed sites and for sites with areas of historic waste disposal, the waste types, designs and operational standards will be variable and may differ from the current requirements. Such variability could comprise areas where 'dilute and disperse', co-disposal and liquid waste disposal techniques have been applied.

With regards to the monitoring of leachate, groundwater and surface water, Regulation 14 of the Landfill Regulations requires that the monitoring measures, in Schedule 3, Paragraphs 3, 4 and 5, should be complied with for **all** landfill types. The monitoring programme for each landfill should therefore be both compliant with the Regulations' requirements and tailored to the hazards associated with the development and the risks presented to the surrounding ground and surface water environment.

2.2.2 Landfill leachate

Leachate Formation

Leaching occurs when soluble components are dissolved (leached) out of a solid material by percolating water. Leachate may also carry insoluble liquids (such as oils) and small particles in the form of suspended solids. Depending upon the nature of the waste types deposited at a site, there may also be potential for the introduction of additional contaminants as a result of biodegradation of wastes.

Almost any material will produce leachate if water is allowed to percolate through it. The quality of leachate is determined primarily by the composition and solubility of the waste constituents. If waste is changing in composition (for example through weathering or biodegradation), the leachate quality will change with time. This is particularly the case in landfills that contain non-hazardous municipal waste. The specific manner in which a landfill site generates leachate is highly dependent upon the wastes accepted at the site, which in turn is intimately related to the site's classification under the Landfill Regulations. The stages in the generation of leachate set out below are representative of landfills that have received non-hazardous municipal wastes:

- Leachate produced in the early stages of decomposition of waste is typically generated under aerobic conditions that produce a complex solution with near neutral pH. This stage generally only lasts a few days or weeks and is relatively unimportant in terms of leachate quality. However, because aerobic degradation produces heat, leachate temperatures can rise, sometimes as high as 80–90ºC, and if this heat is retained it can enhance the later stages of leachate production.
- As decomposition processes develop, waste becomes anaerobic. At the early anaerobic stage (the acidogenic/acetogenic phase), leachate develops high concentrations of soluble degradable organic compounds and a slightly to strongly acidic pH. Ammonium and metal concentrations also increase during this phase. Even small quantities of this high-strength leachate can cause serious damage to surface water receptors.
- After several months or years, methanogenic conditions are established, and the leachate becomes neutral or slightly alkaline, and of lower overall concentration, but it still contains significant quantities of some pollutants (e.g. ammonium).
- As biodegradation nears completion, aerobic conditions may return, and the leachate will eventually cease to be hazardous to the environment.

Leachate hydrology

Leachate within the body of a landfill site is rarely static. Water enters the landfill principally as rainfall infiltrating from the surface, but in some cases also as surface or groundwater inflows (Figure 2.1). Any resultant leachate, which is not contained and managed within the site, could seep through the base or sides of the site or overspill to the surface. Leachate may also be pumped out of the site for treatment, disposal or recirculation (Figure 2.2).

An awareness of the overall 'water balance' is needed to design an effective monitoring programme. The water balance can be summarised by the following simplified equation:

***L* = total liquid inputs – total liquid outputs**

where ***L*** is the amount of liquid contained in storage within the waste.

This simplified equation should be tailored to allow the design of leachate management systems, on a site-specific basis, by considering *inter alia* the infiltration into open and capped cells, the absorptive characteristics of the waste and the rate of waste input.

Landfill hydrology is highly dependent upon the nature of wastes received at a site and the site's landfill classification. Detailed information relating to the determination of landfill water balances, for all landfill classifications, and the required components is provided within separate guidance (Environment Agency, 2003d).

The leachate stored in the waste is not fully available to drain to the base of the site. Some is absorbed by the waste, and some may remain 'perched' above low permeability layers at higher levels in the waste body. The presence of perched bodies of water can cause difficulties in understanding leachate storage from the simple observation of leachate levels.

The rate of infiltration of leachate through waste is the main factor that affects the time needed to achieve waste stabilisation. Consequently, an understanding of the landfill water balance will give an indication of the design life of the site and its monitoring system.

Leachate composition

The composition of any leachate is totally dependent upon on-site landfill conditions and the nature of the deposited waste-types. Consequently, although broad generalities can be made for common waste and leachate types, every leachate should be viewed as being potentially unique.

Much research has been carried out on the composition of landfill leachate, particularly for non-hazardous sites that have received primarily biodegradable wastes (Department of the Environment, 1995; Knox et al 2000; Environment Agency, 2003c).

A separate technical document that provides guidance on the potential composition of some 'post-Landfill Directive' leachates has been prepared by the Environment Agency (2003c).

It is important to stress that an accurate understanding of leachate quality is critical to the assessment of the landfill, particularly the presence of substances on Lists I and II of the Groundwater Regulations.

2.2.3 Leachate leakage from the landfill

While well-engineered landfill sites are unlikely in the short term to leak at rates that will cause any significant impact on water receptors, even the best-engineered landfill sites will leak to some extent. This principle underlies the design of all modern landfill sites.

The rate and location of leakage is determined by:

- the type of material forming the base, sides and capping to the site;
- the head of leachate on the base and sides of the site;
- the groundwater level or piezometric head outside the site;
- the presence of preferential flowpaths (e.g. overspills to surface, boreholes penetrating the landfill base or other damage to engineered containment structures).

The presence of preferential flow paths can dominate leachate egress from any site, and monitoring should take account of potential design weaknesses as well as designed leakage mechanisms, such as seepage through the site base (Figure 2.2).

Although it is accepted that all engineered lining systems leak to some extent, all landfill sites need to comply with the Groundwater Regulations, which requires the management or disposal of listed substances so as to prevent groundwater pollution. More specifically, essential and technical precautions need to be in place to prevent:

- discharges of List I Substances to groundwater;
- discharges of List II Substances that cause pollution of groundwater.

Figure 2.1 Landfill hydrology and water balance components

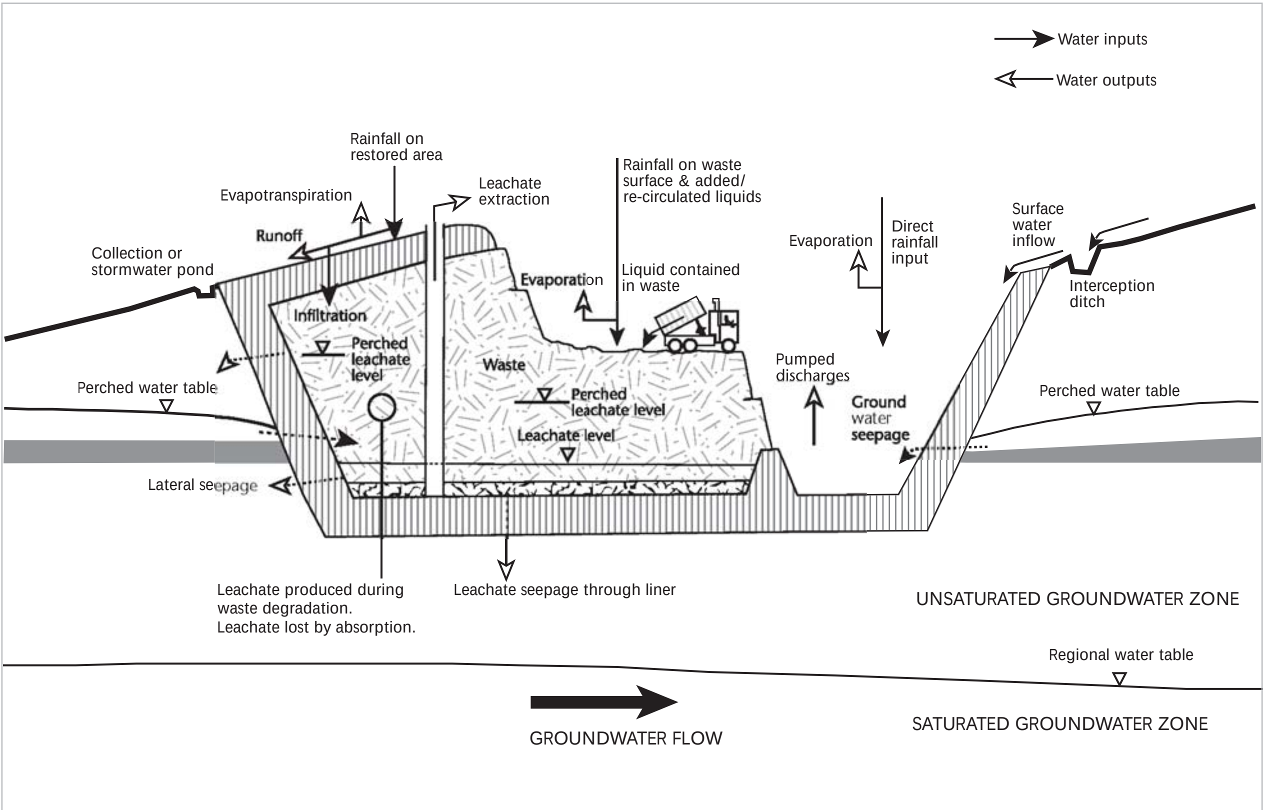
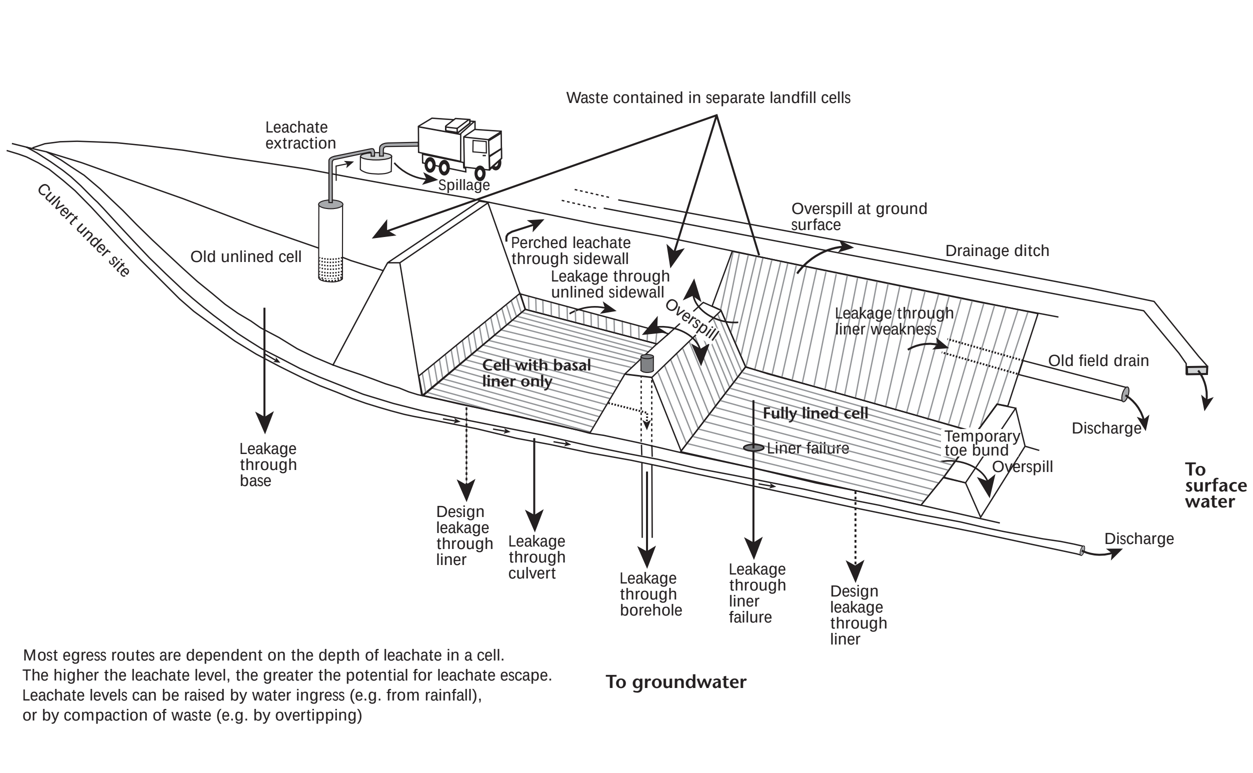


Figure 2.2 Examples of leachate egress routes



2.2.4. Designed leakage – 'acceptable release rates'

The concept of an 'acceptable release rate' for landfill lining systems is based on recognition that all engineered structures do leak to some extent and have a defined lifetime and design limitations. While it is possible that the best of engineered landfill sites will contain and control leachate with minimal leakage, there is always a probability that some failure in engineering will occur.

Groundwater quality may change as a result of leakage of leachate through the landfill liner system. Design performance standards, including risk-based limits of acceptable leakage (which take into account the physical and attenuating properties of the lining systems and underlying strata), should be agreed between the operator and the Agency at the time of site design. The hydrogeological risk assessment of a landfill determines what could be regarded as an acceptable release rate for that particular site setting and set of site circumstances. Integral to this assessment should be the derivation of groundwater Control and Trigger levels, which should be used to determine whether the landfill is performing as designed. For monitoring purposes, these Control and Trigger levels should encompass a range of carefully selected indicator chemical determinands and should be reviewed in the light of ongoing monitoring data.

Detecting water-quality changes and identifying clear breaches of established limits can be a complex process, particularly in the presence of natural cyclic variations in quality and diverse land-use practices that surround many landfill sites. Further guidance is provided in Chapter 7.

Leakage may be:

- diffuse, as in the case of a well-engineered mineral or composite (mineral and flexible membrane) liner;
- discrete, as in the case of a flexible membrane liner, without any underlying mineral liner, with the potential for localised pinhole or tear damage.

Where discrete leakage is possible, monitoring programmes should be designed to detect leakage from small point sources – possibilities include leachate detection layers, resistivity arrays in the unsaturated zone and strategically spaced groundwater-monitoring boreholes.

In comparison, around a site where diffuse leakage may occur:

- monitoring points may be more widely separated;
- attenuation of contaminants during seepage through mineral liners and any underlying unsaturated strata may be significant. If attenuation in the liner or unsaturated zone can be quantified, and risks justified, there may be grounds to reduce monitoring intensity.

2.3 The potential pathway terms

2.3.1 Groundwater flow

The behaviour of groundwater is a complex subject that forms a science in its own right (e.g. Price, 1996). Once leachate emerges through the base of a landfill, it begins to disperse. The direction and rate of this dispersal is determined by:

- the properties of the soil or rock (geology);
- the prevailing groundwater flow conditions (hydrogeology);
- the presence of artificial or natural voids (e.g. mineshafts or caves).

As discussed above, the development of the conceptual site model, which integrates all of the relevant geological and hydrogeological information, is essential to determine both the appropriate source–pathway–receptor terms, as well as the resultant potential risks to water resources. Both of these should be used to decide on monitoring locations and frequencies.

In terms of groundwater flow, the subsurface may be divided into two generalised physical zones:

- the unsaturated zone (above water table);
- the saturated zone (below water table).

Water movement through the unsaturated zone is predominantly downward (gravity driven) until it reaches the water table. Flow through the saturated zone follows the prevailing groundwater gradient. In granular formations without fissures or conduits, unsaturated zone flow is commonly much slower than saturated zone flow, though flow rates can still vary over several orders of magnitude. When fissures or conduits are present, flow rates can approach those found in surface waters (see Section 6.4.6).

An important element of the conceptual site model is the determination of Environmental Assessment Limits (EALs) that are appropriate for the groundwater located beneath and/or adjacent to the landfill. These limits are an integral element of groundwater Trigger-Level determination (Environment Agency, 2003b) and a breach of such a limit may be consistent with the aquifer having been polluted if there are no natural reasons for the breach.

2.3.2 Surface water flow

In comparison with most groundwater flow, surface water flow may be:

- rapid, with the result that contaminants can be transported to a receptor in minutes to hours, rather than days to years;
- of high volume, offering large dilution of contaminants;
- seasonally variable and liable to rapid fluctuations over short time periods, which results in large variations in dilution potential;
- capable of carrying contaminants within sediment load as well as in solution.

The consequence of these factors is that risk assessment should be cautious and take account of the lowest flows in surface water courses, and the frequency of high intensity rainfall events (necessitating careful timing of flow monitoring). Furthermore, quality monitoring should be designed with an understanding of the short travel times involved. This latter issue can be resolved in two ways:

- by accepting that quality monitoring is a 'spot check' rather than an effective early warning system;
- by monitoring at more frequent intervals related to travel time, or continuously in situations where downstream receptors are sensitive to short-term contaminant loadings.

Biological monitoring of surface waters can detect pollution incidents that have occurred in the preceding weeks or months. This type of monitoring also provides an opportunity to detect pollution by its effects, rather than relying on a set of chemical analyses that may or may not include the specific pollutant.

2.3.3 Attenuation of leachate contaminants

Attenuation is the decrease in contaminant concentrations or flux through biological, chemical or physical processes, individually or in combination (e.g. dilution, adsorption, precipitation, ion exchange, biodegradation, oxidation and reduction).

- ***Attenuation in groundwater*** – As water flows through soil and rock in both the unsaturated and saturated zones, a continuous interaction occurs between substances dissolved in the water and substances in the soil or rock. There is an increasing body of research investigating the practicalities of utilising attenuation mechanisms to manage the impacts of contaminant migration (Mather, 1977; Christensen et al., 1994; Mather et al., 1997; Thornton et al., 1997) and specific guidance relating to these processes is provided elsewhere (Environment Agency, 2000a);
- ***Attenuation in surface water*** – The principal means of attenuation in surface water is dilution caused by advection and dispersion. Other (slower) processes include deposition and adsorption onto sediments, volatilisation and degradation of contaminants.

Where attenuation is relied upon in any site, monitoring programmes need to be tailored specifically to identify in detail the flow mechanisms, attenuation processes at work and the capacity of these mechanisms to reduce the concentration of contaminants. In these instances, a robust risk assessment is essential.

2.4 The potential receptors

Receptors may be of value in one or more of the following categories:

- ***Groundwater beneath the site*** – For List I Substances, as defined by the Groundwater Regulations, compliance should be assessed prior to any dilution in the receiving groundwater;
- ***Groundwater at the down-gradient boundary*** – For List II Substances, as defined by the Groundwater Regulations, alternative receptors may be appropriate as compliance points;
- ***Abstractions*** – public and private water abstractions for potable, industrial, agricultural or other legitimate use;
- ***Potential water resources*** – currently unused groundwater or surface water bodies that are potentially usable in future – In particular, groundwater beneath the site itself may be a sensitive receptor;
- ***Biodiversity (ecological value)*** – surface water bodies, including wetlands that support a variety of living organisms;
- ***Amenity*** – a surface water body used for leisure pursuits (e.g. fishing, sailing).

Table 2.1 | Some potentially deleterious properties of leachate on water receptors

Impacts	Leachate component	Short-term impact	Long-term impact
Primary impacts	High suspended solids	Reduction of light-inhibiting macrophyte growth, sedimentation causing smothering of aquatic life, organic particles increasing deoxygenation through microbial breakdown.	Habitat alteration, adsorbed pollutants increase toxicity
	High dissolved solids	Increased salinity altering ecology and reducing value of surface waters for abstraction	Groundwater contamination
	Dissolved toxic compounds	Direct toxicity to humans (e.g. toxic metals, trace organic compounds) or to aquatic life (e.g. from ammonia toxicity to fish)	Biomagnification Bioaccumulation
	Immiscible organic chemicals (e.g. oils and solvents)	Direct toxicity, reduction in reoxygenation rates through water surface, oil coating of plants and animals	Carcinogenic and mutagenic effects on aquatic life Deoxygenation
	High oxygen demand	Deoxygenation of surface water; few plants, invertebrates or fish can survive total deoxygenation	Deoxygenation, ecosystem changes
Secondary (minor) impacts	Organic and biological contamination	Reduced oxygen levels. Contamination of surface waters used for: human potable supplies, irrigation of food crops and recreational waters	Deoxygenation, ecosystem changes; possible contamination of potable groundwater resources
	Nutrients (e.g. nitrate)	Plant/algal blooms	Eutrophication
	Gassing	Direct toxicity to aquatic life	

Leachate contamination may affect receptors in a number of ways depending on the contaminant loading of leachate and the nature of the receptor. A summary of some of the potential effects is given in Table 2.1.

A reasoned design of monitoring programmes for a landfill requires a risk assessment to be undertaken to identify and prioritise risks to each potential water receptor in the vicinity of the site (Chapter 4).

Part 2 Monitoring philosophy

3.0 Monitoring principles

3.1 Introduction

This chapter sets out a number of key principles that underpin the more detailed guidance on the monitoring of landfill leachate, groundwater and surface water given in Part 3 of this document.

This chapter is presented in the following sections:

Section 3.2 describes the purpose of monitoring in terms of landfill site management;

Section 3.3 sets out the importance and function of quality assurance (QA);

Section 3.4 describes the importance of risk assessment in designing monitoring programmes;

Section 3.5 describes statistical issues relevant to monitoring;

Section 3.6 categorises differing monitoring programmes;

Section 3.7 introduces the Environmental Management and Monitoring Programme.

3.2 Purpose and context of monitoring

3.2.1 The purpose of monitoring and the requirements of the Landfill Regulations

Environmental monitoring plays a central role in landfill risk assessment and management and is undertaken to gain information before the start of operations (i.e. to determine the baseline conditions) and during the lifetime of the landfill.
More specifically:

- Regulations 14 and 15 of the Landfill Regulations require landfill operators to carry out monitoring programmes as specified in Schedule 3 of the Regulations during both the operational and after-care phases of site development. Annex III sets out minimum requirements for the monitoring of leachate, groundwater and surface water (Sections 5 to 10). The Regulations also require the operator to notify the competent authority (the Agency) of any significant adverse environmental effects, as revealed by the control and monitoring programme, and to follow the decision of the competent authority on the corrective measures to be taken. With regards to groundwater, this determination should be made using the site's Control and Trigger levels (Environment Agency, 2003b). As a minimum, the operator must also report, at least once a year, all monitoring results to the Agency;
- Schedule 4, Section 1(1)(i) of the PPC Regulations 2000, states that a permit application must include "the proposed measures to be taken to monitor the emissions" into the environment. Regulation 12(9)(e) requires that the permit must contain suitable emission-monitoring requirements and an obligation to supply the Agency with data required to check compliance with the permit. Regulation 12(9)(f) also requires the landfill operator to regularly inform the Agency of the monitoring results and without delay of any incident or accident that is causing or may cause significant pollution.

Monitoring includes measurements undertaken for compliance purposes and those undertaken to assess landfill performance. In this document, the terms compliance and assessment have the following meanings:

- **Compliance**

  the process of complying with a regulatory standard (e.g. maximum leachate head). Under the Landfill Regulations, the compliance level for groundwater quality is specifically termed a 'Trigger level'.

- **Assessment**

  the process of evaluating the significance of a departure from baseline conditions by reference to an adverse trend in data or the breach of a specified limit. Under the Landfill Regulations, the assessment criterion for groundwater quality is specifically termed the 'Control level'.

Assessment Criteria and Compliance Levels – A Simple Analogy

Monitoring a car's speedometer is an essential precaution needed to be carried out by a driver to ensure correct and safe management of the vehicle.

Under normal circumstances, a car driver maintains a speed that is appropriate for the local environment and the nature of the car. In this situation:

- There may be a variety of **assessment criteria** that the driver may use to indicate that the car is travelling in an undesirable manner. These criteria do not represent the statutory speed limit, but could involve a variety of conditions and speeds depending on the site-specific circumstances. For example, the rate of acceleration, the absolute speed of the vehicle given the conditions of the road, etc. Temporary breaches of assessment criteria need to be corrected so as to regain control of the vehicle, but they are not statutory offences.

- **Compliance levels** are, however, analogous to a road's speed limit. If drivers exceed the speed limit they are committing a statutory offence and are liable to prosecution irrespective of whether they feel the vehicle was out of control or not. Different speed limits are appropriate for different road conditions and environments. Lower speed limits are set for more sensitive locations (e.g. outside schools, in residential areas), while motorways warrant higher limits.

3.2.2 The monitoring process in the context of site management

As discussed above, monitoring has a central and continuous role to play throughout the planning, permitting, operational and post-closure phases of every landfill site, only ending on issue of a certificate of completion (Figures 3.1 and 3.2).

Figure 3.2 illustrates the overall framework that governs the landfill monitoring process, with cross-references provided to the appropriate sections of this document. Within this framework, the primary monitoring processes involved are to:

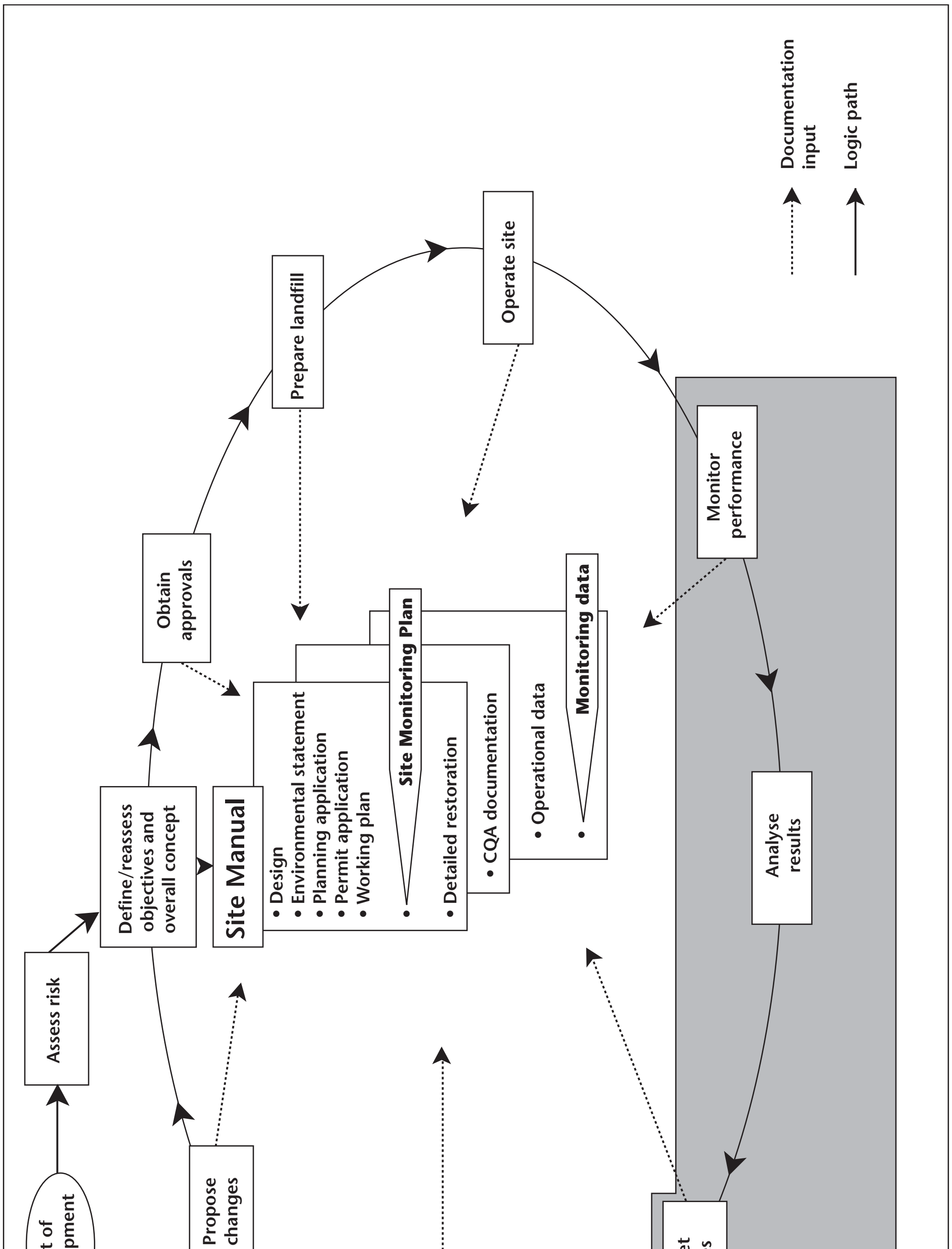
- establish objectives and standards in relation to risk (see Chapters 4 and 5);
- design monitoring programmes to meet objectives (Chapters 6 and 7);
- install and maintain monitoring infrastructure (Chapter 8);
- gather monitoring data (Chapter 9);
- compare monitoring data with design objectives to indicate success or failure (Chapter 10);
- respond to any leachate impacts (either by further monitoring or remediation) (Chapters 7 and 10).

The approach to monitoring adopted in this guidance requires that monitoring should be:

- quality assured;
- based on an understanding of the risks posed by the site;
- statistically justifiable.

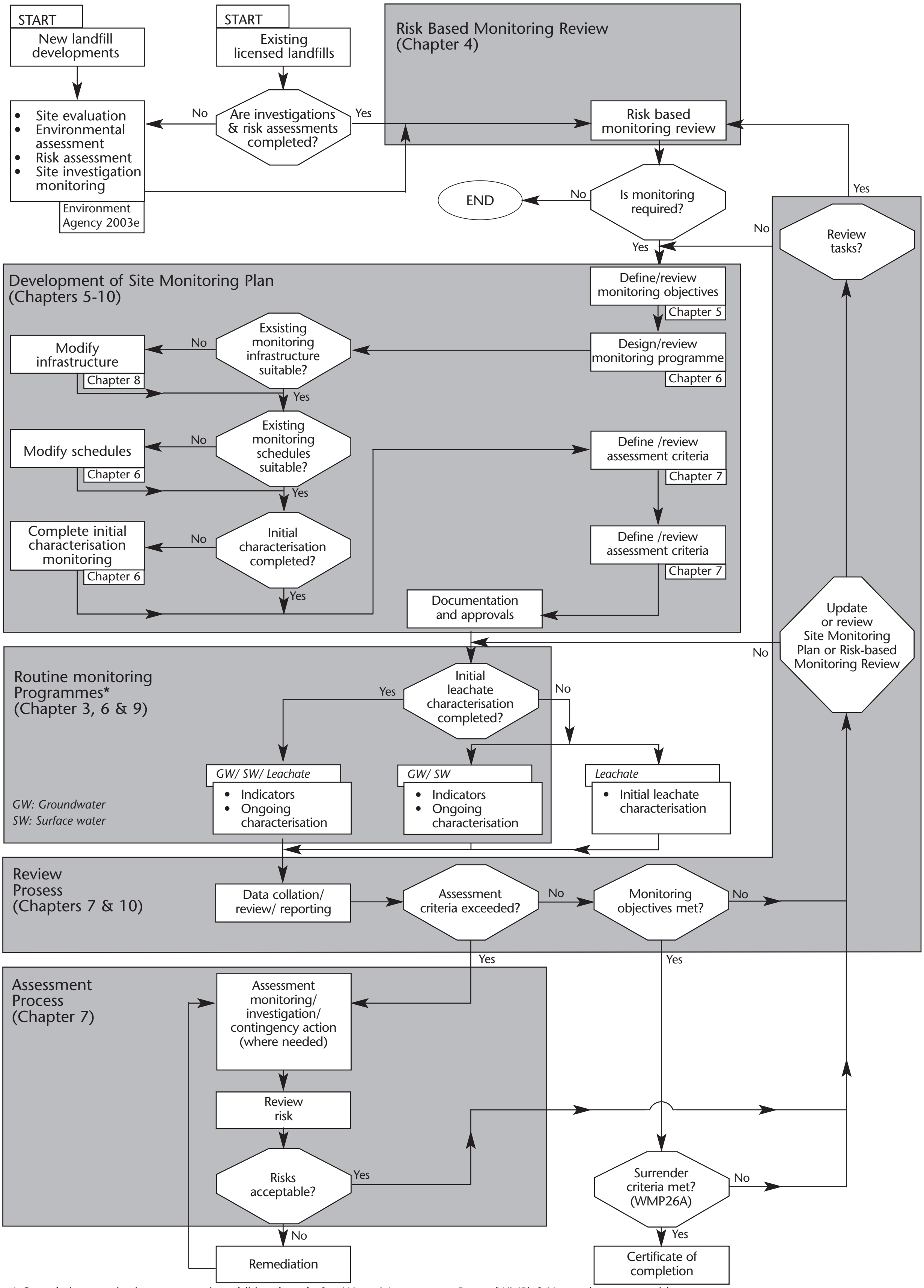
These issues are dealt with in the following three sections.

Figure 3.1 Flow chart showing the context of site monitoring within the framework of landfill development and permitting



Adapted from Waste Management Paper 26B, Figure 3.1

Figure 3.2 | Flow chart of the monitoring process



* Completion monitoring may require additional work. See Waste Management Paper (WMP) 26A or subsequent guidance.

3.3 Quality assurance

Data gathered during monitoring programmes need to be reliable and fit for their intended purpose. As required by the PPC Regime, QA and QC protocols should be incorporated into all elements of the development of monitoring infrastructure and monitoring programmes. Documentation that specifies QA procedures should be included within the specific site monitoring and/or management plan (see below).

QA plans should specifically address the following issues.

- certification of monitoring infrastructure (Chapter 8).
  This should be seen as an extension of normal construction quality assurance (CQA) procedures applicable to other landfill engineering practices.
- consideration of appropriate methods of sampling, laboratory analysis, data handling, interpretation and reporting (Chapter 9)

QC procedures are used to assess the adequacy and appropriateness of sampling and measurement strategies (Chapter 9).

Regulation 14(6) of the Landfill Regulations requires the quality control of the analytical operations of the control and monitoring procedures to be carried out by competent laboratories (e.g. those subject to a third party accreditation scheme).

3.4 Monitoring in relation to risk

3.4.1 General risk assessment requirements

As discussed above, a landfill site's monitoring programme needs to be designed and tailored according to the site's setting and the degree of risk that it presents to the environment. Separate technical guidance details the required risk assessment process (Environment Agency, 2003b). However, in summary, the risk assessment process needs to include:

- development of an accurate conceptual site model that integrates all of the available information and defines the appropriate sources, pathways and receptors;
- screening and prioritisation of the risks;
- the need to match the effort required with the potential risks;
- the need for an appropriate level of essential and technical measures to manage the risk.

The risk assessment process needs to establish whether the site complies with both of the following:

- the Groundwater Regulations (i.e. List I substances are prevented from entering groundwater and the introduction of List II substances into groundwater is limited so as to avoid pollution);
- the Landfill Regulations (i.e. to provide the basis for deciding whether):
  - ◊ leachate needs to be collected, in accordance with Schedule 2, Paragraph 2(1)(c) of the Landfill Regulations;
  - ◊ the Landfill Regulations engineering measures, as set out in Schedule 2, Paragraph 3 are required, or can be reduced, to protect the groundwater and surface water, in accordance with Schedule 2, Paragraph 3(8) of the Landfill Regulations.

In addition to the above, the Landfill Regulations also require that groundwater Control and Trigger levels are determined in order to identify whether the site has had a significant adverse environmental effect. This determination process should be carried out as part of the risk assessment process.

A monitoring programme should be designed to test critically and review the site's compliance with the above requirements. It should also take into account the risks presented by the landfill and the nature of the pathway and/or receptor terms.

3.4.2 Risk-based monitoring review

This guidance formalises the risk-based approach to landfill development and management by recommending a risk-based approach to the formulation of monitoring programmes. These should be a natural extension of the hydrogeological risk assessment work carried out for a site (Environment Agency, 2003b), and should draw upon information such as the conceptual site model, the appropriate sources, pathways and receptors, the Control and Trigger levels for the landfill and the estimated potential risks presented to the environment.

The risk assessment process should involve the preparation of a 'risk inventory', which rationalises and prioritises the pathways and receptors that should be monitored. This inventory should form the basic design tool for specifying the details of monitoring locations and schedules. The specific preparation of the risk-based monitoring review is described in Chapter 4.

3.5 Statistical aspects of monitoring

3.5.1 Introduction

The design of monitoring programmes and the interpretation of data should follow sound statistical principles. For example, a statistical understanding of the variation of a measurement prior to commencement of landfill construction and operation may help to:

- avoid wrongly attributing changes in the environment to the impact of landfill leachate;
- provide a justification for increasing or decreasing the sampling frequency, or for changing the analytical method and QC procedures.

Statistical principles applied to good laboratory practice are described in the document published by the Standing Committee of Analysts (1996) and in other standard texts (Cheeseman and Wilson, 1989), while specific guidance relating to the interpretation of groundwater quality has been prepared separately (Environment Agency, 2002d).

The two areas for which statistical methods are most applicable to monitoring are:

- ***monitoring programme design*** – i.e. the collection of a valid baseline data set, the choice of measurement frequencies and the specification of the reliability of measurement methods;
- **assessment of monitoring data** – i.e. the use of appropriate statistical tests to determine whether an impact is significant.

Guidance on the principles and terminology used in this document is provided in the following sub-sections.

3.5.2 Baseline data

To be able to use monitoring data to detect impacts from leachate, the normal pattern of variation in a monitoring record needs to have been established at an early stage in the monitoring process.

Baseline (or background) monitoring data are defined in this document as measurements that characterise physical, chemical or other distinctive properties of groundwater and surface water unaffected by leachate contamination. Monitoring data, including those collected during and after operation of the landfill, remain part of the baseline record until a significant deviation from the established pattern of baseline variation is identified (Figure 3.3). It is important to note that this definition of baseline refers to data and not to any particular monitoring points or monitoring programmes.

Data can be compared with baseline monitoring records in two ways.

- ***comparison with the historic baseline*** – this may be undertaken by comparing data from individual or groups of monitoring points with historical trends in the same monitoring point(s);
- ***comparison with up-gradient or remote monitoring points*** – this may be undertaken by comparing individual or groups of monitoring points down-gradient of the landfill with up-gradient or remote monitoring points in the same groundwater body.

3.5.3 Specifying reliability and frequency of measurements

To specify the reliability and frequency of a measurement, it is necessary to have an understanding of the certainty with which the measurement results must be known. This in turn is determined by the baseline variability of that measurement, and the amount of deviation from the norm that would give cause for concern (significant deviation). This sub-section defines these concepts as they are used in this guidance.

Uncertainty

Ideally, monitoring measurements should represent the actual conditions being sampled, and should not be subject to uncertainty. In practice, however, all physical, chemical and biological measurements have errors associated with them. The presence of these errors leads to a degree of uncertainty in the quoted result. Numerical uncertainty has been defined as:

"the interval around the result of a measurement that contains the true value with high probability" (Thompson, 1995).

Uncertainty in a final measurement result arises from the following sources:

- poorly understood variations that occur naturally (e.g. seasonal variations) or as a result of contamination[3];
- random fluctuations in the performance of the sampling and measurement systems (random errors);
- bias introduced by the sampling and measurement systems (systematic errors) – unless it can be predicted and corrected, bias is also a source of uncertainty.

Sampling and measurement errors affect the accuracy and precision of measurement results (see Section 9.13.2).

Baseline variation

A baseline monitoring record displays variations in data that incorporate all of the above sources of uncertainty to a greater or lesser degree (e.g. Figure 3.3). The total variability in a measurement value in the absence of landfill development can be identified from a good baseline record. For practical monitoring purposes, the initial baseline variation should be determined following the initial period of characterisation monitoring (Figure 3.3).

Significant deviation

The significant deviation may be estimated by a fixed-limit value used either for compliance or assessment purposes (e.g. the groundwater Control and/or Trigger levels). In these situations, the reliability of the data in relation to the fixed-limit value becomes critical. The closer data are to the limit value, the more reliable they need to be (i.e. uncertainty needs to be minimised).

In other situations, the choice of significant deviation may be an operational decision (e.g. to provide adequate warning of a potential problem) or may be related statistically to baseline variability.

The use of limit values and assessment criteria to define significant deviation is discussed further in Section 3.6.4 below, and in Chapter 7.

Tolerable uncertainty

The purpose of a measurement should be to provide a result so that it is possible to distinguish a significant deviation from the 'normal' variability of that measurement. The 'tolerable uncertainty' for a measurement is defined here as the degree of uncertainty that is acceptable without compromising the purpose of the measurement.

Tolerable uncertainty is specified by the operator to enable effort to be focussed on measurements for which greater reliability is required, and to avoid wasted effort where reliability is less of an issue. A tolerable uncertainty should be specified, as a minimum, for all 'indicator' monitoring measurements, and preferably for all measurements. It may be stated as a fixed variation (e.g. ±10 mg/l) or as a percentage variation (e.g. ±25%) in the value of a measurement, as long as it achieves the purpose of expressing how certain a measurement needs to be.

In general, where measurements are close to compliance limits, the tolerable uncertainty needs to be as low as possible (i.e. greater QA is needed).

For measurements that are well below compliance limits greater tolerable uncertainty may be acceptable, depending on how significant deviation has been defined for that measurement. Tolerable uncertainty values can only be fully defined for a measurement after:

- sufficient baseline data have been collected
  the results of initial characterisation monitoring and any other subsequent baseline data are used to define the value and variability of the measurement in the absence of the landfill;
- the likely value of any assessment or compliance limit is known
  this defines the value of the measurement that would give cause for concern.

Since an initial characterisation monitoring has to be carried out before tolerable uncertainty is known, any initial monitoring should be undertaken with a high degree of QA (Section 9.13), assuming low tolerable uncertainty for all measurements.

[3] If these variations are understood and characterised, they can be accounted for and their contribution to uncertainty diminishes.

Once tolerable uncertainty values are established, these will help guide the most appropriate choice of:

- QC effort;
- methodology for obtaining samples;
- methodology for performing measurements;
- sample frequency;
- the number of samples needed.

The concept of tolerable uncertainty therefore allows sampling programmes to be designed to achieve results appropriate for their intended purpose. For this reason, the term 'appropriate sample' is used in this guidance in preference to 'representative sample' (the latter term implies that uncertainty will be kept to a minimum at all costs). Use of appropriate sampling should mean that effective monitoring is carried out for minimum cost and effort. Tolerable uncertainty is not in itself a regulatory tool, although failure to apply the concept may lead to ineffective monitoring or unnecessary breaches of assessment limits, both of which would be the subject of regulatory attention.

Further guidance on specifying tolerable uncertainty is given in Section 6.3.5. Further discussion of errors and sampling QC is provided in Chapter 9.

3.5.4 Assessing monitoring results

For monitoring to serve its purpose, data must be assessed in relation to both assessment criteria and compliance limits (e.g. groundwater Control and Trigger levels). Predetermined contingency plans need to be implemented following the breach of an assessment or a compliance limit. An 'assessment criterion' is a statistically robust means of determining whether a limit has been breached or an adverse trend has developed.

Assessment criteria should be set:

- with due regard for the normal pattern of variation in the absence of the landfill, so that natural changes are not mistaken for landfill impacts;
- to detect genuine impacts as early as possible.

Circumstances may arise at some sites where there is ambiguity in differentiating between an impact arising from a landfill and the normal pattern of variation, particularly where other external sources of contamination are present. In these situations, consultation will be required between the site operator and the Agency to establish assessment criteria in the light of site investigation and monitoring results.

Assessment criteria should be proposed by the operator and agreed by the Agency. Where an unacceptable impact is confirmed as due to leachate, predetermined contingency actions need to be implemented.

Specific guidance relating to the above is presented within Chapter 7, and other guidance is given by the Agency (Environment Agency, 2003b).

3.5.5 Data management

The collection of large amounts of monitoring data necessitates the development of data management systems. Data need to be collated in a format that allows flexibility for data analysis and presentation, while safeguarding the integrity of the data. Data management should involve the means to validate and maintain the quality of data. For example, all data stored and manipulated on computers need to be validated carefully and cross-referenced against other archived paper records and original source material (Section 10.7).

Presentation of data in tabular and graphic formats, which are clear and intuitively understandable to personnel unfamiliar with a particular landfill site, is an important part of data management. A number of computerised geographic information systems (GIS), database and spreadsheet systems now make data management easier, and landfill operators are encouraged to utilise such systems for reporting purposes.

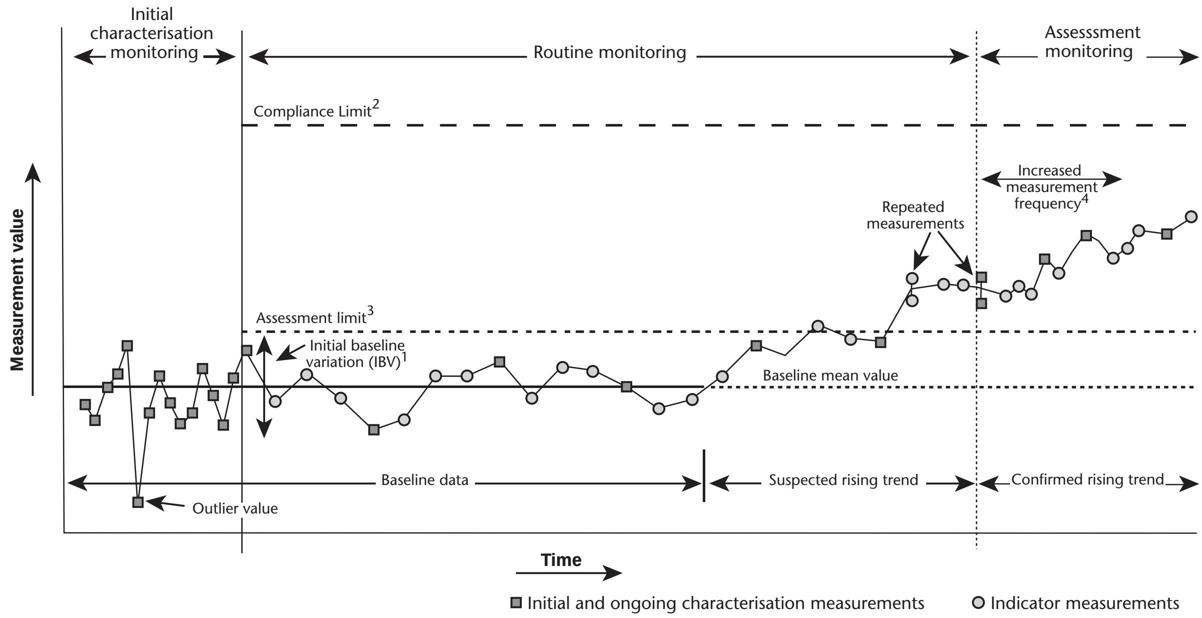
Specific technical guidance that touches upon the nature of data management for landfills has been prepared (Environment Agency, 2000h), while further guidance on the storage of data and information requirements for reporting is provided in Chapter 10. Chapter 7 sets out additional guidance on the use of graphic statistical methods to represent data trends.

3.6 Monitoring programmes

This guidance groups landfill monitoring programmes into five categories:

- initial characterisation monitoring of groundwater and surface water;
- routine monitoring of groundwater and surface water;
- leachate characterisation monitoring;

Figure 3.3 Illustration of statistical concepts in relation to landfill monitoring programmes.



1. Initial baseline variation (IBV) would typically be defined using a statistical measure of variation such as range or standard deviation.
2. Compliance Limit is a regulatory standard.
3. Assessment limit is for early warning puposes. It may be a fixed limit (as illustrated), a time varying limit (see Figure 7.1), or may be defined as an unacceptable rate of change umrelated to a specific limit.
4. Breach of the Assesssment Limit leads to implementation of preplanned contingency action, in this case assessment monitoring. Increased monitoring frequency could be accompanied by an increased range of indicator measurements.

- assessment monitoring (including Control and Trigger levels for groundwater);
- completion monitoring (Environment Agency, 2000c).

In addition to the above, the Agency periodically undertakes audit monitoring.

Monitoring of processes other than the landfill itself (e.g. fuel storage, discharge consents and leachate treatment) should also be managed as part of the integral monitoring of the site. Guidance for these is provided elsewhere and does not form part of this document[4].

Figure 3.3 illustrates how initial, routine and assessment monitoring programmes are related to the statistical concepts presented in Section 3.5. Explanatory notes for each of the five categories of monitoring programme are provided in the following sub-sections.

3.6.1 Initial characterisation monitoring of groundwater and surface water

Schedule 3, Paragraph 3(1) of the Landfill Regulations requires sampling to "be carried out in at least three locations before filling operations in order to establish reference values for future sampling".

Initial characterisation monitoring is a period of monitoring to define the normal range of variation in surface water and groundwater. The frequency and range of monitoring data collected need to be sufficient to be able to characterise seasonal and other non-landfill influences. A broad range of measurements is required because, in most cases, detailed characterisation of the water will not have been undertaken historically, and the detailed nature of future impacts could not be fully predicted.

For new sites, initial characterisation monitoring needs to be completed prior to commencement of infill in order to draft assessment and compliance conditions into the site permit or operational plan. At older operational or closed sites, where historic monitoring data are absent or inadequate, initial characterisation monitoring may need to be initiated at a later stage, using monitoring locations representative of conditions unaffected by the landfill.

4 See Environment Agency 'Consents Manual' (continuously updated) and Environment Agency, 2000: Consenting of Dangerous Substances in Discharges to Surface Waters. (Consultation draft).

3.6.2 Routine monitoring of groundwater and surface water

Routine monitoring of groundwater and surface water is undertaken to maintain continuity with the initial characterisation monitoring programme and to concentrate effort on comparing the performance of landfill operations with conditions specified in the site permit or authorisation documents. Routine monitoring can be divided into two parts, as follows:

- ***Indicator measurements*** – to provide more frequent monitoring of measurements specified for compliance purposes, and including a number of additional parameters capable of indicating impacts by leachate.

  Parameters to be measured most frequently would be selected from the results of initial characterisation monitoring programmes and incorporate anticipated leachate indicators (e.g. ammoniacal nitrogen, chloride and total organic carbon (TOC) are likely to be selected for biodegradable landfill sites). As the results of the initial leachate characterisation monitoring become available, indicators may need to be revised to reflect measured leachate characteristics.

  Schedule 3, Paragraph 4(4) of the Landfill Regulations recommends monitoring for pH, TOC, phenols, heavy metals, fluoride, As, oil/hydrocarbons.

- ***Ongoing characterisation measurements*** – a periodic repeat of the same measurements undertaken during the initial characterisation monitoring programme, but at a lower frequency than the indicator measurements.

This provides a periodic screening of all monitoring measurements. Other monitoring requirements may also be incorporated (e.g. requisite surveillance of groundwater as required by the Groundwater Regulations).

3.6.3 Leachate characterisation monitoring

Leachate characterisation monitoring is undertaken to provide a 'benchmark' of the source pollutants. The complexity of the processes involved in the production and evolution of leachate mean that significant variations are likely to occur in the composition and physical characteristics of leachate, both with time and between different parts of the landfill. Any monitoring regime should be sufficiently flexible to respond to site-specific changes that may occur in leachate levels and composition. It is usually during the process of infilling and restoration of the site, and the early stages of leachate production, that the greatest uncertainties arise in both the hydraulic performance of a landfill and in leachate quality. More intensive monitoring at these early stages is needed to maintain confidence in the ability of the landfill to maintain leachate levels below specified maxima and to demonstrate that leachate quality falls within the design parameters used for risk assessment or compliance purposes.

In this document, leachate characterisation monitoring is divided into two parts, as follows:

- initial leachate characterisation monitoring;
- routine leachate monitoring.

Initial leachate characterisation monitoring

This is an initial period of detailed monitoring undertaken until a recognisable pattern of change in leachate level and composition has been established. Typically, this would continue for a minimum period of two years following restoration of a landfill cell. Initial leachate characterisation monitoring should begin as soon as possible after the first deposit of wastes, even if early results simply confirm the absence of free leachate.

Other characterisation monitoring programmes (e.g. screening of leachate for List I and List II Substances as part of a hydrogeological risk assessment) could also be initiated at this stage.

Routine leachate monitoring

Routine monitoring of leachate is undertaken primarily to compare the performance of landfill operations with conditions specified by the site licence or permit and consists of:

- ***Leachate indicator measurements*** – to provide more frequent monitoring of measurements specified for compliance purposes, and additional parameters that are likely to vary significantly between characterisation surveys.

For example, parameters to be measured most frequently could be those needed to monitor landfill design criteria (e.g. leachate levels);

- ***Ongoing leachate characterisation measurements*** – a periodic repeat of the same measurements that were undertaken during the initial leachate characterisation monitoring programme, but at a lower frequency. (Other monitoring requirements, such as periodic screening of leachate for List I and List II Substances, where this is specified as a consequence of a hydrogeological risk assessment, could also be considered to form part of the ongoing characterisation monitoring.)

3.6.4 Assessment monitoring

Assessment monitoring may include a combination of a greater intensity of monitoring (e.g. more frequent monitoring combined with an increased range of measurements) or site investigation.

The need for assessment monitoring could be triggered by a number of situations. For example, where significant departures from baseline or design conditions are identified, or where a greater degree of monitoring information is needed to define natural attenuation and migration processes.

3.6.5 Completion monitoring

Completion monitoring is part of a process conducted towards the end of a site's licensed or permitted lifetime in order to demonstrate that the landfill is no longer capable of harming human health or the environment.

Completion monitoring requires that a trend of improving leachate quality has been established by ongoing monitoring programmes. Consequently, all monitoring data collected up to this point form an essential part of the detail needed to demonstrate completion conditions. A completion report is needed to support the application to surrender a permit or licence and to demonstrate that waste stabilisation has been achieved. This may necessitate re-investigation, a period of more intensive monitoring and a re-appraisal of risk.

3.6.6 Relationship of monitoring programme categories to PPC landfill stages

Categorisation of monitoring programmes in PPC is based on five defined phases in the lifecycle of a landfill site:

Phase 1: Planning and Permitting (pre-landfilling);

Phase 2 (Landfill Regulations – Regulation 14): Operational Phases (during landfilling and final restoration);

Phase 3 (Landfill Regulations – Regulation 15): Post closure and aftercare period (from closure of site up to surrender of permit or licence);

Phase 4: Site Completion (surrender of permit or licence);

Phase 5 Afteruse.

The concepts of initial characterisation, routine and assessment monitoring do not always fit comfortably within these stages. For example, initial characterisation monitoring of groundwater and surface water should be completed during Phase 1. However, at existing operational or closed sites, where historic monitoring data are absent or where poor monitoring has been undertaken to date, it may extend into Phase 2 or even Phase 3. Routine monitoring should be the normal standard of monitoring from Phase 2 up to site completion (Phase 4). Assessment monitoring could occur at any stage, such as to investigate anomalous trends in monitoring data. During the fifth, afteruse phase, monitoring is unnecessary.

3.7 The site Environmental Management and Monitoring Programme

The technical specification for all landfill monitoring programmes should be incorporated into one updateable Environmental Management and Monitoring Programme for the site, so that all of the different monitoring regimes can be easily reviewed. This programme should include the:

- Leachate Management and Monitoring Plan;
- Groundwater Management and Monitoring Plan;
- Surface Water Management and Monitoring Plan;
- Landfill Gas Management and Monitoring Plan.

Each of these plans should include the proposed monitoring and sampling programmes, assessment criteria and compliance levels (e.g. groundwater Control and Trigger levels), the contingency action plan and the reporting procedure.

Guidance on the contents of the Environmental Management and Monitoring Programme(s) is presented in Part 3. These documents and their contents need to comply with the requirements of the PPC regime as set out in this document.

As with all PPC documentation, the site Environmental Management and Monitoring Programme should be reviewed by the site operator and updated regularly. Any changes should be agreed with the Agency.

4.0 Risk-based approach to monitoring

4.1 Introduction

The development of a landfill monitoring programme that is risk-related needs to be based on a thorough understanding of the site setting, the sensitivity of the surrounding groundwater and surface water to leachate pollution and the potential migration pathways between the site and each receptor (i.e. a robust conceptual model). A risk-based approach to monitoring is therefore an essential prelude to the proper design of a monitoring programme and should form part of the technical precautions identified as part of the risk assessment process. *In most circumstances, therefore, there will be no need for duplication of effort or reporting as the risk-based monitoring programme will be determined as part of the risk assessment process.*

The hydrogeological risk assessment carried out for the site should provide sufficient information relating to the conceptual model and the nature of the risks presented by the site. Separate guidance has been prepared for this process (Environment Agency, 2003b).

The hydrogeological risk-assessment should:

- produce a conceptual model of the site and surrounding area through prior investigation;
- determine the essential and technical precautions that should be taken;
- provide a technical rationalisation for the design of a monitoring programme, to focus monitoring effort on actual risks, as part of technical precautions;
- determine appropriate groundwater Control and Trigger levels for the site.

Accordingly, the hydrogeological risk assessment should result in the identification of risk-based monitoring objectives, particularly in respect of the groundwater Control and Trigger levels derived during the assessment.

In the absence of the need for a hydrogeological risk assessment, a separate risk-based monitoring review should be undertaken. The information that this review should use, and its outputs, should be similar to those of a hydrogeological risk assessment, although the outputs should be focused exclusively on the monitoring requirements rather than on other technical precautions.

A review of water receptors at risk, and how these can be monitored effectively, presents technical and commercial benefits for operators and technical benefits for the Agency. For example:

- at any type of landfill where there are few or no receptors at significant risk, the risk-based approach to monitoring may provide the means to justify a relaxation of monitoring programmes;
- at any type of landfill at which risks to receptors from landfill leachate are significant, the risk-based approach to monitoring should enable the monitoring strategy to be justified within a consistent policy framework.

Guidance in this chapter is presented in two parts:

Section 4.2 describes the review process;

Section 4.3 describes the documented outputs of the review, which should be incorporated into the Environmental Management and Monitoring Programme.

4.2 The review process

4.2.1 Introduction

The objective of the risk-based approach to monitoring is to bring together (and, if necessary, supplement) the data on risks to receptors, to provide a documentary record of the information used in designing the monitoring programme (see Section 3.4).

Issues required to be covered during the risk-based monitoring review exercise may already be adequately addressed within other documents (e.g. Baseline Site Reports, Hydrogeological Risk Assessments), in which case reference to these will be acceptable. For new sites, the production of risk-based monitoring plans and reviews should be part of the development strategy undertaken during the risk assessment stages of the planning and permitting process (Figure 3.1).

4.2.2 Review tasks

The main starting point for the review should be the development of a conceptual site model. For a new landfill, the main effort should be at the start of the site-planning process, while for existing sites the revision of the conceptual site model should be an ongoing process carried out in the light of additional information. Specific tasks within the review process are:

- identification of all receptors at potential risk;
- determination of the most stringent EALs for potential contaminants present, or potentially present, within the leachate. This indicates the potential sensitivity of the groundwater, as well as providing information that could be used to determine the appropriate Control and Trigger levels (Environment Agency, 2003b);
- an initial review of the risks posed by the site to the individual receptors throughout its lifetime and afterwards;
- prioritisation of risks to individual water receptors for monitoring purposes;
- periodic reassessment of risks to receptors during the lifetime of the site.

This should be undertaken in the light of the results of monitoring (particularly where there is any evidence of leachate impact), in response to changes in the development of a landfill, or where changes in surrounding land usage influence groundwater or surface water flow or quality. The maximum interval between reassessments should be no greater than that required for Groundwater Regulations reviews (maximum four years). Implementation of the Site's Contingency Action Plan may prompt earlier reviews.

4.2.3 Information requirements for the risk-based approach to monitoring

The risk-based approach to monitoring involves gathering technical information on the site design, construction, history and waste input alongside information on surrounding surface water and groundwater and other individual receptors at risk. Groundwater and surface water should be evaluated as both pathways and receptors. The review exercise should place the site within defined surface water and groundwater catchment areas, so that all external sources of contamination that may influence monitoring results are identified clearly.

The process of reviewing information may be a desk exercise for sites with existing site-investigation information and risk assessment. Other sites may require specific site investigation.

An example list of information to be collated and reviewed is presented in Table 4.1. For small sites with receptors at low risk, most of the information may be summarised in simple tabular format combined with a catchment plan that incorporates brief comments on the risks. For sites with receptors at greater risk, more detail is needed.

4.2.4 Uncertainties in risk assessment

It is possible that the risk-based approach to monitoring will reveal uncertainties, which can only be resolved by ongoing monitoring or investigation. For example:

- ambiguities arising as a result of contamination by neighbouring land usage;
- unusual natural water quality variations.

Even where risks to receptors are difficult to define, an Environmental Management and Monitoring Programme may still be formulated. This Programme should address uncertainties on a case-by-case basis, as agreed in consultation between the operator and the Agency. Specific objectives should be established for monitoring and further investigation. Where an Environmental Management and Monitoring Programme is being prepared prior to the issue of a permit, a statement should also be included to clarify at what stage of monitoring or investigation a permit could reasonably be issued.

4.3 Documentation from the risk-based monitoring review exercise

4.3.1 Review outputs

Specific outputs from a risk-based monitoring review exercise are similar to those associated with the groundwater risk-assessment process and may include:

- landfill hydrogeological setting (conceptual model)
  to illustrate a conceptual understanding of the groundwater and surface water setting of the landfill and identifying hydraulic relationships between the landfill and receptors at potential risk;
- landfill characterisation details
  summary of landfill geometry, waste input and design details that help to define the hazard posed by the site to groundwater and surface water;
- summary of conceptual site model (Environment Agency, 2000d) with associated risk inventory
  summary of receptors, pathways and risk prioritisation as a tool for directing monitoring effort.

Elements of each of these issues are highlighted in the following sections.

4.3.2 Hydrogeological setting drawings

To aid a conceptual understanding of the site setting in relation to surrounding groundwater and surface water, at least one drawing that encompasses the landfill site and any receptors at risk should be prepared.

Aerial photographs to illustrate land usage and geographic features, including surface water drainage patterns, can usefully supplement such a drawing.

For smaller sites in relatively simple hydrological settings, it may be possible to produce a single drawing that encompasses all the relevant water interests in the area. For larger sites in more complex environments, a series of drawings and sections may be necessary to differentiate, for example, between groundwater flow in multiple systems, or to illustrate the pathways to individual groundwater and surface water receptors.

Groundwater catchments may be shaped irregularly where flow is influenced by fissure flow, man-made conduits, pumping from boreholes or dewatering operations. In most cases the production of hydrogeological setting drawings will be a matter of judgement based on an understanding of the local hydrology and hydrogeology, but it should be recognised that there are many inherent difficulties and uncertainties in producing these. Where uncertainties exist that are relevant to the design of a monitoring programme, catchment boundaries should be reviewed and agreed with the Agency.

In general, the drawing(s) and section(s) should illustrate:

- Each groundwater system in which there are receptors at potential risk. These should illustrate the recharge area up-gradient of the landfill site and the discharge points down-gradient. The area down-gradient of the site, which could potentially be affected by leachate contamination, should be drawn with allowance made for possible lateral dispersion of contamination diverging from flow lines. Groundwater level contours should be shown (Figure 4.1).
- Surface water catchment of each discharge point from the site at the point of entry into an off-site water course.
- Surface water catchment of points of discharge to surface water courses from groundwater seepage.
- Catchments where other external land users impact on the same water systems.
- Abstractions and other receptors should be shown on the hydrogeological setting drawings. Deflection of groundwater contours in the vicinity of groundwater abstractions should be shown to illustrate the current or future recharge capture zone for each source.
- Hydrogeological setting drawings should show geographic features clearly and include a scale and north-point.

The purpose of these drawings is:

- to place the landfill in the context of surrounding land use
  to identify the potential influence of the landfill and neighbouring activities on groundwater and surface water;
- to identify the hydraulic relationship between water receptors in the area of the landfill site
  for example, wetlands, boreholes, groundwater seepage to stream courses;
- to define the area available for groundwater recharge up-gradient of the site
  to provide information to support groundwater flow calculations where appropriate.

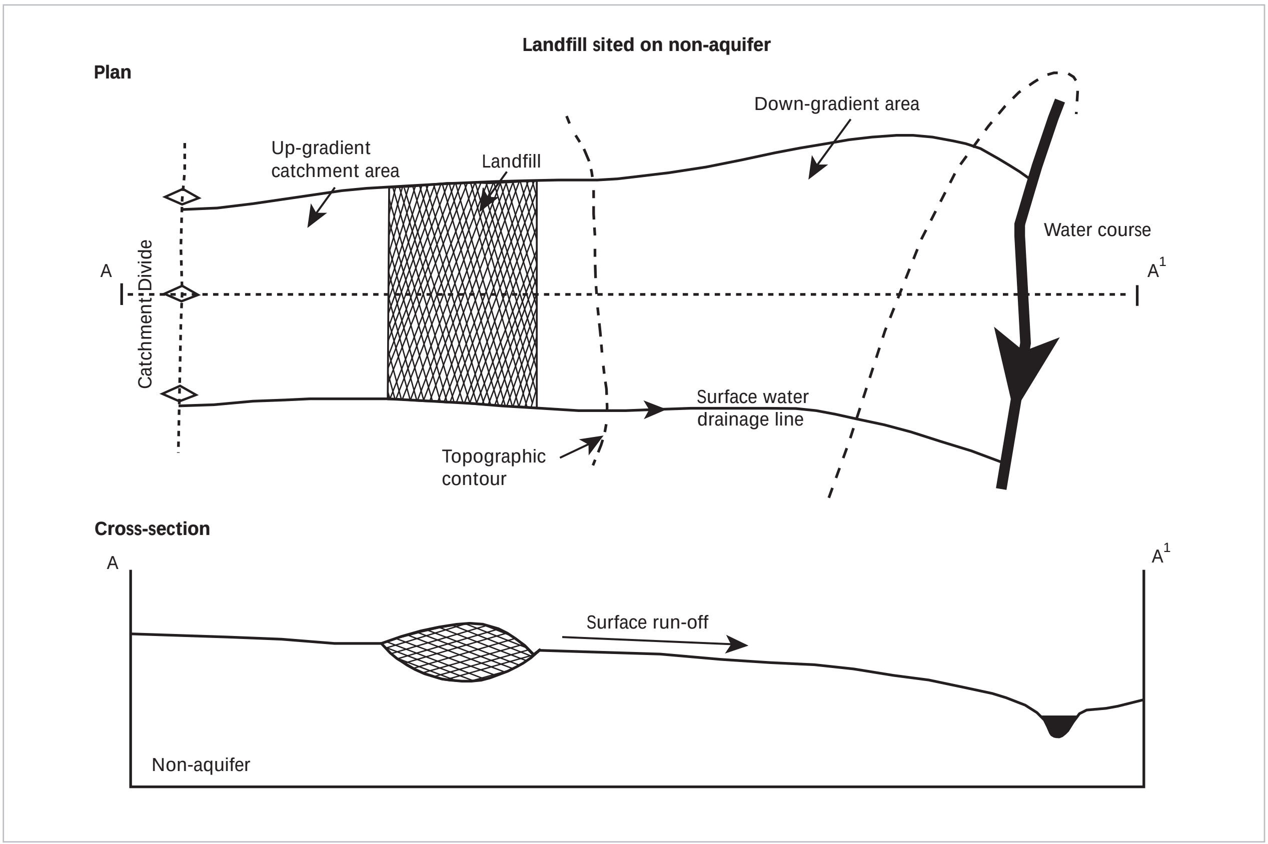
Some examples of hydrogeological setting drawings are given in Figure 4.1.

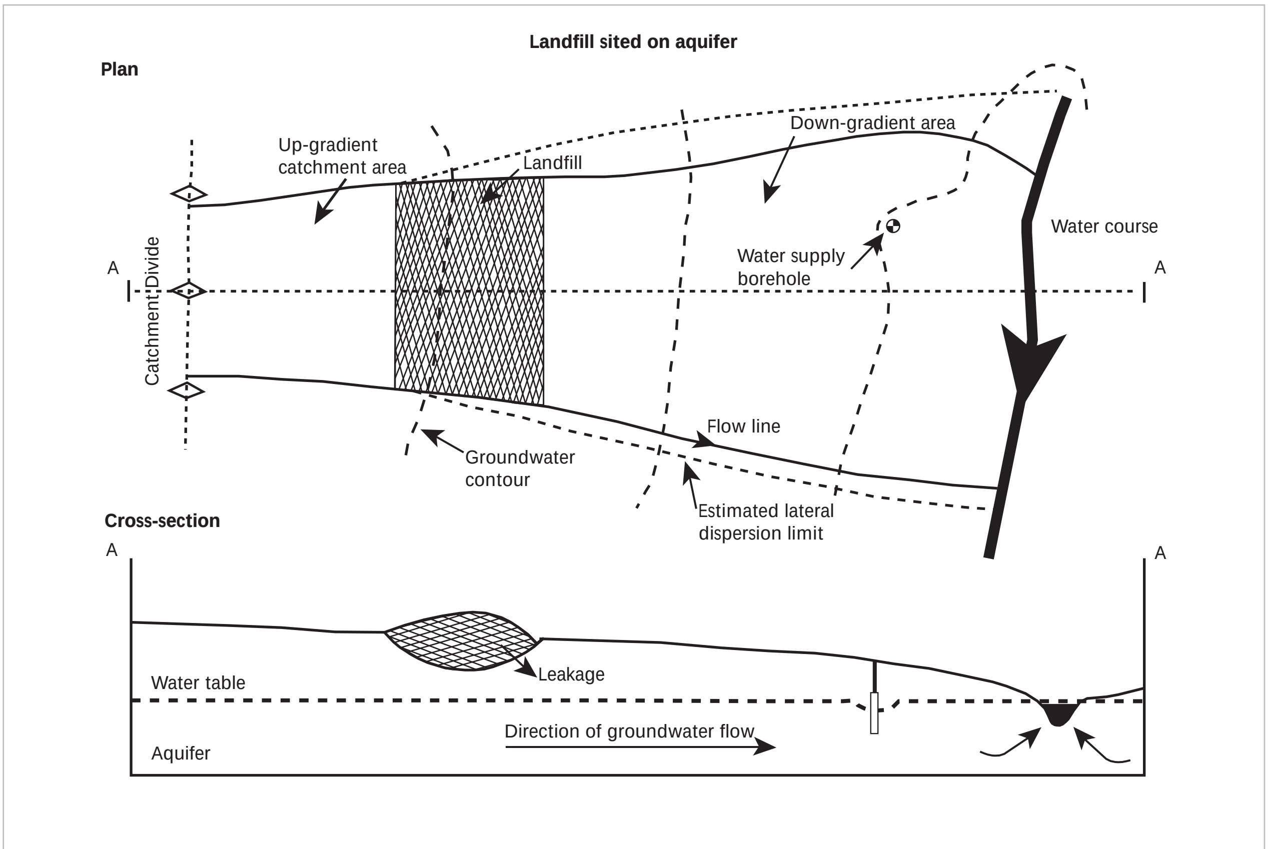
Table 4.1 Summary of example information required in a risk-based monitoring review

The landfill site	• site geometry (area, depth, volume, cell structure) • waste type (either proposed, or recorded by waste-input monitoring) • operational methods (infill rate, compaction methods, cover methods) • in-situ waste properties (density, permeability) • leachate composition • engineering design • liner properties and basal leakage calculations (including maximum acceptable leachate head derived from risk assessment) • other leakage mechanisms • discharge points and consents • surface run-off • other contaminant sources
Surrounding land use and historical land development	• identification of man-made conduits (e.g. mine shafts/adits/workings, drainage features/field drains/culverts, boreholes/wells, service trenches/pipelines, tunnels) • identification of external sources of contamination (e.g. road drainage, septic tanks, soakaways, agriculture, industrial and domestic discharges, sewage treatment works) • characterisation of impact on water quality and quantity from external sources at site boundary (baseline) • receptors at risk (developments, amenities)
Rainfall and catchment statistics	• rainfall statistics (based on Met Office, Agency or site records) • catchment area (up-gradient and down-gradient areas)
Hydrology (surface water features)	• identification of surface water features within site catchment area and on-site • a review of relationship between groundwater flow and surface water features • quantification of surface water flows • surface water quality standards • characterisation of surface water quality (baseline) • ecological features • receptors at risk, pollution pathways, transport and attenuation mechanisms • discharge and disposal routes for leachate
Geology and hydrogeology (groundwater systems)	• description of geology/identification of natural voids • identification of groundwater systems (plans and cross-sections) • description of unsaturated zone • hydraulic characteristics (direction, quantity and rate of flow) • classification of groundwater systems and water quality standards, including groundwater vulnerability classification • groundwater Control and Trigger levels • receptors at risk (e.g. aquifers, springs, abstractions, with details of source protection zones or recharge capture zones[5] where applicable) • pollution pathways, transport and attenuation mechanisms.

5 An assessment of future recharge or source protection zones may be necessary for abstractions that are not currently abstracting but may do so in the future.

Figure 4.1 Examples of simplified landfill hydrogeological setting drawings





4.3.3 Landfill characterisation details

A summary of the main elements of the landfill site design, landfill site classification and waste input should be provided. Where large quantities of data are involved these should be summarised with descriptive statistics[6]. Information provided should be relevant to monitoring and, where it is available in other parts of a landfill's documented development or operational plans, it may be referenced rather than reproduced. The following is a checklist of information that, if relevant for the site, should either appear in the risk assessment or risk-based monitoring review and should be readily available and clearly referenced.

- A site plan identifying:
  - ◊ the area of the site to be landfilled;
  - ◊ the cell structure in existence or planned;
  - ◊ the location of any surface water features (including culverts);
  - ◊ site drainage arrangements, including the location of any existing or proposed discharges from the site to surface waters;
  - ◊ the location of any other site facilities that have the potential to introduce contamination to groundwater or surface water.
- A table summarising the quantity of proposed or actual waste types deposited at the site.
- A statement of operational methods and waste properties, such as rate of filling, compaction and cover methods, measured or calculated waste density and permeability.
- A table or series of tables summarising the conditions applicable to any discharge and/or trade effluent consents issued by the Agency or a water utility, together with any available data on the actual quality of these discharges.
- For sites in which leachate control is an integral part of the landfill design, a table or series of tables should be produced, for each separate landfill cell in the site, to summarise the following information (all levels should be expressed as mAOD[7]):
  - ◊ the minimum and maximum base levels of each cell;
  - ◊ the minimum and maximum level of any intermediate retaining walls surrounding each cell;
  - ◊ the actual or proposed minimum restored surface level of each landfill cell before and after settlement;
  - ◊ maximum recommended or actual leachate level to be used for permit control (as determined by the hydrogeological risk assessment).
- A table summarising the assumed leachate quality used in a risk assessment of the site including for each determinand:
  - ◊ maximum and minimum assumed values;
  - ◊ most likely assumed value, and assumed variation over time;
  - ◊ any other relevant statistics.
- A tabular summary of attenuating properties of the lining system at the base of each landfill cell (where relevant to the risk assessment), including:
  - ◊ type of liner;
  - ◊ maximum and minimum thickness of lining system;
  - ◊ hydraulic conductivity descriptive statistics (estimated and/or measured);
  - ◊ cation exchange capacity descriptive statistics (estimated and/or measured);
  - ◊ descriptive statistics for any other attenuating properties used for design purposes;
  - ◊ maximum acceptable leakage rate;
  - ◊ assumed overall attenuation factor for specific determinands assumed in the site design.
- For sites with multiple basal liners, the above information may either be condensed into an overall summary of the assumed effectiveness of the basal lining or presented for each layer.
- A summary of the physical nature and attenuating properties of the unsaturated zone below each landfill cell:
  - ◊ names and mineralogies of the geological formations;
  - ◊ maximum and minimum thickness;
  - ◊ hydraulic conductivity descriptive statistics (estimated and/or measured);
  - ◊ cation exchange capacity descriptive statistics (estimated and/or measured);
  - ◊ descriptive statistics for any other attenuating properties used for design purposes;
  - ◊ maximum acceptable leakage rate;
  - ◊ assumed overall attenuation factor for specific determinands assumed in the site design;
  - ◊ estimated travel time through the unsaturated zone.

6 'Descriptive statistics' refers to a summary of site investigation or other supporting data and may include, for example: the number of samples, minimum, maximum, average, median, standard deviation, *95 percentile*

7 m.AOD: metres above Ordnance Datum.

4.3.4 Catchment details

A summary of the main hydrological and hydrogeological information for the catchment area, within which the landfill is located, should be provided. The following is a checklist of information that, if relevant for the site, should either appear in the risk assessment or risk-based monitoring review and should be readily available and clearly referenced.

- Climatic data[8]:
  - ◊ mean annual rainfall;
  - ◊ effective rainfall (e.g. for bare soil and restoration surface);
- Groundwater data (for each separate groundwater system identified):
  - ◊ name of geological formation;
  - ◊ Agency aquifer classification (e.g. Major Aquifer, Non-Aquifer), groundwater vulnerability classification and identification of any source protection zones.
  - ◊ existing water quality, regulatory standards applicable to the groundwater system (e.g. potable water quality) and the groundwater Control and Trigger levels derived for the site;
  - ◊ licensed and unlicensed abstractions;
  - ◊ total area of the defined groundwater catchment area(s) up- and down-gradient of the site;
  - ◊ maximum and minimum thickness of saturated zone below site;
  - ◊ groundwater flow direction;
  - ◊ hydraulic gradient;
  - ◊ maximum and minimum thickness of saturated strata within defined catchment area(s);
  - ◊ assumed mixing depth below site;
  - ◊ hydraulic conductivity (estimated or measured);
  - ◊ effective porosity (estimated or measured);
  - ◊ maximum and minimum width of flow below site;
  - ◊ volume of groundwater flow available for dilution, as used in design calculations [9];
  - ◊ groundwater flow velocity (estimated or measured);
  - ◊ assumed or measured attenuating properties used for design purposes;
  - ◊ groundwater discharges.
- Surface water data (for each separate identifiable water course):
  - ◊ name of surface water body;
  - ◊ surface water system (i.e. 'tributary of River x', 'part of y catchment');
  - ◊ existing water quality and Agency water quality classification;
  - ◊ relevant water quality objective or other applicable regulatory standards (e.g. environmental quality standards, class limits, drinking water quality), and any compliance levels or assessment criteria derived for the site;
  - ◊ licensed and unlicensed abstractions;
  - ◊ riparian ownership and rights;
  - ◊ conservation status or amenity value, including fisheries status[10];
  - ◊ stream flow statistics [low (Q95 or Q90)[11] and median flow rates at specified locations][12].

4.3.5 Risk inventory

To prioritise risks for monitoring purposes, the probability that leachate will impact each specific receptor via an identifiable pathway should be evaluated. This information should be summarised in the form of a risk inventory. The risk inventory should itemise each receptor and potential contaminant pathway and indicate how this might be monitored. An example of how information may be arranged is provided in Table 4.2. This particular example is grouped by receptors, since the risks to these are categorised more easily. Alternative arrangements of information may be more suited to other sites, as long as all potential leachate escape routes to receptors are identified for monitoring purposes. The generalised examples given in Table 4.2 are by no means comprehensive and should be replaced by site specific details.

The risk inventory provides a convenient summary of information assessed in the risk-based monitoring review. It should be incorporated into the Environmental Management and Monitoring Programme to focus the design of the overall monitoring strategy for the site. The inventory will be used to specify the monitoring objectives, which are described in the following chapter (Section 5.4.1).

8 Data can be gathered from weather stations established on the landfill, though longer term statistical or interpretative data is generally more reliably obtained from the Met Office and Environment Agency.
9 Dilution is not an acceptable attenuating mechanism for List I substances.
10 Data on fisheries and biological status of many water courses is available from the Environment Agency Fisheries, Ecology and Recreation Department.
11 i.e. the 95 or 90 percentile low flow value.
12 Flow statistics for larger stream courses may be available from the Agency.

Table 4.2 Examples of issues to be summarised in a risk inventory to aid monitoring programme design for a landfill Site

Water receptor at risk		Contaminant source	Possible pathway			Monitoring priority		Possible monitoring locations
Description	**Vulnerability[1]**	**Mechanism**	**Description**	**Travel time**	**Mitigation**	**Measurements**	**Risk[2]**	
Groundwater below and down-gradient of site	Dependent on aquifer	Below-ground seepage of leachate	Containment system Unsaturated zone Groundwater flow	Dependent on presence or absence of each pathway and flow mechanisms	Travel time relative to attenuation[3] rates	List I and II Substances and other appropriate quality standards	*	Leakage detection layer Unsaturated zone monitoring (e.g. resistivity array) Boreholes on down-gradient site boundary
Groundwater abstraction	Dependent on abstraction use	As above	As above	As above plus direction and distance to abstraction	Attenuation properties Travel time	Water quality standards relevant to abstraction	*	As above plus Borehole(s) on pathway Abstraction point
Stream in catchment area	Dependent on EQS[4] and flow conditions	Surface leachate seepages and run-off	Overland run-off Run-off via ditches and field drains	Rapid, particularly following heavy rainfall	Interceptor ditches Settlement lagoons	Suspended solids EQS for surface water	*	Known seepages Interception points Receiving water course
As above	As above	Leachate treatment or storage plant	Consented discharges Accidental discharges	Immediate	Automated monitoring Engineered safety controls.	Determinands required by consent conditions	*	Discharge point Receiving water course
As above	As above	Below-ground seepage of leachate	Containment system Unsaturated zone Groundwater flow	Dependent on presence or absence of each pathway and flow mechanisms	Travel time relative to attenuation[3] rates	EQS for surface water	*	Leakage detection layer Unsaturated zone monitoring (e.g. resistivity array) Boreholes on down-gradient site boundary Borehole(s) on pathway Receiving water course (in high-risk situations)
Surface water abstraction, conservation or amenity feature	Dependent on use	All of above	All of above plus Surface water flow	All of above	All of above	Appropriate standards for receptor	*	All of above

Note

[1] Vulnerability refers to seriousness of impact if it did occur, and not to the probability of impact.

[2] Risk classification is site specific and dependent on source (leachate quality), travel time, attenuation factors and receptor vulnerability. *Risk classification should be quantitative, ranked or qualitative (e.g. 'insignificant', 'low', 'medium', 'high'), according to circumstances.

[3] Attenuation mechanisms primarily include dilution, retardation and biodegradation.

[4] EQS, Environmental quality standard for surface water.

Part 3 The environmental management and monitoring programme

5.0 Design issues and monitoring objectives

5.1 Introduction

The Landfill Regulations (Regulations 14 and 15) require operators to carry out monitoring programmes as specified in Schedule 3 of the Regulations during both the operational and after-care phases of site development. This Schedule sets out minimum requirements for the monitoring of leachate, groundwater and surface water that must be implemented within the monitoring programme of any landfill. In addition to this, the risk-based approach to monitoring (Chapter 4) may highlight additional requirements that should be considered within the design of any programme.

The remaining chapters of this guidance describe the process of designing a programme of monitoring for landfill leachate impact and specifying this information under the PPC regime in an environmental management and monitoring programme. This overall programme will comprise the individual plans [e.g. leachate management and monitoring plan, groundwater and surface management and monitoring plan(s) and a landfill gas management and monitoring plan] which may be the subject of other guidance [e.g. gas monitoring (Environment Agency, 2002b), engineering design and construction (Environment Agency, 2003d)].

The site environmental management and monitoring programme will provide the principal information source regarding site monitoring throughout its permitted lifetime. For non-inert sites, this is likely to be a considerable number of years after the site has ceased to operate. This document, which should form part of the developmental or operational plan (see Figure 3.1), should therefore provide information about the key elements of the site and surrounding area relevant to the ongoing monitoring programmes.

Production of the environmental management and monitoring programme is an iterative process. Periodic review against monitoring objectives is necessary in the light of monitoring results, changes in technology, legislation and technical guidance.

Guidance is given in this chapter as follows.

Section 5.2 outlines the issues to be addressed when designing site-monitoring programmes and preparing the content of the site environmental management and monitoring programme;

Section 5.3 highlights the need for technical competence and the use of a wide skill base for different monitoring tasks;

Section 5.4 provides example specifications of monitoring objectives. These form the framework around which the site environmental management and monitoring programme should be formulated;

5.2 Content of the environmental management and monitoring programme

5.2.1 Division of contents

Monitoring and environmental management details applicable to a landfill site should be presented in a form that complies with the requirements of the Landfill Directive and PPC regimes, as set out in this document and the PPC Application Form for the Landfill Sector (Environment Agency, 2002a).
The Environmental Management and Monitoring Programme should comprise the appropriate management plans, which should contain documented objectives, design details and procedures to be adopted for site monitoring and environmental management. The objectives set out within the plans should include compliance with the requirements of both the Landfill Regulations and the PPC Regime.

5.2.2 Specifications within management plans

With regards to monitoring, the management plan should incorporate specifications to include the following issues:

1. management structure and technical competence (Section 5.3);
2. monitoring objectives (Section 5.4);
3. the number and location of monitoring points (Section 6.2);
4. monitoring measurements (Section 6.3);
5. monitoring schedules (Section 6.4);
6. assessment and compliance criteria, and contingency actions (Chapter 7 and hydrogeological risk assessment guidance, Environment Agency 2003b);
7. design of monitoring points (Chapter 8);
8. monitoring methodology (Chapter 9);
9. data management and reporting procedures (Chapter 10);
10. QA (Section 10.3), including QC measures for items 7, 8 and 9 above.

Some of the above issues should be considered concurrently, though the sequence given is recommended to address all monitoring issues fully.

5.2.3 Technical appendices

Technical reference information needed for monitoring programmes should ideally be collated into an accessible format for reference by site monitoring personnel and the Agency. Where such data have been comprehensively collated for other purposes (e.g. within a hydrogeological risk assessment) cross-referencing to these sources may be acceptable.

The objective of collating information is to provide one single, updateable document that contains all of the necessary information for monitoring, including:

- a summary of the risk-based approach to monitoring;
- monitoring infrastructure details;
- sampling protocols;
- baseline data summaries.

5.3 Management and technical competence

5.3.1 Management structure and systems

Each management plan should identify the person responsible and the management structure in place for delivery of the plan. Reference may be made to the operator's environmental management system (EMS). This should include the mechanisms for liaison between the different people involved and with the Agency.

5.3.2 Technical competence

Although PPC Permits that specify technical skills or qualifications for monitoring personnel are unlikely to be issued, they may contain conditions that specify the need for appropriate QA and QC systems, which necessitate the use of appropriately qualified and technically competent staff.

Monitoring is a multidisciplinary scientific activity that requires a variety of inter-related managerial and technical skills. While many routine tasks can be undertaken by personnel with a basic scientific background, there will usually be a need for appropriate training in monitoring and QC procedures to reinforce this basic knowledge. Depending on the complexity of the monitoring regime, there may be a need during the development and implementation of a monitoring programme for the involvement of a number of different personnel with specific technical competencies. Examples of specialist skill areas are illustrated in Table 5.1.

5.3.3 Training

Training of personnel should follow standards established by bodies such as the Waste Management Industry Training and Advisory Board (WAMITAB). Attendance on specialist short courses undertaken by recognised training bodies should be encouraged, and reinforced with in-house training by supervisory staff. All monitoring personnel should be encouraged to be members of professional institutions and to keep their professional accreditation up to date by participation in continuous professional development (CPD) programmes.

The use of inexperienced personnel on monitoring programmes without prior training is not acceptable. Training records of monitoring personnel (whether

Table 5.1 Examples of the possible range of technical skills needed for a monitoring programme

Tasks	Monitoring activity	Management				Risk review and specification of monitoring programmes						Design and certification of monitoring infrastructure			Field surveys			Data collation, interpretation and reporting			
		Programme co-ordination	Quality control	Liaison with Agency	Liaison with sub-contractors/laboratory	Risk-based monitoring review	Monitoring objectives	Monitoring schedules	Design of compliance/trigger tests	Contingency planning	Monitoring protocols	Leachate	Groundwater	Surface water	Routine monitoring surveys	Biological sampling	Volatile organic sampling	Data collation	Data validation	Data review and interpretation	Reporting
Routine [1,2]					•						•					•	•			•	•
Specialist [1,2]	Monitoring Manager[3]					•	•	•	•	•	•	•	•	•	•	•	•	•	•		
	Supporting specialist skills																				
	Hydrogeology		•		•					•		•					•	•	•	•	•
	Landfill engineering		•															•			•
	Chemistry		•		•	•	•	•	•									•	•	•	•
	Hydrology		•			•	•	•	•	•							•	•	•	•	•
	Biology		•		•	•	•	•	•					•				•	•	•	•
	Database/IT		•		•	•												•	•	•	•
	Mathematics /statistics		•			•	•	•										•	•	•	•

Notes

1. Indicates the primary specialist skills needed for a specific monitoring activity.
2. • Indicates additional skill areas where advice may be needed for a specific monitoring activity.
3. The Monitoring Manager should be a competent professional with a specialism in at least one of the supporting disciplines.

sourced from in-house or from sub-contractors or consultants) should be made available to the Agency on request.

5.4 Monitoring objectives

5.4.1 Specification and grouping of objectives

Site-specific monitoring objectives should be listed in each management plan. These should be unambiguous, practically achievable and form the principles for monitoring on which all subsequent sections of the plan should rely. Objectives should be periodically reviewed, particularly for situations in which changes to the site design occur or external influences impact on the surrounding water environment.

For any given site, objectives should be set that meet the specific risks identified in the risk-based monitoring review (Chapter 4) and/or hydrogeological risk assessment (Environment Agency, 2003b). Each objective should clearly state the risk that is to be monitored and the method of measurement.

Example monitoring objectives are given in this chapter. Objectives are sub-divided under the following headings related to the monitoring programmes defined in Section 3.7, but include additional issues, such as non leachate related sources of contamination and water balance:

- objectives for monitoring landfill leachate (leachate characterisation monitoring);
- objectives for monitoring other contaminant sources within the landfill area;
- objectives for initial characterisation monitoring of groundwater and surface water;
- objectives for routine monitoring of groundwater and surface water;
- objectives for site water-balance monitoring.

The example objectives given in this chapter should not generally be quoted verbatim in the respective management plans, but should be used as a guide for developing site-specific objectives. For example, a number of groundwater objectives may be needed to address the risks associated with the potential for contamination of individual receptors. The example objectives have been developed with non-hazardous biodegradable waste landfill sites in mind and modifications would be necessary for any other classes of landfill. In general, sites that pose high risks will require additional objectives. Sites with low risks may be served by fewer objectives.

For example, a demonstrably inert site located on a non-aquifer and remote from water receptors may only require a short-term monitoring programme during operation (see Objective 4 below), whereas an inert site in a more sensitive groundwater environment (e.g. on a major aquifer or adjacent to a wetland), would benefit from limited groundwater monitoring to provide assurance that the impact from landfill operations is not significant (i.e. all objectives excluding Objective 1 would apply).

5.4.2 Objectives for monitoring landfill leachate

Objective 1: To determine the level of leachate within the landfill:

1a:to determine the head of leachate on the base of the site in each landfill cell so that the effectiveness of leachate management and extraction systems in complying with design and regulatory maximum levels can be determined;

1b:to determine the level of leachate adjacent to the site boundary in order to monitor compliance with design and regulatory maximum levels and to provide early warning of the potential for overspill of leachate to surface waters or the potential for lateral seepages into groundwater;

1c:to determine leachate levels for the purpose of improving estimates of leachate volumes within the site to assist in the design, operation and maintenance of leachate management systems;

1d:to determine leachate levels for comparison with design assumptions of levels used in calculations of potential basal and lateral seepage rates.

If any of the above objectives cannot be achieved and the risk to the water environment is significant, increased monitoring of groundwater and surface waters will usually be required.

Objective 2: To determine the quality of leachate and its variation in space and time within the body of the landfill:

2a:to identify specific chemical characteristics of leachate that may help in unambiguously identifying leakage into groundwater and surface water;

2b:to provide information on the state and rate of stabilisation of the waste body for comparison with the design lifetime of the containment and monitoring systems and to assist with the demonstration of stabilisation in an application to surrender a permit or licence;

2c:to determine the presence of harmful substances in leachates in relation to the risk at defined receptors (e.g. the presence of List I or List II Substances in leachate should be used to guide the monitoring programme for groundwater under the Groundwater Regulations 1998);

2d:to determine the quality of leachate for discharge to a treatment system.

Objective 3: To determine the level, flow and quality of leachate and its variation in time, in surface storage and treatment systems:

3a:to determine the level of leachate in a storage lagoon in relation to overflow maxima;

3b:to determine the volume of leachate discharged from storage or treatment systems;

3c:to identify specific chemical characteristics of leachate that are required to support a consented discharge from storage lagoons and/or treatment systems.

5.4.3 Objectives for monitoring other contaminant sources within the landfill area.

Objective 4: To provide QA that other sources of potential water contamination within the landfill site are controlled as designed:

4a:to detect any spillage of fuel from fuel stores and/or bunded areas;

4b:to detect any spillage of contaminated water from wheel washers and other cleaning areas;

4c:to detect any spillages from chemical storage areas, waste transfer areas or waste processing areas of any type;

4d:to detect any poorly controlled run-off from landfill areas that may carry suspended solids or contamination.

Many of the above issues are covered by standard planning and permit conditions. Where good engineering controls are in place, monitoring may simply be based on observational records. Provision of specific monitoring points and sampling will only be required where leakage is threatened or is present, particularly from non-engineered or poorly engineered facilities.

Objective 5: To provide monitoring information required by the terms of a surface water discharge consent:

5a.to provide water quality and flow measurements as specified in a consent to discharge to surface water.

Monitoring of discharges by the operator may be specified in the consent and it is recommended that details be included in the environmental management and monitoring programme.

5.4.4 Objectives for initial characterisation monitoring of groundwater and surface water

For new sites, initial characterisation monitoring programmes should be initiated at least one year in advance of site development (see Section 6.4.4 for circumstances when more than one year is required). For older sites with inadequate monitoring records, initial characterisation monitoring programmes may be introduced retrospectively and should be undertaken in conjunction with the assessment of any historical or other relevant data.

Objective 6: To characterise the underlying and surrounding groundwater systems for future comparison against any landfill impacts and to determine compliance and assessment limits where appropriate:

6a:to determine initial baseline groundwater level, including variability and trends;

6b:to determine initial baseline groundwater quality, including variability and trends (including List I and List II Substances), which will facilitate the derivation of both Control and Trigger levels.

Objective 7: To characterise surface water quality and level and/or flow for future comparison against any landfill impacts and to determine assessment and compliance limits where appropriate:

7a:to determine initial baseline water quality of surface waters, including variability and trends;

7b:to determine initial baseline stream flow (where required for dilution calculations), including variability and trends;

7c:to determine initial baseline water level in surface water bodies (where required for hydrological assessment), including variability and trends.

5.4.5 Objectives for routine monitoring of groundwater and surface water

Once initial characterisation monitoring has been completed, routine monitoring should form the normal pattern of monitoring.

Objective 8: To carry out routine monitoring of groundwater to provide ongoing baseline data, and to discern potential breaches of Control and Trigger levels:

8a:to carry out routine monitoring of groundwater level;

8b:to carry out routine monitoring of groundwater quality.

Objective 9:To carry out routine monitoring of surface water to provide ongoing baseline data, and to discern potential breaches of assessment and compliance levels:

9a:to carry out routine monitoring of surface water level or flow;

9b:to carry out routine monitoring of surface water quality.

5.4.6 Objectives for site water balance monitoring

Objective 10:To quantify water inputs and outputs within the site:

10a:to determine natural water input from rainfall;

10b:to determine the volume of liquid added to each hydraulically separate landfill cell;

10c:to determine the volume of leachate removed from each hydraulically separate landfill cell;

10d:to determine the total volume of leachate discharged off-site.

6.0 Monitoring locations and schedules

6.1 Introduction

Landfill site monitoring programmes should be designed to meet both the minimum requirements of the Landfill Regulations and site-specific monitoring objectives that have been determined by risk assessment. This latter objective means that the number and location of monitoring points, as well as the monitoring schedules, should be determined on a site-specific basis while accommodating the Regulations' minimum requirements. Consequently, risk assessment techniques may lead to instances in which the appropriate monitoring measurements and frequencies vary from those provided in the example schedules contained within this guidance. For example, less stringent requirements may be justifiable for sites that pose low risks to receptors. Conversely, more exacting requirements may be needed for higher risk landfills in more sensitive locations.

As stated above, it is stressed that, when carrying out the risk-based design of the monitoring network, operators should be mindful of the minimum requirements of the Landfill Regulations, which are set out in the appropriate sections below.

The Agency expects all proposals for monitoring programmes to be justified by risk assessment and summarised in the Environmental Management and Monitoring Programme, in accordance with guidance in this document.

Guidance is given in this chapter as follows.

Section 6.2 the number and location of monitoring points;

Section 6.3 monitoring measurements typically carried out at landfill sites;

Section 6.4 specification of monitoring schedules for different monitoring programmes.

6.2 The number and location of monitoring points

6.2.1 Preamble

This section provides general guidance on the minimum number and locations of monitoring points required for leachate, groundwater and surface water monitoring.

All landfill sites need to comply with the minimum monitoring requirements of the Landfill Regulations. However, when selecting monitoring locations, it is important to be aware of the purpose of monitoring, as defined in the monitoring objectives and the risk-based monitoring review. As all landfills are unique, the guidance given in this section should be viewed as being for example only. Ultimately, the number and location of monitoring points needs to be determined by risk-based design.

Examples that summarise monitoring point assessments for sites in low- and high-risk settings are presented in Tables 6.1 and 6.2

Table 6.1 Example summary of monitoring point assessment for a site posing a low risk to water receptors

Monitoring location	Purpose	Type of monitoring point	Number and spacing of monitoring points (minimum requirements of Landfill Regulations)
Groundwater on site boundary[1]	To assess quality and levels	Boreholes	One up-gradient and two down-gradient per groundwater system
Surface water at outfall from site	Impact on quality from suspended solids in run-off	Surface water	At least one point upstream and one point downstream of each outfall

1. Unless reliable waste input and/or leachate monitoring is established and demonstrates unambiguously that polluting leachate is not being produced. However, groundwater Control and Trigger levels will still need to be derived.

Table 6.2 Example summary of monitoring point assessment for a biodegradable site posing a moderate-to-high risk to water receptors

Monitoring location	Purpose	Type of monitoring point	Typical number of monitoring points
Landfill cells	Leachate level and quality at base of site or within waste mass	Sumps, boreholes	Two monitoring points for leachate head per 5 ha[1] cell in addition to a leachate extraction point
	Leachate quality in drainage layer (site base)	Drainage collection point	One appropriate quality point per 5 ha cell Level monitoring points as above
Leakage detection layer	To determine leakage	Drainage collection point	At least one per 5 ha cell
Electrical resistivity array in unsaturated zone	To determine leakage	Resistivity array	Suitably designed and extensive electrode array[2]
Groundwater on-site boundary	Quality and levels to be monitored for comparison to assessment criteria	Boreholes	A minimum of one up-gradient and two down-gradient per groundwater system
	Compliance with Groundwater Directive (Regulation 15 of WML Regulations 1994 or Groundwater Regulations 1998) to confirm no discharge of List I Substances		Spaced a maximum of 100 m apart on down-gradient boundary
Groundwater between site and receptors at risk	Potential impact on quality in down-gradient water abstraction well and surface water course	Boreholes	At least one for each receptor and/or pathway located on the pathway(s) that connect the landfill and the receptor(s)
Surface water at outfall from site	Impact on surface water quality	Surface water	At least one point upstream and one point downstream of each outfall

Notes:
1. 1 ha = 10,000 m^2
2. The long-term reliability and durability of resistivity arrays for unsaturated zone monitoring is uncertain.

6.2.2 Number and location of leachate monitoring points

The location of monitoring points in relation to leachate drainage systems and collection sumps should be chosen carefully. Leachate levels need to be representative of levels across the landfill as a whole and not artificially lowered by proximity to a dewatering point.

In determining the number of leachate monitoring points required at a site, the following guidance should be followed.

The ***Landfill Regulations*** (Schedule 3, Paragraph 2) suggest the following minimum standards, although provision is made in the Regulations to adapt some of the requirements according to site conditions:

- samples of leachate, if present, must be collected at 'representative points' – *the guidance below indicates what can be regarded as a 'representative point';*
- sampling and measuring (volume and composition) of leachate must be performed separately at each point at which the leachate is discharged from the site – *to obtain representative samples, leachate should be collected from abstraction points prior to undergoing any treatment;*
- for leachate, a sample, representative of the average composition, shall be taken for monitoring – *the location points suggested below should provide samples of average composition;*
- during the operational phase of development, leachate volume needs to be measured on a monthly basis[13]; following restoration, this frequency may be reduced to every six months depending on the outcome of a risk-based monitoring review;
- leachate composition needs to be sampled on a quarterly basis during the operational phase of development[14]; following restoration, this frequency can be reduced to every six months depending on the outcome of a risk-based monitoring review.

Not withstanding the minimum requirements of the Landfill Regulations, in carrying out the risk-based review in relation to determining the number of leachate monitoring points required at a site, the following guidance should be followed.

- Leachate levels and quality samples can be obtained from the same or separate monitoring points, as long as the monitoring objectives can be achieved. For example, samples could be taken from underdrainage or abstraction points, with levels obtained independently from other monitoring points remote from the point of leachate removal.
- Where leachate can be shown to drain freely through the waste and can be removed via a basal drainage system, a sample of the drained leachate will be acceptable as appropriate for leachate quality at the site base.
- Where perched leachate levels are developed and/or hydraulic continuity in landfill cells is poor, the number of sample points should be based on that recommended in Table 6.3.
- At least two leachate-level monitoring points in addition to a collection sump should be provided for each hydraulically separated cell of less than 5 ha in size. For larger cell sizes, the guidance in Table 6.3 should be followed. These points should be capable of recording the level of leachate in relation to the base of the site.
- Level monitoring points should include points remote from leachate drainage and pumping systems. Sumps or boreholes designated for level monitoring and that are frequently pumped should be tested to determine the time of recovery to rest level. Levels should be taken from these points after the pumps have been switched off and sufficient time to obtain a reliable rest water level has passed. Where this cannot be achieved a level reading can still be taken, but a record of pumping activity should be made.

Additional monitoring points and controls may be needed where leachate levels (perched or otherwise) cannot be controlled adequately, particularly where there is a threat or incidence of overspill to surface water or of lateral seepage to groundwater.

[13] It is recognised that the frequency of sampling could be adapted on the basis of the morphology of the landfill waste. If the evaluation of data indicates that longer intervals are equally effective, they may be adapted.

[14] If the evaluation of data indicates that longer intervals are equally effective, they may be adapted. For leachates, conductivity must always be measured at least once a year.

Table 6.3 Minimum number of leachate monitoring points.

Site area (ha)[1]		Number of monitoring points[2]
From	To	
0+	5	3
5+	10	4
10+	25	6
25+	50	9
50+	75	11
75+	100	13
100+	125	15
125+	150	16
150+	175	17
175+	200	18
200+	250	19
250+ and upwards		20

Table details taken from Waste Management Paper 26A, Table 3.1.

1. For landfills operated in a phased, cellular manner with hydraulically isolated leachate collection systems, the area referred to in the table is that of each cell.
2. At least two monitoring points in each cell should be situated away from the point of leachate discharge.

6.2.3 Number and location of groundwater monitoring points

The requirements of the Landfill Regulations are as follows:

- For all sites at which groundwater monitoring is specified, there should be at least one measuring point in the groundwater inflow region (i.e. up-gradient of the landfill), and two in the outflow region (i.e. down-gradient);
- the number of monitoring points can be increased on the basis of a specific hydrogeological survey and the need for an early identification of accidental leachate release into the groundwater (i.e. the hydrogeological risk assessment and/or the risk-based monitoring review);
- samples must be carried out in at least three locations before the filling operations to establish reference values for future sampling.

In addition, all landfills require groundwater Trigger levels to be set for one or more downstream groundwater wells, using risk assessment techniques, to provide an indication of when significant adverse environmental impacts have occurred. In addition, Control levels need to be set to monitor landfill performance in the context of the predictions from the risk assessment. The monitoring schedule needs to recognise this requirement.

Risk assessment techniques should therefore be used to determine the most appropriate number and location of groundwater monitoring points. Where risk assessment has not been used to position boreholes at sites at which receptors are at higher risk, the following guidance should be followed when determining the minimum number of groundwater monitoring points required.

Additional boreholes on site boundaries:
For engineered containment sites where any leakage of leachate is likely to be diffuse (e.g. by use of mineral liners), at least one borehole should be provided per 100 m width of site on the down-gradient landfill site margin. These should be located as close as possible to edge of the landfill, but for practical purposes should be no closer than 10 m and no further than 100 m from the waste margin.

For engineered sites in which leakage could potentially occur from holes or tears over a restricted area (e.g. by use of artificial sheet liners) or sites located above fissured strata and in which a leachate detection layer is absent or non-operational, at least one borehole should be provided per 50 m width of the down-gradient landfill site margin. These should be located as close as possible to edge of the landfill, but for practical purposes should be no closer than 10 m[16] *and no further than 100 m from the waste margin.*

Additional boreholes in relation to receptors at risk:
Any plausible pathways between the landfill site and a water receptor should be intercepted by at least one monitoring point, which may be additional to the boreholes on the site boundary. For more sensitive receptors, where flowpaths are uncertain, more than one monitoring point is likely to be required.

Remote or novel monitoring schemes:
For the highest risk sites additional remote monitoring schemes may be appropriate (e.g. resistivity arrays installed within an unsaturated zone below the landfill site). Where these are deployed, they should be proved to be operationally reliable over a period of several years following construction of the overlying landfill.

In selecting monitoring locations, consideration should be given to choosing points:

- where the pathway is well understood, to minimise uncertainty;
- as close as possible to the leachate source (but no closer than 10 m from the edge of a landfilled area), to provide an early warning of leachate migration.

It may not always be possible to satisfactorily meet both these requirements at one location, in which case additional monitoring points are required.

Monitoring requirements (in terms of numbers and location) can increase in complexity as monitoring progresses, particularly if leachate contamination is detected and results in a requirement for assessment monitoring (Figure 6.1).

In many cases, groundwater monitoring locations are needed outside the permitted area of operations and on land outside the ownership of the site operator. It is vital to obtain the necessary permissions to access this land and to maintain access for monitoring purposes[17].

The separation distance between groundwater monitoring points is site specific and, where justified by the risk-based monitoring review, may be varied from those stated above. The vertical positioning of monitoring points can also be an issue and requires a good conceptual understanding of geological and hydrogeological conditions at a site. For example a contamination 'plume' may develop which sinks below the water table as it progresses further down-gradient from the site (see Figure 6.1). Factors

[15] This would be demonstrated by comparison between monitoring points and the main leachate collection point.
[16] In some instances (e.g. rotary air flush drilling in fissured strata) a larger distance is necessary.

[17] Legal rights of access are provided for in Section 35(4) of the Environment Protection Act 1990 as amended by Paragraph 67, Schedule 22 of the Environment Act 1995.

such as the amount of rainfall recharge, gravitational settlement, and hydrodynamic dispersion can all influence the vertical component of contaminant transport in groundwater.

6.2.4 Number and location of surface water monitoring points

The Landfill Regulations specify that, for flowing waters, at least two surface water monitoring points, one upstream and one downstream of the landfill site, are required. However, this is a minimum requirement and risk assessment techniques should be used to determine the most appropriate number and location of monitoring points.

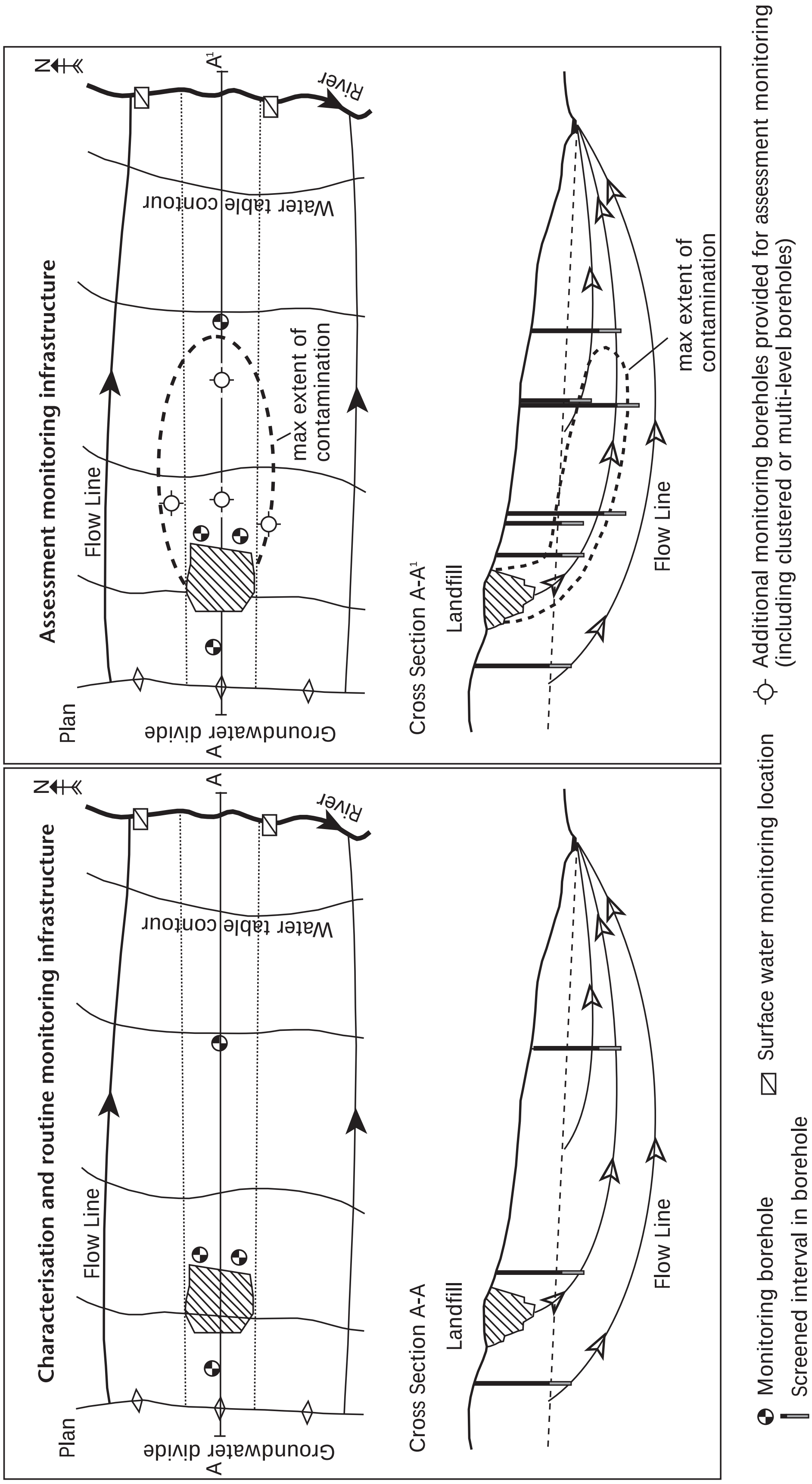
In determining the number of surface water monitoring points required at a site, the following guidance should be followed:

- For surface waters that are sensitive to small changes in water quality (e.g. wetlands), at least two upstream and two downstream monitoring points are required. This requirement may be relaxed if justified by the risk-based monitoring review and in agreement with the Agency.
- At least one monitoring point is required for each area of ponded water, wetland or lake located within the site boundaries or within the down-gradient catchment area of the site, where these are potentially at risk. Additional monitoring points may be required in relation to risk.

The distance between surface water monitoring points in a flowing water course should be determined on a site-specific basis, with reference to the hydraulic characteristics of the water course. In many cases, surface water monitoring locations are needed outside the permitted area of operations and on land outside the ownership of the site operator. It is essential that the necessary permissions to access this land and to maintain access for monitoring purposes are obtained.[18]

18 Legal rights of access are provided for in Section 35(4) of the Environment Protection Act 1990 as amended by Paragraph 67, Schedule 22 of the Environment Act 1995.

Figure 6.1 Diagrammatic groundwater and surface water monitoring infrastructure



6.3 Monitoring measurements

Monitoring information presented within an Environmental Management and Monitoring Programme should include tables that specify:

- monitoring measurements to be undertaken;
- the units of measurement;
- the tolerable uncertainty;
- the detection limit (where appropriate);
- the analytical method.

The Landfill Regulations state that:

- for leachates "The parameters to be measured and substances to be analysed vary according to the composition of the waste deposited; they must be laid down in the permit document and reflect the leaching characteristics of the wastes";
- for groundwater, "The parameters to be analysed in the samples taken must be derived from the expected composition of the leachate and the groundwater quality in the area. In selecting parameters for analysis account should be taken of mobility in the groundwater zone. Parameters could include indicator parameters in order to ensure an early recognition of change in water quality." Recommended parameters are: pH, TOC, phenols, heavy metals, fluoride, AS and oil/hydrocarbons.

Consequently, the selection of monitoring measurements should take into account the requirements of the Landfill Regulations and should be related to the characteristics of the waste mass and the resultant leachate, as well as the surrounding groundwater and surface water. Initially, this relates to the waste types deposited until leachate generation and monitoring has begun. The final choice of measurements is site specific, and subject to the results of the risk-based monitoring review. Periodic review of the selection of monitoring measurements should be undertaken. For landfills that accept biodegradable wastes, it is suggested that ammoniacal nitrogen and chloride should be included in any monitoring regime.

Initial and ongoing characterisation monitoring programmes encompass a broad suite of measurements to determine the identifying characteristics of leachate, groundwater and surface water. After the initial characterisation is complete, a range of indicator measurements may be selected for use in routine monitoring programmes.

Monitoring measurements can be sub-divided into the following broad categories:

- observational and physical measurements;
- principal chemical composition measurements;
- minor chemical composition measurements;
- biological measurements.

Toxicity measurements, which are increasingly in use for sewage detection, may in future become more important for landfill monitoring purposes. These are at an early stage of development for leachate monitoring and are therefore not covered in any detail by this guidance.

The above categories of measurement are discussed in the following sections.

6.3.1 Observational and physical measurements

These include:

- simple observations that can be recorded into a log book or by photography

  (e.g. surface seepages of leachate);
- measurements that can be undertaken with simple field equipment

  (e.g. water levels);
- measurements that can be automated or estimated

  (e.g. leachate discharge volumes).

Examples of typical observational and physical measurements used in monitoring programmes are provided in Table 6.4.

6.3.2 Principal chemical composition measurements

These include the main chemical constituents typical of leachate and natural waters, such as physicochemical indicators and major ions, which account for the majority of dissolved minerals in water (Table 6.5).

Major Ion Balance

Where a sufficient number of major ions are analysed (see Table 6.5), a major ion balance should be routinely undertaken and reported by the analytical laboratory as part of normal laboratory QC procedures.

The difference between analysed cations (positively charged) and anions (negatively charged) can be expressed either as a percentage of total cations, or anions, or the sum of both. To standardise the approach for monitoring purposes the following formula should be used:

Percentage difference =

$$\frac{\text{Sum of cations (meq/l)} - \text{Sum of anions (meq/l)}}{\text{Sum of cations (meq/l)} + \text{Sum of anions(meq/l)}} \ 100$$

Cations and anions are identified in Table 6.5. Cations and anions are expressed in units of milliequivalents per litre (meq/l). Conversion factors from mg/l to meq/l are provided in Appendix 13.

The use of QC checks, including major ion balance, is described in Section 10.6.

6.3.3 Minor chemical composition measurements

Minor chemical constituents (Table 6.6) can be subdivided under the following headings.

- inorganic and organic contaminants, including trace metals;
  these will vary between waste types;
- substances or properties that are harmful at identified receptors
  these are substances not included in the above or major chemical constituency categories, but that may be selected for particular attention in relation to specific receptors;
- other substances required by regulatory conditions or discharge consent;
  for example, List I and List II Substances in relation to discharges to groundwater; Red List substances and dissolved methane in relation to discharges to sewer or surface water.

Table 6.4 Description of example observational and physical monitoring measurements

Type of measurement	Measurement	Specification	Units	Tolerable uncertainty
Observational measurements	Observation of landfill run-off	Weekly/monthly logged observation of site conditions during and following rainfall	n/a[1]	2
	Observation of other contaminant sources	Weekly/monthly logged observation of drainage arising from other contaminant sources	n/a	2
	Observation of vegetation	Weekly/monthly logged observations of vegetation die-back	n/a	2
Water balance measurements	Rainfall	Annual and monthly total and effective rainfall	mm	2
	Volume removed[3]	Volume of leachate removed from each cell by drainage or pumping	m^3 per unit of time	2
	Volume added[3]	Volume of leachate or other fluids added onto or into each landfill cell	m^3 per unit of time	2
	Volume discharged[3]	Volume of leachate removed off-site	m^3	
Surface water flow measurements	Surface water flow	Flow rate	l/sec	2
Level measurements	Leachate level	Level of liquid in monitoring point recorded by reference to surveyed datum level	mAOD[4]	2
	Groundwater level	Level of water in monitoring point recorded by reference to surveyed datum level	mAOD	2
	Surface water level	Level of water recorded by reference to surveyed datum level	mAOD	2
	Base of monitoring point	Level of base of monitoring point by reference to surveyed datum level	mAOD	2

1. n/a, not applicable.
2. The tolerable uncertainty would be determined following completion of the initial characterisation monitoring and may not necessarily be applied to all measurements. It may be expressed as a percentage or a fixed value. It is site and measurement specific (see Section 6.3.5).
3. Typically, data should be summarised into monthly totals collated from daily or more frequent records.
4. mAOD, metres above Ordnance Datum.

Table 6.5 Examples of principal chemical composition measurements.

Determinand	Symbol	Units	Minimum reporting value[1]		Field/ Lab[2]	Major ion balance[3]	Tolerable uncertainty[4]
			A	B			
Temperature	Temp	°C	±1[5]	±5[5]	F		4
pH	pH	pH units[6]	±0.1[5]	±0.5[5]	F and L		4
Electrical conductivity	EC	μS/cm[6]	10	50	F and L		4
Dissolved oxygen[7]	DO	mg/l	±1[5]	±1[5]	F		4
Redox potential[7]	Eh	mV	±1[5]	±5[5]	F		4
Total suspended solids	TSS	mg/l	5	5	L		4
Total dissolved solids (gravimetric)	TDS	mg/l	10	20	L		4
Ammoniacal nitrogen (as N)	NH_4-N	mg/l	0.05	1	L	(+)	4
Total oxidised nitrogen (as N)[8]	TON	mg/l	0.2	0.2	L	(–)	4
Volatile fatty acids (C_2–C_5)	VFA	mg/l	0.1	0.1	L	(+)[9]	4
Total organic carbon (filtered)	TOC	mg/l	0.2	1	L		4
Biochemical oxygen demand	BOD	mg/l	1	10	L		4
Chemical oxygen demand	COD	mg/l	5	20	L		4
Calcium[10]	Ca	mg/l	1	20	L	+	4
Magnesium[10]	Mg	mg/l	1	20	L	+	4
Sodium[10]	Na	mg/l	1	10	L	+	4
Potassium[10]	K	mg/l	1	10	L	+	4
Total alkalinity (as $CaCO_3$)	Alk	mg/l	5	10	F or L	–	4
Sulphate	SO_4	mg/l	3	10	L	–	4
Chloride	Cl	mg/l	1	10	L	–	4
Iron[10]	Fe	μg/l	20	50	L	(+)	4
Manganese[10]	Mn	μg/l	10	10	L	(+)	4

1. Actual reporting values should be determined in consultation with the analytical laboratory. 'A' reporting values or better should always be used if attainable. Reporting values 'A' are for 'clean' waters. 'B' values are for leachates. Values for brackish waters should be agreed with the analytical laboratory and the Agency.
2. Measurements designated 'L' would normally be determined at a laboratory, though selected field measurements of indicator parameters may be acceptable to the Agency subject to agreement of calibration procedures.
3. Determinands marked '+' are cations and '–' are anions used for major ion balance calculation. Bracketed values are those frequently at sufficiently low concentration in natural waters to omit from calculation, but that would normally be included in a major ion balance for leachates.
4. The tolerable uncertainty is determined following completion of the initial characterisation monitoring and may not necessarily be applied to all measurements. It may be expressed as a percentage or a fixed value. It is site, location and measurement specific (see Section 6.3.5).
5. Typical instrumentation accuracy required, rather than reporting value.
6. Calibration temperature should be stated. Normally, this is 20°C.
7. Where DO and Eh measurements are required ,these should only be determined in the field. Analyses on groundwater samples should only be taken in flow-through cells. Measurements would not normally be carried out on leachate samples.
8. Total oxidised nitrogen may be expressed as the sum of nitrate (NO_3) and nitrite (NO_2) analyses.
9. If volatile fatty acids are included in a major ion balance, a correction is required for the effect of these acids on the alkalinity value (see Appendix 13).
10. All metals should be dissolved metals unless conditions require total metals (e.g. for surface water or groundwaters that are fast flowing, or where precipitation of Fe/Mn is occurring in otherwise clear water).

Table 6.6 Examples of minor chemical composition measurements.

Substances	Determinand[1]	Symbol	Units	Minimum reporting value[2]		Tolerable uncertainty[3]
				A	B	
Examples of inorganic substances	Cadmium[4]	Cd	μg/l	0.1	1	3
	Chromium[4]	Cr	μg/l	10	10	3
	Copper[4]	Cu	μg/l	10	10	3
	Nickel[4]	Ni	μg/l	10	10	3
	Lead[4]	Pb	μg/l	10	10	3
	Zinc[4]	Zn	μg/l	10	10	3
	Orthophosphate (as P)	o-PO_4	mg/l	0.1	0.1	3
	Arsenic	As	μg/l	10	10	3
	Barium	Ba	μg/l	10	10	3
	Boron	B	mg/l	0.1	0.1	3
	Cyanide	CN	μg/l	10	10	3
	Fluoride	F	μg/l	50	50	3
	Mercury	Hg	μg/l	1	1	3
	Dissolved methane	Dis CH_4	μg/l	5	5	3
Examples of organic substances	Phenols (e.g. by HPLC)[5]	Mono-P	mg/l	0.1[6]	1	3
	Mineral oils/hydrocarbons[7]	Min Oil	μg/l	10[6]	10	3
	Pesticides (e.g. Atrazine, Mecoprop)	–	μg/l	1[6]	1	3
	Polychlorinated biphenyls	PCBs	μg/l	0.5[6]	0.5	
	Chlorinated solvents (e.g. trichloroethylene)	–	μg/l	1[6]	1	3
Other substances monitored for regulatory purposes	Other List I and List II determinands specified by Regulation 15 survey	List I List II	–	–	–	3
	Other Red List/List I determinands for leachate discharge	Red List List I	–	–	–	3

1. All analyses would normally be determined at a laboratory. Field measurements of some determinands may be allowable subject to approval of calibration procedures.
2. Actual reporting values should be determined in consultation with the analytical laboratory. 'A' reporting values or better should always be used if attainable. Reporting values 'A' are for 'clean' waters. 'B' values are for leachates. Values for brackish waters should be agreed with the analytical laboratory and the Agency.
3. The tolerable uncertainty is determined following completion of the initial characterisation monitoring and may not necessarily be applied to all measurements. It may be expressed as a percentage or a fixed value. It is site, location and measurement specific (see Section 6.3.5).
4. All metals should be dissolved metals unless conditions require total metals (e.g. for surface water or groundwater that is fast flowing, or where precipitation of Fe/Mn is occurring in otherwise clear water).
5. HPLC, high performance liquid chromatography. There are many phenolic compounds. Exact analysis should be specified in consultation between the operator, Agency and analytical laboratory.
6. Lower minimum reporting values will be necessary in some circumstances (e.g. compliance with drinking water limits).
7. Method of mineral oil/hydrocarbon determination should be specified in consultation between the operator, Agency and analytical laboratory.

6.3.4 Biological measurements

If required by risk assessment, biological measurements may include the identification of specific organisms in relation to impact on water resources (e.g. analysis of coliform bacteria in relation to impact on potable water supplies) or indicator measures of biotic communities (which can be used to classify the quality of stream water).

Examples of biological measurements are provided in Table 6.7.

6.3.5 Specifying tolerable uncertainty

Tables 6.4 to 6.7 exclude any specification of values or percentage limits that relate to the tolerable uncertainty of each monitoring measurement. The tolerable uncertainty should take account of the intended use of the data and should be specified, as a minimum, for those measurements to be used for routine indicator monitoring and assessment (see Section 6.4.4 and Chapter 7). Tolerable uncertainty is not only site and measurement specific, but may also vary between monitoring points on the same site. Specification of tolerable uncertainty is an iterative process, which should be kept under review constantly throughout the life of a monitoring programme.

Two primary considerations for specifying the tolerable uncertainty of a measurement are:

- the difference in value between baseline and any assessment value to be used (see Chapter 7). Where baseline values are close to assessment limits, a greater reliability in measurements is needed (i.e. smaller tolerable uncertainty);
- the uncertainty achieved in the initial characterisation monitoring[19] .

Where there is a conflict between these two considerations, the uncertainty associated with the initial characterisation monitoring should, wherever possible, be reduced (e.g. by using a different analytical method). Where this is impracticable, the assessment limit may need to be changed (see Section 7.2.6).

For many monitoring measurements, large uncertainties (e.g. above 35%) may be acceptable. Where this is the case, there is justification for using less stringent sampling and measurement methods, and collecting a fewer number of samples. Where

Table 6.7 Examples of biological measurements

Biological measurement	Description	Units/score	Tolerable uncertainty[1]
Coliform bacteria	Indicator of faecal contamination	MPN[2] index/100 ml or no. cfu/100 ml[3]	1
Chlorophyll a	Used to assess the total biomass of algae present. An indicator of nutrient enrichment	mg/m^3	1
Toxicity tests	Organisms (e.g. the microcrustacean *Daphnia magna* can be exposed to water from the monitoring site to assess the presence of toxic conditions)	e.g. 48 hour LC_{50}[4]	1
Macroinvertebrate community	Assessment of the species and abundance of benthic macro-invertebrates	Similarity indices, diversity indices, biotic scores (e.g. BMWP[5] and Chandlers Score)	1

1. The tolerable uncertainty is determined following completion of the initial characterisation monitoring and may not necessarily be applied to all measurements. It may be expressed as a percentage or a fixed value. It is site and measurement specific (see Section 6.3.5). For biological and microbiological measurements, uncertainty is generally higher than for chemical or physical measurements.
2. MPN: Most probable number.
3. cfu: Colony forming units.
4. LC_{50}: Lethal concentration of a substance, which has a measurable effect on 50% of test organisms within 48 hours.
5. BMWP: Biological monitoring working party score.

19 Total standard deviation on analytical samples, even for straightforward determinands, can range from 25% to 60% in groundwater samples (e.g. see Barnard *in* Keith, 1996).

uncertainties need to be lower, such as where monitored levels are close to compliance levels, steps should be taken to ensure that methods and sample numbers are appropriate, to ensure that uncertainties are within the specified range. QC procedures should be sufficient to demonstrate that this is the case. The following examples are provided for illustration, but should be read in conjunction with the principles that underlie assessment limits (Chapter 7) and QC (Chapter 9):

- Chloride concentration in a stream adjacent to a household waste landfill has a mean value of 20 mg/l. An assessment limit or Control level of 70 mg/l is agreed with the Agency to accommodate design leakage and maintain a good quality of water in the stream. Reliability is not an issue in this instance, and the main concern is to ensure any possible rising trend in data is not masked by poor QC. A tolerable uncertainty of ±100% (20 mg/l) from baseline mean is not unreasonable in these circumstances, regardless of statistical variation. However, having established the baseline variability within lower limits (Figure 6.2a), a lower tolerable uncertainty limit of, say, ±35% (7 mg/l) of baseline mean ought to be attainable (Figure 6.2a).
- Boron is identified as an indicator of leachate from a pulverised fuel ash landfill during initial leachate characterisation monitoring. The mean baseline concentration of boron in groundwater is determined as 0.5 mg/l and an assessment limit or Control level of 2 mg/l is agreed. A tolerable uncertainty of ±50% (0.25 mg/l) from baseline mean is considered acceptable in the circumstances. However, if the mean were to rise to, say, 1 mg/l, tolerable uncertainty would have to be changed to, say, 30% (0.3 mg/l) from the new mean, to provide sufficient resolution closer to the assessment limit (Figure 6.2b).
- Trichloroethylene (a List I Substance) is detected in leachate within an industrial waste landfill. An assessment limit or Control level of 5 μg/l is set for leachate concentrations at monitoring points within the landfill. Reliability is critical and tolerable uncertainty needs to be as low as possible. The laboratory detection limit is established at 3 μg/l and the tolerable uncertainty stated as 1 μg/l above the detection limit (Figure 6.2c). QC samples should accompany all samples taken for this and other volatile organic substances.

Data should be evaluated against specified tolerable uncertainty on a periodic (e.g. annual) basis. Where variability exceeds the tolerable uncertainty, this may result from:

- excessive errors, which should be remedied by improved QC;
- increased natural variability, which may need increased sample numbers to define the natural variation;
- a developing trend. The significance of the trend should be assessed as described in Chapter 7. In this situation, evaluation against tolerable uncertainty is not feasible until the data stabilise around a new mean value.

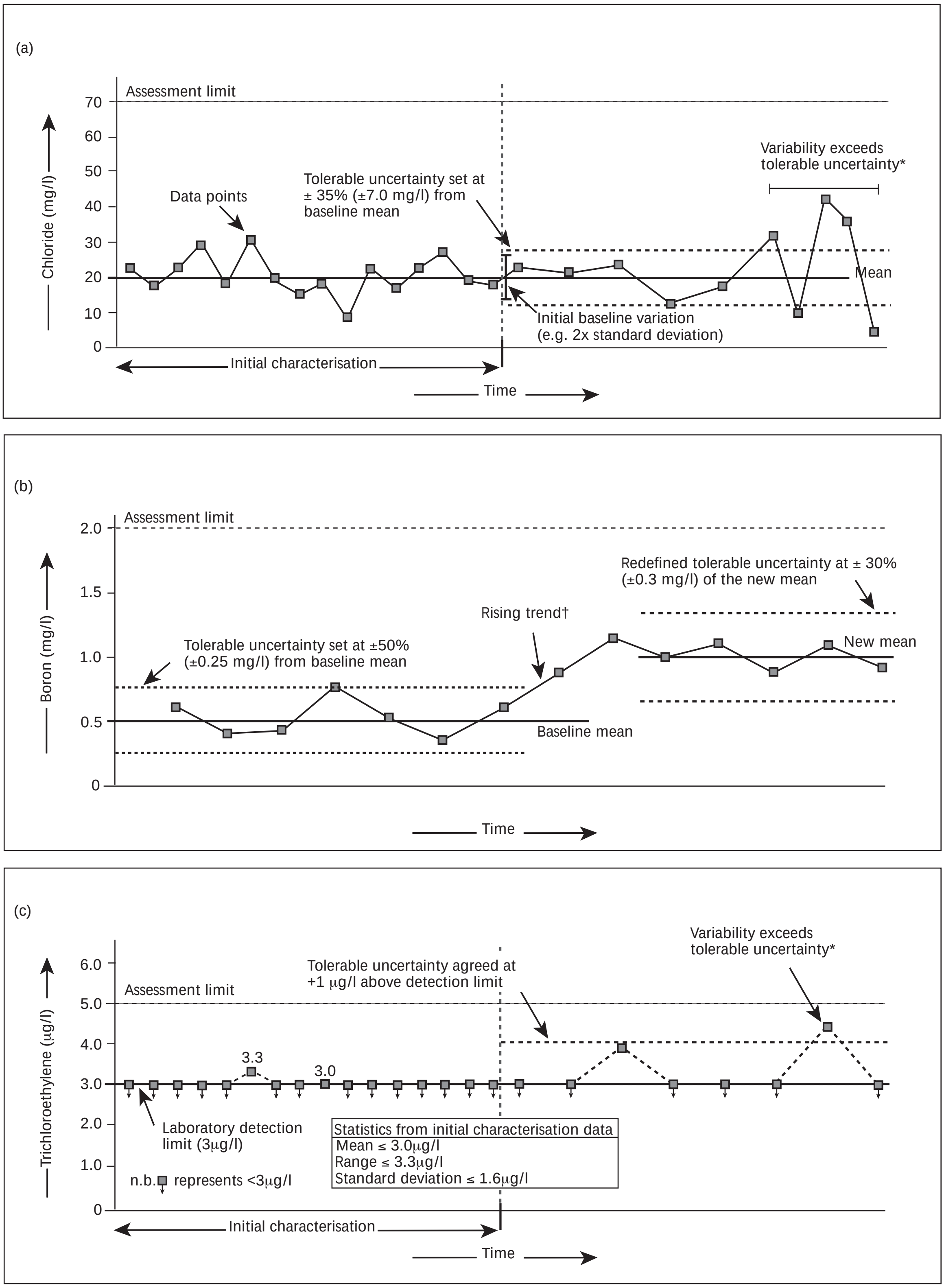
6.4 Specification of monitoring schedules

6.4.1 Introduction

Specification of monitoring schedules should result in a series of tables within each management plan that summarise frequency of surveys and monitoring measurements to be undertaken. Examples for a non-hazardous biodegradable landfill site are given in Tables 6.9, 6.10 and 6.11. In finalising schedules for any site, there is a balance to be achieved between the number of monitoring points, the monitoring frequency and the need to provide sufficient information to ensure compliance. This can only be judged in relation to the minimum requirements of the Landfill Regulations, site-specific conditions and the sensitivity of receptors.

The minimum requirements of the Landfill Regulations are set out in Table 6.8.

Figure 6.2 Illustrations of tolerable uncertainty



Notes

* When tolerable uncertainty is exceeded QC measures should be increased, and sample numbers may need to be increased in order to better define natural variations.

† If a trend becomes apparent, this becomes a matter for assesssment (see Chapter 7), and determination of uncertainty will not be feasible until values stabilise again.

Table 6.8 Minimum monitoring schedules as required by the Landfill Regulations[1]

Parameter	Operational phase	After-care phase[2]
Leachate volume	Monthly[3, 2]	Every six months
Leachate composition[4,5]	Quarterly[2]	Every six months
Volume and composition of surface water[6]	Quarterly[2]	Every six months
Level of groundwater	Every six months[7]	Every six months[7]
Groundwater composition	Site-specific frequency[8,9]	Site-specific frequency[8,9]

1. Samples of leachate must be collected at representative points. Sampling and measuring (volume and composition) of leachate must be performed at each point at which leachate is discharged from the site. Reference: General Guidelines on Sampling Technology, ISO 5667-2 (International Standards Organisation, 1991).
2. Longer intervals may be allowed if the evaluation of data (risk-based review) indicates that they would be equally effective. For leachates, the conductivity must always be measured at least once a year
3. The frequency of sampling may be adapted on the basis of the morphology of the landfill waste (in tumulus, buried etc.). This has to be specified in the permit.
4. The parameters to be measured and the substances to be analysed vary according to the composition of the waste deposited. They must be specified in the conditions of the landfill permit and reflect the leaching characteristics of the waste.
5. These do not apply where leachate collection is not required (see Schedule 2, Paragraph 2 of the Landfill Regulations).
6. On the basis of the characteristics of the landfill, using the risk-based monitoring review, the Agency may determine that these measurements are not required.
7. If there are fluctuating groundwater levels, the frequency must be increased.
8. The frequency must be based on the possibility for remedial action between two samples if a Control level and/or Trigger level is reached, i.e. the frequency must be determined on the basis of knowledge and evaluation of the velocity of groundwater flow (the hydrogeological risk assessment and/or the risk-based monitoring review)
9. When a trigger level is reached, verification is necessary by repeating the sampling (as set out in the contingency action plan). When the level has been confirmed, the contingency action plan set out in the permit conditions must be followed.

Notwithstanding the minimum requirements of the Landfill Regulations, as set out above, in carrying out the risk-based review in relation to determining the appropriate monitoring schedule, the following guidance should be followed.

Use of historical monitoring data to satisfy initial characterisation requirements

At operational landfill sites, or at sites where detailed environmental impact and risk assessments have been undertaken for planning purposes, monitoring data may already be available. It may be possible to use this data to form all or part of the initial characterisation monitoring records. Such data are acceptable where they have been quality assured and are statistically valid for their intended purpose. Justification for the use of historical data by the site operator or developer should be documented at the time of submission of the preliminary environmental management and monitoring programme. Where measurements needed for assessment or compliance purposes are absent from the historical record, specific characterisation programmes may need to be implemented to obtain them.

For operational sites with poor monitoring records, it may be necessary to initiate a specific period of intensive characterisation monitoring to establish baseline conditions.

At sites where the model monitoring schedules in Waste Management Papers 4 and 26A have been followed historically, the retrospective introduction of initial characterisation monitoring programmes should not be necessary unless the risk-based approach to monitoring identifies a clear need for this. A review of monitoring results, including a statistical summary of all data identifying baseline information, should be documented within the Environmental Management and Monitoring Programme.

Table 6.9 Summary of example monitoring scheme for a non-hazardous biodegradable landfill site posing a moderate to high risk to water receptors

Leachate or water body being monitored[1]	Monitoring measurements	Frequency of monitoring			Minimum number of monitoring points
		Initial characterisation[2]	Routine (indicators)	Routine (ongoing characterisation)	
Landfill leachate (within the waste body)	Leachate level	Monthly	Monthly	–	Two per 5 ha cell plus one extraction point[4].
	Monitoring point base	Six-monthly	–	Annually	
	Volume removed	Monthly	Monthly	–	
	Volume added	Monthly	Monthly	–	
	Composition	Six-monthly[3]	Six monthly	Annually	
Landfill leachate (in surface storage)	Leachate level	Site specific	Site specific	Site specific	One per storage facility
	Composition	Site specific	Site specific	Site specific	
Landfill leachate[5] (at discharge points)	Volume discharged	Site specific	Site specific	Site specific	One per discharge
	Composition	Site specific	Site specific	Site specific	
Landfill run-off[6]	Observation	–	Site specific	Site specific	Site specific
	Composition	–	Site specific	Site specific	
Other contaminant sources within licensed landfill area[7]	Observation	–	Site specific	Site specific	One per contaminant source
	Composition	–	Site specific	Site specific	
Groundwater	Water level	Monthly	Monthly[8]		Three per groundwater system
	Monitoring point base	During sampling	-	Annually	
	Composition	See Section 6.4.3	Quarterly[9]	Six-monthly[10]	
Surface water (in water courses)	Water level	Site specific	Site specific	Site specific	Two per water course
	Flow	Site specific	Site specific	Site specific	
	Composition	See Section 6.4.3	Monthly[11]	Six-monthly	
	Biological assessment	Site specific	Site specific	Site specific	
Surface water (in ponds)	Water level	Site specific	Site specific	Site specific	One per water body.
	Flow	Site specific	Site specific	Site specific	
	Composition	See Section 6.4.3	Monthly	Monthly	
	Biological assessment	Site specific	Site specific	Site specific	
Surface water (at discharge points)	Composition Discharge volume	As required by consent	As required by consent	As required by consent	One per discharge

1. Excluding rainfall and other meteorological data, which should be collated annually from site or Met Office data.
2. See Sections 6.4.2 and 6.4.3, which provide specific guidance on initial monitoring frequencies.
3. Increase frequency to quarterly for unstable leachate or polluting sites.
4. That is two monitoring points remote from extraction point for leachate level monitoring. Leachate quality monitored in extraction point for cells with complete basal drainage system. For other cells, two leachate sampling points required (e.g. extraction point plus one remote monitoring point).
5. Monitoring programmes will be largely dictated by the conditions of the consent to discharge.
6. Run-off from open landfill surfaces should be separated from contact with waste. Run-off can become contaminated by contact with waste or by accumulation of solids.
7. Examples: wheel washers, fuel storage tanks, chemical stores, waste receipt and handling areas, leachate treatment plants.
8. Decrease to quarterly or six-monthly if normal seasonal fluctuations have been established.
9. Decrease to six monthly or annually if stable conditions are proved or for low-risk sites. Increase frequency where groundwater flow velocities are high (see Table 6.11).
10. Decrease to annually if stable conditions are proved or for low-risk sites. Increase frequency where groundwater flow velocities are high (see Table 6.11).
11. Decrease to quarterly depending on type of water body and flow rate. Continuous monitoring may be required in sensitive environments.

6.4.2 Initial characterisation monitoring of groundwater and surface water

Minimum number of samples for initial characterisation

As illustrated in Figure 3.3, baseline data are those that are characteristic of conditions in the absence of any impacts arising from landfill development. The baseline can extend for a considerable period after commencement of landfill operations. However, to minimise ambiguity in the interpretation of data following the commencement of landfill operations, it is necessary to gather as much baseline information as possible in advance of landfill development. This is the primary purpose of initial characterisation monitoring for groundwater and surface water.

It is not possible to set universally applicable guidelines that specify the minimum number of samples needed to ensure that initial characterisation monitoring data are statistically valid for their intended purpose. Some authors have suggested a minimum of 20 samples are needed, others 16, but all with reservations[20]. The number of samples needed depends ultimately on the baseline variability of the measurement and the tolerable uncertainty required.

To standardise approaches for landfill monitoring, the following guidance is given.

- For most landfills, initial characterisation monitoring should be undertaken for at least one year prior to landfill development, but wherever possible for a longer period.
- For sites that can be demonstrated to pose low risks to receptors, initial characterisation monitoring should start at least three months prior to deposit of wastes and may be completed following commencement of waste input, subject to agreement with the Agency.
- The monitoring frequency used during the initial characterisation monitoring period should be sufficient to characterise seasonal variation. Normally, quarterly or more frequent (e.g. monthly) sampling is required.
- In the absence of information to support alternative strategies, at least 16 sets of data should be obtained per uniform water body. Less stringent requirements would only be acceptable where data are demonstrated to be statistically valid for their intended purpose.
- Where water characteristics are uniform in a water body, samples could reasonably be obtained from a combination of several monitoring points. For example:
  - ◊ Four monitoring points could be monitored quarterly to obtain 16 samples within a 1 year period;
  - ◊ Three monitoring points could be monitored every two months to obtain 18 samples within a one year period.
- For situations in which local variations in water characteristics are present, initial characterisation monitoring needs to be carefully planned for each monitoring point to establish baseline conditions adequately[21].

Initial characterisation monitoring for biological samples

Biological measurements are often subject to much greater variability than physical and chemical measurements, and the establishment of true baseline conditions may require a period of several years. The initial characterisation period should be used to measure seasonal variation, and to establish any significant correlation between biological and physical/chemical measurements. To achieve this, biological measurements should be:

- taken at least as frequently as the physical and chemical measurements;
- co-ordinated with the physical and chemical measurements so that relationships can be investigated.

6.4.3 Initial leachate characterisation monitoring

Leachate levels and quality can vary significantly over short time periods, particularly during the operational stage of landfilling. It is at the earliest stages of formation that leachate from biodegradable wastes is at its most polluting and hydraulic conditions the least predictable. Information concerning List I Substances should also be collected at an early stage of the landfill's development.

To allow for this uncertainty at sites where leachate monitoring is undertaken, an initial period of leachate characterisation monitoring should be carried out in each hydraulically separate landfill cell until:

- landfilling and final capping, including all barrier and soil layers, have been fully engineered (i.e. capping covers the entire surface area of the cell);
- hydraulic conditions within the cell are stable;

[20] For example, see Blakey *et al*. (1997), and Sara and Gibbons *in* Nielson (1991).
[21] At least two surface water monitoring points per uniform water body are required. At least three groundwater boreholes per uniform water body are required.

- leachate composition has reached a relatively stable state (e.g. methanogenic), demonstrated by a minimum of four sampling events over a period of two years.

For many non-hazardous biodegradable landfills, initial characterisation monitoring could reasonably be undertaken monthly for physical measurements such as leachate levels, and six-monthly for chemical composition measurements (Table 6.6). More frequent sampling of leachates for chemical analyses is probably only necessary in a small number of instances. Examples of these are as follows:

- where risks are high;
  e.g. where there is a risk that leachate could escape rapidly from the site in an uncontrollable manner;
- where leachate is chemically unstable;
- where water quality analyses are necessary to meet specific compliance conditions.

6.4.4 Routine monitoring programmes

Extending the baseline

If the initial characterisation monitoring is unable to establish statistical trends satisfactorily, or if anomalous data are generated at specific monitoring points, it may be necessary to increase the frequency of routine monitoring programmes for specific monitoring points and/or for specific measurements. Details need to be agreed between the site operator and the Agency and specified within an updated Environmental Management and Monitoring Programme.

All initial characterisation monitoring measurements should be repeated at least annually within the cycle of routine monitoring programmes to provide a screening check. This process ensures that unforeseen changes in non-indicator measurements are not overlooked, and allows an opportunity to review the use of specific indicators.

Establishing indicators

The concept of indicator monitoring applies equally to leachate, groundwater and surface water. It allows the use of a selected number of determinands and measurements based on the site's hydrogeological risk assessment and the risk-based design process. Indicator monitoring measurements should primarily include those needed for regulatory purposes, such as those being used for Control and Trigger level determination. The indicators should be:

- those required by regulation (i.e. Control and Trigger level determination);
- distinctive of leachate in comparison with groundwater and surface water,

  i.e. indicators that are found at consistently higher concentration in leachate than in groundwater or surface water (e.g. ammoniacal nitrogen and chloride for a biodegradable site), or that cause impacts directly related to leachate. The Landfill Regulations recommend "pH, TOC, phenols, heavy metals, fluoride, AS, oil/hydrocarbons";
- those that are relatively easy to measure within a specified tolerable uncertainty (Section 6.3.5);
- mobile, stable and persistent,

  i.e. unlikely to be retarded or altered relative to other contaminants (e.g. chloride);
- complementary,

  i.e. determinands that do not unnecessarily duplicate information provided by other indicators;
- those that can be used for QA.

The final selection of indicator measurements and monitoring frequencies for any site should be based on knowledge gained from the risk-based monitoring review and from the interpretation of initial characterisation monitoring results.

6.4.5 Example monitoring schedule

An example monitoring schedule for a non-hazardous biodegradable landfill site that poses a moderate-to-high risk to receptors is provided in Table 6.10. This table illustrates a suite of physical and chemical measurements, which could conceivably be used for characterisation and indicator monitoring. The frequency of ongoing characterisation monitoring for groundwater, surface water and leachate should be at least annual, but a greater frequency may be specified as a result of risk and a review of initial characterisation monitoring data. The frequency of indicator monitoring is specified in relation to compliance conditions, risk and travel times (see following sections).

The selection of specific monitoring suites and frequencies should always be based on an understanding of the risks and the characteristics of waste, leachate and the surrounding groundwater and surface water. For sites where risks to receptors are low, monitoring schedules need not be as onerous as at sites where risks are high.

6.4.6 Justification for increasing the frequency of groundwater monitoring surveys

Predicting the rate of movement of leachate contamination in groundwater systems is a complex process that involves an understanding of not only the physical flow mechanisms, but also the natural attenuation processes at work. Where these issues have been addressed in the hydrogeological risk assessment it should be possible to identify an appropriate monitoring frequency. The recommended frequency should take account of three distinct groundwater flow mechanisms:

- Intergranular flow
  Groundwater flow is primarily through evenly distributed and interconnected pore spaces. Intergranular flow is in general slower and more predictable than fissure flow. Natural attenuation processes are also more predictable and effective.
- Fissure flow
  In formations in which pores are either absent or too small to transmit water freely, water movement may occur primarily through fissures. Flows are less predictable and potentially more rapid than intergranular flow. Attenuation processes are less predictable, though the volume of flow in such instances may provide high dilution. Some formations (e.g. some sandstones) may transmit water both by intergranular and fissure flow.
- Flow in conduits.
  Flow is almost entirely channelled through discrete solution channels or discontinuities (e.g. in some limestone formations) or man-made conduits (e.g. mineshafts/workings). Chemical and biological attenuation processes are likely to be negligible, though dilution can be high. Flows can be as fast as surface water flow.

The example frequencies for groundwater monitoring set out in Table 6.10 are based on the assumption that flow rates are relatively slow. However, there are situations when, in the event of leachate escape through the liner system, the rate of contaminant movement may be more rapid than can be monitored reliably by quarterly or six-monthly surveys, in which case surveys that are more frequent may be needed.

Table 6.10 Example of monitoring suites for a non-hazardous biodegradable landfill site posing a moderate to high risk to water receptors

Measurement	Leachate within site		Leachate discharges		Groundwater		Surface water	
	C	I	C	I	C	I	C	I
Water level	•	•			•	•		
Mon. point base	•				•			
Flow rate			(•)	(•)			(•)	(•)
Vol. removed	•	•						
Vol. added	•	•						
Vol. discharged			•	•				
Temp	•	•	•	•	•	•	•	•
DO					(•)	(•)	•	•
Eh					(•)	(•)		
pH	•		•	•	•	•	•	•
EC	•		•	•	•	•	•	•
TSS							•	•
NH_4-N	•		•	•	•	•	•	•
TON (oxidised-N)	•		•		•	•	•	•
TOC	•		•	•	•	•	•	•
BOD	•		•	•	(•)	(•)	•	•
COD	•		•	•	(•)	(•)	•	•
Ca	•		•		•		•	
Mg	•		•		•		•	
Na	•		•		•		•	
K	•		•		•		•	
Alk	•		•		•		•	
SO_4	•		•		•		•	
Cl	•		•	•	•	•	•	•
Fe	•		•		•		•	
Mn	•		•		•		•	
Cd	•		•		•		•	
Cr	•		•		•		•	
Cu	•		•		•		•	
Ni	•		•		•		•	
Pb	•		•		•		•	
Zn	•		•		•		•	
Fluorides	(•)		(•)		(•)		(•)	
Other inorganics	(•)		(•)		(•)		(•)	
Phenols	•		•		(*)		(*)	
Volatile fatty acids	(•)		(•)		(•)			
Mineral oil/ hydrocarbons	(•)		(•)		(*)		(*)	

Table 6.10 Example of monitoring suites for a non-hazardous biodegradable landfill site posing a moderate to high risk to water receptors (continued)

Measurement	Leachate within site		Leachate discharges		Groundwater		Surface water	
	C	I	C	I	C	I	C	I
Dissolved methane			(*)					
List I/List II	(*)		(*)		(*)		(*)	
Biological measurements							(•)	(•)

See text for explanatory details. Monitoring suites and frequency of monitoring will vary based on site-specific conditions.
See Tables 6.4 to 6.7 for details of measurements and Table 6.9 for example monitoring frequencies.
Symbols: C, characterisation measurements; I, Indicator measurements.
(•) analysed if required by site-specific conditions or for assessment purposes.
(*) analysed if required by regulatory conditions (e.g. discharge consent or Groundwater Regulations 1998).

The flow velocity of groundwater in saturated granular formations can be determined by simple groundwater theory where:

$$v = Ki/n$$

where
v is groundwater flow velocity [length/time]

K is hydraulic conductivity [length/time]

i is hydraulic gradient [length/length]

n is effective porosity [Dimensionless]

Using the above velocity of flow, the travel time, *t*, to a receptor located at distance, *s*, from the site would be:

$$t = s/v$$

where
t is travel time [time]

s is distance [length]

Where a significant granular unsaturated zone exists, or where natural attenuation processes are at work, the actual time taken for contaminants to reach the receptor may be significantly greater than the time calculated using the above equation. Where natural conditions are suitable, contaminants may never reach the receptor, while some attenuation processes are finite and may only temporarily delay the onset of contamination. Good site-investigation data and careful analysis are required if these elements are to be incorporated into travel time calculations.

For the purpose of this guidance, the minimum groundwater monitoring frequency should be determined in relation to the physical groundwater travel time between the landfill site and potential receptors. The variability of a monitoring measurement (determined from baseline monitoring) should also influence the monitoring frequency.

Table 6.11 presents guidance that is applicable to intergranular and fissured flow. Where anticipated travel time to a receptor exceeds two years, there is no reason to increase monitoring frequencies above those given in Table 6.9. Where travel time is shorter than two years, increased monitoring frequencies are justifiable. Also, where variability in measurements is high and close to or exceeds the tolerable uncertainty, increased monitoring frequencies would be appropriate.

Table 6.11 Groundwater monitoring: examples of minimum survey frequencies based on travel time.

Travel time to receptor (months)	Minimum recommended monitoring frequency[1]
>24	Six monthly
>12 to 24	Quarterly
6 to 12	Monthly
<6	RA[2]

1. The *range* of measurements used would depend on the risk to the receptor as defined in the risk-based monitoring review (Chapter 4).
2. RA – Risk assessment based. Sites in such environments should incorporate engineering and monitoring measures capable of providing early warning of leachate escape (e.g. leakage detection layers, resistivity arrays). These measures must be able to survive for the lifetime of the site. Where these are absent, monitoring should be at least monthly at monitoring points between the site and receptors. Where leachate is known to escape from the site, receptors should be monitored at increased frequencies determined by investigation and risk assessment.

For situations in which groundwater travel times to receptors are less than six months, it is likely that the main flow paths will be via fissures and the effectiveness of conventional groundwater monitoring infrastructure alone in detecting leakage is questionable. In these instances, if a leakage detection layer is operational below a site, this may provide an additional means of monitoring. Where an effective leakage detection layer is absent, and risks to receptors are significant, a minimum of monthly groundwater monitoring on the down-gradient boundary should be carried out, supplemented by at least monthly monitoring of receptors and routine re-evaluation of risk to these.

6.4.7 Justification for increasing the frequency of surface water monitoring surveys

The example frequencies for surface water monitoring within this chapter are based on the assumption that the prime need for monitoring is for characterisation purposes. This allows an appreciation of the long-term variation in water quality, but is not suitable for detecting short-term impacts.

Where the risk assessment identifies that there is potentially a large short-term risk to the quality of surface water from leachate, more frequent biological and chemical monitoring, including the installation of continuous monitoring systems, may be appropriate. Situations in which this should be considered include:

- where surface water receives treated (or untreated) leachate from a direct discharge point or where there is a threat of overspill from leachate;
- where the quality of surface water is sensitive to pollution loading, such as low flow situations, water used for potable supply, water of high conservation value (e.g. some SSSIs) or designated as supporting salmonid species.

Biological monitoring frequencies

If required by risk assessment, routine biological measurements that involve community assessments of organisms present at the sampling points may be carried out on a quarterly basis, or even less frequently if seasonal variation is well established by characterisation monitoring.

Biological measures designed to indicate trends (e.g. the measurement of chlorophyll to indicate eutrophication) should be repeated at least monthly. Other biological measures designed to give early warning of toxicity may vary in frequency depending upon the sensitivity of the receptor and assessment of the risks.

6.4.8 Assessment monitoring

Assessment monitoring is necessary when it becomes apparent that an impact from the landfill is probably occurring. This is typically indicated by breach of an assessment criterion (see Chapter 7 and Figure 3.3). For groundwater, the primary assessment limit is the Control level, which should be set as part of the hydrogeological risk-assessment process.

The specification of assessment monitoring schedules should be based on a re-evaluation of risk using all available relevant monitoring data. The schedule should include those measurements for which potential impacts have been demonstrated, and others that may assist in distinguishing between landfill impacts and changes through other causes. Assessment monitoring frequencies should be determined by consideration of travel time, and time required to implement any remedial action. It may be appropriate to investigate further the use of alternative tracers indicative of leachate contamination, such as tritium. Tritium, where present in leachate, can often be used as a positive indicator of leachate contamination in groundwaters and surface waters (see Robinson and Gronow, 1995; Robinson, 1996).

Should assessment monitoring become necessary, the schedule should be agreed in consultation between the Agency and the operator. The site contingency plan should be followed if breaches of the assessment criteria occur.

7.0 Assessment criteria and contingency actions

7.1 Introduction

Regulations 14 and 15 of the **Landfill Regulations** require landfill operators to carry out control and monitoring programmes during both the operational and after-care phases of site development. If the programme shows that there are significant adverse environmental effects, the operator must notify the competent authority (i.e. the Agency) and must follow the decision of the Agency on the nature and timing of corrective measures to be undertaken. These remedial measures should be carried out at the operator's expense.

This chapter presents the principles underpinning the establishment of assessment criteria, compliance levels and contingency actions to address incidences of leachate contamination.

Guidance is given in this chapter as follows:

Section 7.2 the principle of compliance and the process of assessment;

Section 7.3 definition and specification of assessment criteria;

Section 7.4 issues related to contingency actions including site investigation and assessment monitoring.

7.2 Compliance and assessment

The terms compliance and assessment in relation to monitoring are defined as follows.

- **compliance** is the process of complying with a regulatory standard (e.g. maximum leachate head) – note that, under the Landfill Regulations, the compliance level for groundwater quality is specifically termed a Trigger level;
- **assessment** is the process of evaluating the significance of a departure from baseline conditions by reference to an adverse trend in data or the breach of a specified limit. Under the Landfill Regulations, the assessment criterion for groundwater quality is specifically termed a Control level.

The term 'compliance' is therefore reserved for statutory conditions, which may be established in the site permit (e.g. maximum leachate levels, groundwater Trigger levels. The term 'assessment' relates to the process of evaluating the significance of departures from baseline conditions, or breaches of non-statutory limits (e.g. groundwater Control levels). A well-planned method of assessment, agreed between the operator and the Agency, will help to:

- avoid breaches of compliance conditions (e.g. Trigger levels);
- provide clarity and avoid ambiguity if compliance conditions (e.g. Trigger levels) are breached.

7.3 Assessment criteria

7.3.1 Definition and purpose of assessment criteria

Assessment criteria are intended to draw the attention of site management and the Agency to the development of adverse trends in monitoring data. They should be treated primarily as an early warning system to enable appropriate investigative or corrective measures to be implemented, particularly where there is the potential for a compliance limit to be breached.

The primary assessment criteria for groundwater quality are the Control levels, which are required by the Landfill Regulations, and are derived as part of the hydrogeological risk-assessment process – note that Control levels are specific to groundwater quality and do not apply to groundwater levels, leachate or surface water.

Assessment criteria can be developed for several different purposes, such as to provide:

- a means of determining whether a compliance limit has been breached
  to avoid ambiguity, an agreed method is required to determine when breaches have occurred. Apart from the simple instance in which a single measurement in excess of the limit is used to define a breach, a statistical test is needed;

- a means of detecting an adverse trend before a compliance limit is reached
  this ensures that an early warning system is in place to allow reassessment of risk and implementation of contingency actions before the compliance limit is exceeded;
- a method for assessing monitoring data in relation to other advisory limits or conditions.

The determination of adverse trends and the rules to govern what is and what is not a breach of a limit can be a subjective process. Clarity on how these issues are to be resolved is an important part of the permitting process. Guidance is provided in the following sections on the establishment and use of assessment criteria to meet this need.

7.3.2 Aims of assessment criteria

Assessment criteria should aim to:

- identify unambiguous adverse trends which:
  - ◊ in leachates are indicative of departures from design conditions set for leachate levels or leachate quality;
  - ◊ in groundwater or surface water are indicative of leachate impacts;
- allow for variation in water quality from baseline conditions, to accommodate design leakage at the maximum acceptable release rate for the site (Figure 7.1a);
- allow sufficient time to take corrective or remedial action before impacts can cause harm to the environment or human health.

7.3.3 Components of assessment criteria

To fully define an assessment criterion, up to nine individual elements should be specified in each monitoring plan included within the Environmental Management and Monitoring Programme.

- Criterion objective.

  The objective should state the specific purpose for which the assessment criterion is being used. This will be related to factors identified by the conceptual model, the hydrogeological risk assessment or the risk-based monitoring review.

- Identification of monitoring points to be covered by the criterion.

  Criteria may be applied to individual monitoring points (e.g. a single monitoring borehole) or to groups of monitoring points (e.g. all monitoring points in a specific landfill cell, an entire groundwater system or a surface water body).

- The monitoring measurements to be used.

  A single indicator measurement (e.g. leachate level, chloride concentration) or a group of measurements (e.g. chloride, ammoniacal nitrogen, TOC) could be utilised.

- The frequency of measurement.

  Measurement frequency is specified in the monitoring schedule and should be commensurate with risk and the need to obtain appropriate data with a sufficient level of confidence for assessment purposes.

- The compliance limit (e.g. a Trigger level for groundwater quality) for each monitoring measurement (where statutory conditions apply).

  A regulatory limit established in the PPC Permit or other relevant document. This will only apply to some measurements.

- An assessment limit (e.g. Control levels for groundwater quality) for each monitoring measurement.

  A limit usually set below a compliance limit, which if exceeded would precipitate pre-determined contingency actions. An assessment limit is not required if the compliance limit itself is being assessed, or if the assessment test (see below) is for an adverse trend rather than being governed by a fixed limit.

- An assessment test for each monitoring measurement.

  A statistical or procedural test that confirms breach of an assessment limit or the development of an unacceptable trend.

- A response time.

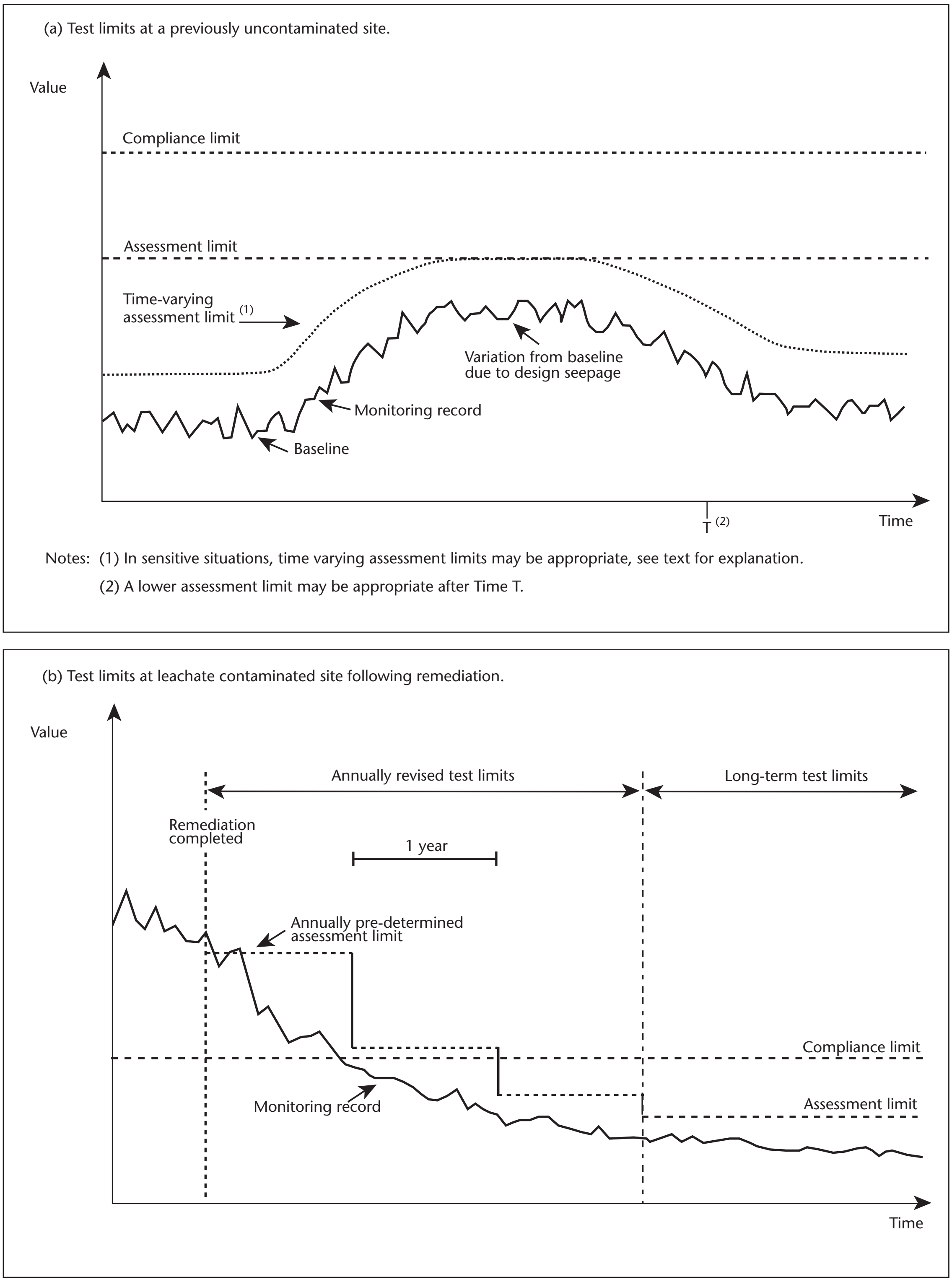
  A maximum specified time (measured from the date of a measurement that confirms a breach in the assessment criterion) in which to implement contingency actions.

- Contingency actions.

A sequence of pre-planned actions to be implemented within the specified response time.

Examples of assessment criteria for monitoring data from a hypothetical, biodegradable landfill are presented in Tables 7.1 to 7.4 at the end of this chapter. Criteria are site specific and need to be carefully developed in relation to local conditions.

Figure 7.1 Illustration of general principles of compliance and assessment limits



7.3.4 Assessment limits and tests

Assessment limit

Establishing assessment limits requires the use of the following sources of information:

- the site risk assessment and monitoring review. *including details of compliance limits, maximum leachate levels and maximum acceptable release rates derived from engineering design standards;*
- statistical characterisation of baseline data collected during initial characterisation monitoring. *whenever assessment limits are reviewed after commencement of site operations, the baseline statistics should be updated using any routine monitoring data that form part of the baseline record.*

An assessment limit may, for example, be fixed by reference to the resultant concentrations of contaminants that may occur within the downstream groundwater following the development of the site (i.e. a groundwater Control level), which allows for variability from baseline values. Alternatively, for other measurements such as leachate levels, the assessment limit may simply be set at an arbitrary or technically justified value less than the compliance limit, as a means of providing an early warning system.

The acceptance of a maximum acceptable release rate can lead to difficulties in establishing assessment criteria that need to take account of the possible increase in some water quality determinands. In practice, this means that assessment limits need to be either re-evaluated periodically or fixed at a concentration that anticipates an increase above baseline concentrations (Figure 7.1a). In the case of groundwater or surface water that has been subject to remediation, assessment limits may need to be revised downwards periodically until an acceptable quality of water is achieved (Figure 7.1b).

More details relating to the role of control monitoring for groundwater are presented within separate technical guidance (Environment Agency, 2003b).

Assessment test

The assessment test may be a statistical or qualitative test used to confirm a breach of the assessment limit or the development of an adverse trend. The use of statistical tests to define adverse trends in landfill monitoring data is the subject of ongoing development work, and separate technical guidance that specifically relates to the statistical analysis of groundwater quality has been prepared by the Environment Agency (2002d).

Examples of statistical tests are:

- a simple breach of the test limit on a single occasion (deterministic approach);
- probabilistic assessment of breach of the test limit for single determinands using methods such as:
  - ◊ control chart rules (e.g. a simple breach of the test limit on a specified number of occasions);
  - ◊ cusum charts;
  - ◊ process capability index;
- probabilistic assessment of breach of the test limit for multiple determinands using methods such as:
  - ◊ multivariate control charts;
  - ◊ water quality indices (e.g. principal component analysis, pollution indices);

The reliability of indices and multivariate control charts is difficult to validate and both should be used cautiously. If poorly designed, both methods can mask trends in individual determinands rather than enhance their detection.

Examples of data for a single determinand interpreted using some of the above methods are illustrated in Figure 7.2.

When a breach in an assessment criterion is confirmed by the assessment test, the operator should follow the actions set out within the site's contingency plan, which gives the appropriate actions and timescales. This plan should include the Agency being formally notified in writing immediately.

An example flow chart to illustrate how the assessment test procedure may be implemented practically to evaluate the impact by a contaminant on groundwater quality and initiate planned responses is provided as Figure 7.3.

7.3.5 Minimum use of assessment criteria

Assessment criteria should be used selectively and need not be applied to every single monitoring point or measurement. Assessment criteria (i.e. Control levels) for List I Substances in groundwater cannot be defined as the compliance levels are set at minimum reporting values. Accordingly, regular List I testing of groundwater samples may not be justified. Monitoring of conservative List II Substances with higher risk factors than the List I Substances found in leachate should be used to determine when sampling for List I Substances in groundwater is warranted. In addition, monitoring of landfill leachate to ensure that concentrations of List I Substances do not rise above those used in a hydrogeological risk assessment would also provide another assessment criterion (Control level).

The following specific assessment criteria should be developed for non-hazardous biodegradable landfill sites or sites where risks to receptors are significant:

- To confirm that leachate levels remain below a fixed maximum level above the site base (expressed as mAOD).
  Compliance and assessment limits should be set in relation to risk assessment assumptions used in the design of the site to calculate the maximum acceptable release rate.
- To provide sufficient warning to prevent leachate levels from overspilling to ground surface.
  Where leachate levels in older landfill sites cannot be practically reduced, maximum leachate levels should be established for the site, to ensure surface outbreaks of leachate do not occur.
- To enable timely action to be taken to prevent deterioration in water quality in groundwater.
  Control levels need to be set for groundwater quality that is present down-gradient of the site. These are required to provide early warning of a potential breach of the site's Trigger levels, which are compliance limits.
- To enable a timely response to prevent deterioration in water quality in surface waters.
  To monitor the impact of discharges from the site to water courses by reference to determinands, such as ammoniacal-nitrogen, suspended solids or BOD.

At sites located in areas with water receptors at low risk, there may only be a need for assessment criteria that address risks of contamination to surface water courses from surface run-off.

7.3.6 Problems with assessment criteria

Derivation of statistically based assessment criteria may reveal situations in which a compliance limit or assessment limit lies within the baseline data range of groundwater and surface water quality. This will cause obvious difficulties in the design and permitting of the landfill. In such cases, one or a combination of the following actions may be taken.

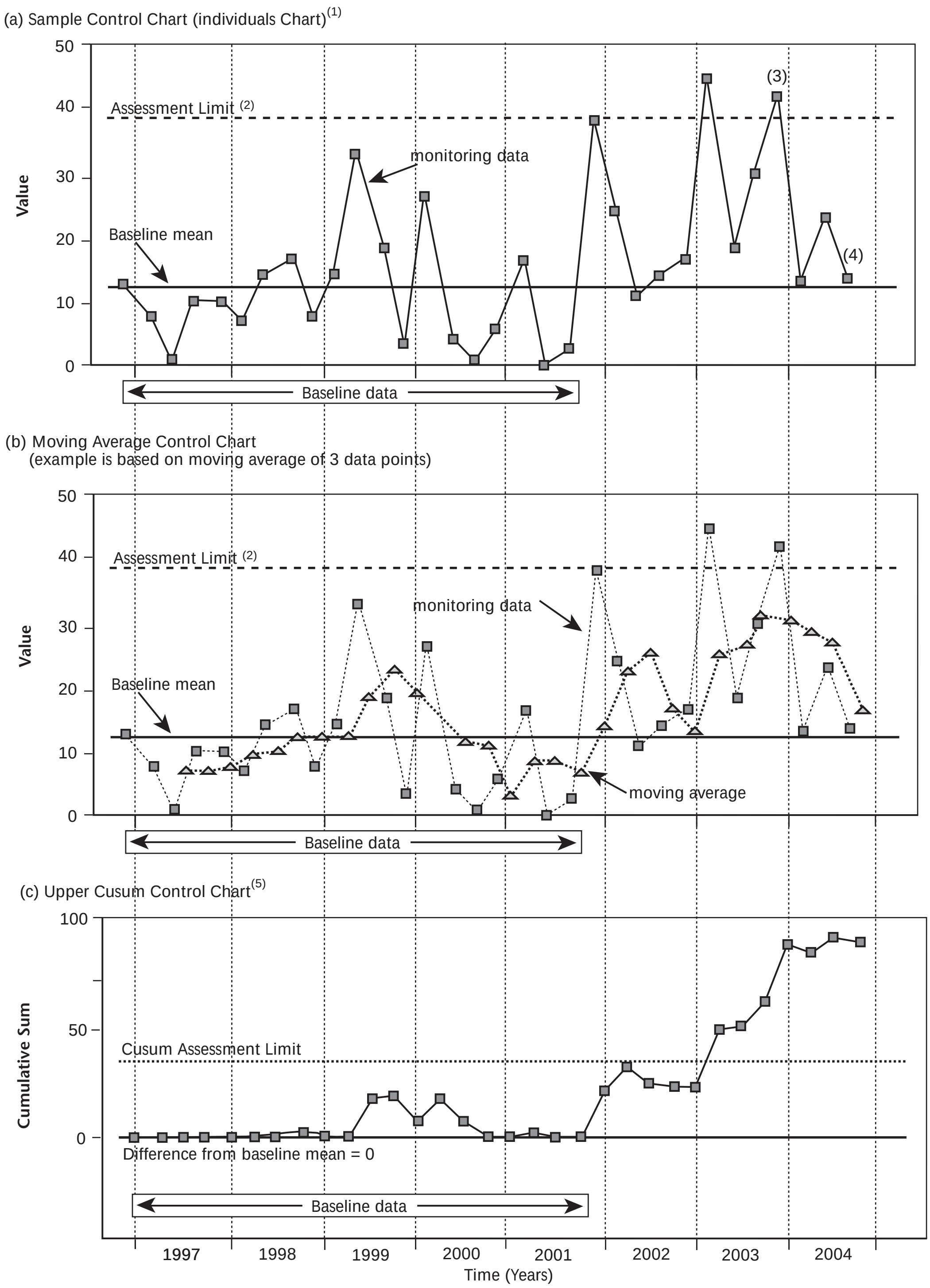
- Revise the compliance and/or assessment limit.
This can only be achieved by a deliberate alteration to the risk, for example by protecting or removing a receptor.
- Improve the reliability of the assessment of baseline behaviour by reducing uncertainty associated with sampling and analysis.
  This may be achieved by introducing more stringent sampling protocols and using improved analysis techniques. Variability will be better defined by increasing the number of samples taken (by increasing sampling frequencies or using additional monitoring points).
- Develop a time-varying (decreasing) assessment limit/Control level, using the compliance limit/Trigger level as a target to be achieved by a specified time (e.g. Figure 7.1b).
  This is particularly applicable to situations in which remediation has been undertaken, and would need to be negotiated between the site operator and the Agency.

7.3.7 Assessment criteria and breaches

The breach of a compliance limit specified in a PPC Permit or associated documents would suggest unacceptable performance of the landfill. Any breach of a compliance limit, such as a Trigger level for groundwater quality, could lead to costly and time-consuming measures. In the absence of any corrective action being implemented by the site operator, the Agency may take enforcement action. Consequently, all compliance limits and associated assessment criteria should be developed carefully and as a result of consultation between the site operator and the Agency.

Statutory compliance limits are difficult to change once they have been fixed in a site permit condition. Assessment limits or related conditions established within the environmental management and monitoring programme should be perceived more flexibly. Their intention is to aid in evaluating monitoring data sensibly. When risks are re-evaluated or monitoring data reveal unexpected variation or trends, it may be necessary to review and occasionally change assessment criteria. However, any proposed changes to assessment conditions in the Environmental Management and Monitoring Programme need to be justified technically and implemented only after consultation and agreement between the site operator and the Agency.

Figure 7.2 Examples of use of control charts to interpret trends in monitoring data.



Notes:

(1) For further explanation of control charts see Oakland 1996.

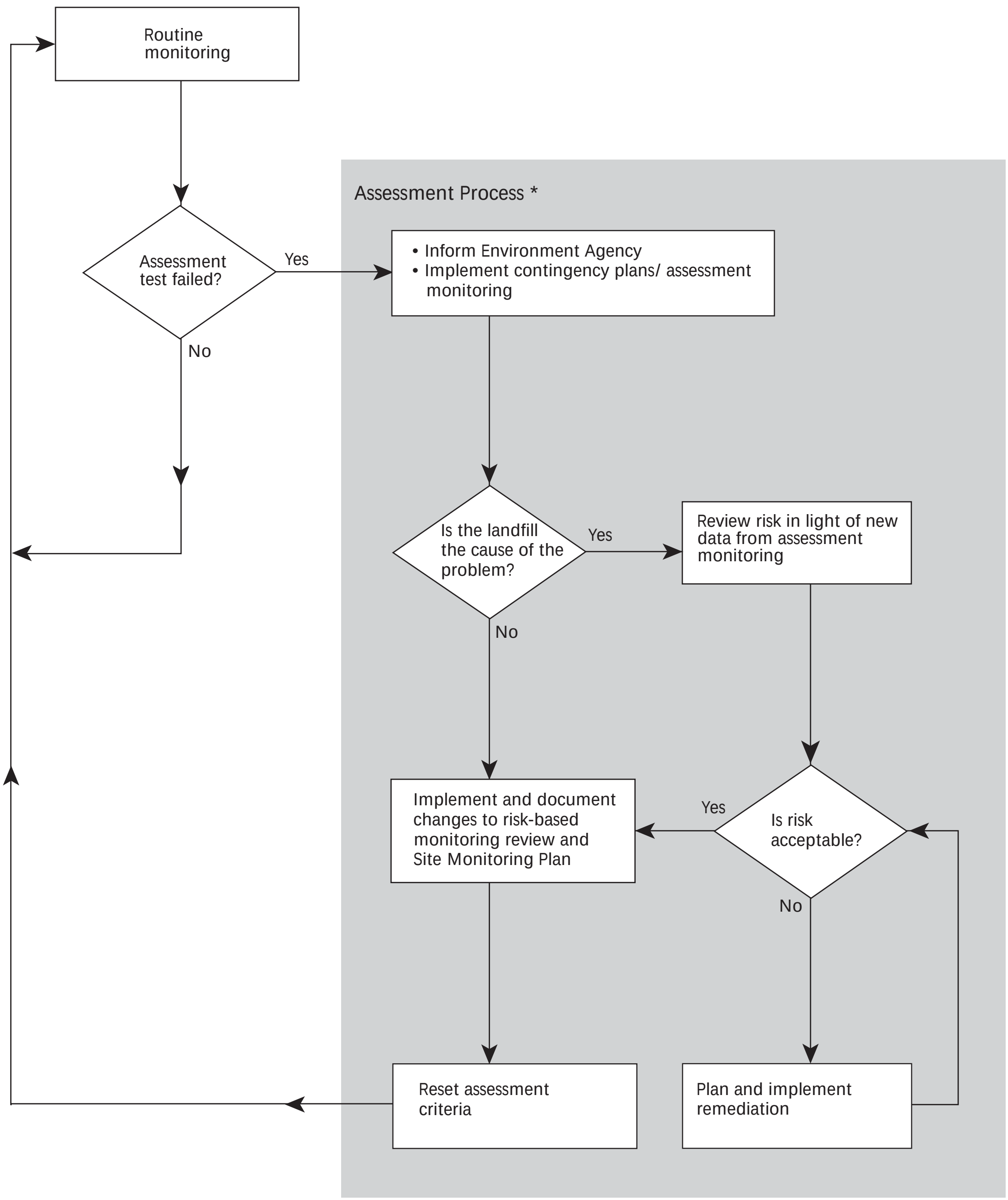
(2) An assessment limit is not necessarily the same as the 'action limit' defined in standard control charts.

(3) Rules governing the interpretation of control charts to identify breaches in an assessment limit or development of an adverse trend should be separately formulated. The point marked as (3) could, for example, indicate a breach in assessment limit based on a rule which is triggered by 2 breaches within 4 successive measurements (or some variation on this).

(4) A control rule could be deviced in which a significant departure from baseline conditions is confirmed by a successive number of values recorded above the baseline mean (in this case, 9 values).

(5) Each point on the upper cusum chart is calculated as the cumulative summation of the positive difference between the baseline mean and the actual recorded value.

Figure 7.3 Example flow chart illustrating possible responses to breach of an assessment limit.



* The Environment Agency should be fully consulted throughout this process. Any changes to monitoring programmes or remediation action must be agreed in consultation between the site operator and the Environment Agency.

7.4 Contingency Actions

7.4.1 Procedure in response to breaches in assessment limits

The actions to be taken following breaches of assessment criteria should be specified clearly and linked to a response time. The time period for undertaking any actions vary from completion on the same day (e.g. for a spillage into a surface watercourse) to several years (e.g. where more subtle variations in groundwater quality are being evaluated).

In all cases where breaches are confirmed as being caused by leachate contamination, a revised assessment of risk should be implemented. Where the risk is proved to be small, assessment criteria may be re-evaluated in consultation between the site operator and the Agency, and revisions incorporated into the risk assessment and the Environmental Management and Monitoring Programme.

The steps to be taken in responding to a breach of an assessment criterion, or a pollution incident, are:

- advise site management;
- advise the Agency;
- confirm by repeat measurements or observation (if time allows);
- in the case of an obvious polluting incident, initiate pre-planned preventative and/or corrective measures immediately;
- review existing data;
- establish the source (if there is doubt) and extent of the problem (by assessment monitoring or site investigation);
- determine whether the risks caused are harmful to human health or the environment;
- set in place a procedure to implement corrective measures or, if the risks are acceptable, re-evaluate the assessment criteria and monitoring programmes and return to routine monitoring.

Where risks are unacceptable, corrective or remediation measures should be initiated and a strategy to monitor their effectiveness should be determined in consultation with the Agency.

7.4.2 Emergency action

For many groundwater bodies, it may take several months or years to evaluate the onset of leachate contamination and to establish whether there has been a breach in either the Control or the Trigger levels. In these instances, there should be sufficient time to collate and assimilate data and to initiate corrective measures. In the case of leachate escape into surface water, there may be little time to undertake a formal assessment of the problem. Immediate action may be needed and the Agency should be informed and involved as soon as possible. Contingency measures for such emergencies should be specified clearly.

Examples of situations that require emergency contingency measures include:

- overspill or excessive discharge of leachate to a surface water course;
- leakage from a leachate distribution and pumping system;
- spillage from fuel storage tanks or other potentially polluting facilities on the site;
- siltation of surface water courses from site run-off.

All contingency measures should be kept under constant review and should be documented within the site authorisation documents.

7.4.3 Assessment monitoring

Assessment monitoring may be required as part of the contingency action, particularly where there is uncertainty as to the cause or full extent of the problem. Typical situations in which increased monitoring may be needed are:

- departures from design conditions within the landfill site
  for example, to monitor rapidly rising leachate levels (induced, e.g., by waste compaction) or to record changes in leachate composition that exceed concentrations used in the risk assessment for designing the landfill;
- to evaluate potential impact on sensitive water receptors
  if routine monitoring of groundwater or surface water reveals leachate contamination that threatens the viability of a sensitive water receptor (e.g. a borehole abstraction) then more intensive monitoring will be needed to evaluate the risk;
- to evaluate the effectiveness of natural attenuation
  sites that rely on natural attenuation to control leachate egress will need to undertake a significant commitment to monitoring to be able to reliably map the rate of advance an /or degradation of contamination through strata.

Where assessment monitoring indicates a source of contamination other than leachate, assessment criteria may need to be suspended temporarily, in consultation with the Agency. In these cases, baseline conditions should be re-evaluated so that assessment criteria capable of distinguishing and responding to leachate impacts can be re-established.

7.4.4 Corrective action and remediation

If a breach of an assessment criterion is shown to be caused by leachate from the landfill, and a risk assessment has shown that the risk is unacceptable, remedial action is required.

While some corrective action may be relatively simple to undertake (e.g. removing an obvious source of pollution, such as a leaking pipe) others can be very costly and technically complex (e.g. in-situ groundwater remediation). In all cases, the need for remediation should be balanced against the risk posed to groundwater and surface water receptors and the environmental benefits gained by remediation. In complex cases, specialist advice should be taken and remedial actions and their objectives agreed in consultations between the site operator and the Agency.

Table 7.1 Example assessment criterion for leachate levels

Criterion objective To detect an unacceptable permanent rise in leachate levels in a landfill cell	
Measurement:	Leachate level expressed as mAOD
Frequency:	Monthly
Monitoring points:	All leachate level monitoring points in cell A
Compliance limit[1]:	*X* mAOD in landfill cell A
Assessment limit[1]:	*Y* m AOD[2]
Assessment test[3]:	Mean of all leachate heads exceeds Y mAOD in more than 50% of measurements over a six month period[4].

Contingency action[5]	**Response time[6]**
Advise Agency.	One day
Check efficiency of leachate removal systems and initiate contingency actions.	One month
Report to Agency on re-appraisal of risks to groundwater and surface water and options for corrective measures (e.g. pumping to reduce levels).	Three months
If risks are acceptable: document revised assessment criterion to Agency If risks are unacceptable: implement corrective measures	Six months

Example is for illustrative purposes only. Exact details should be site specific.

1. Compliance and assessment limits should be set in relation to hydrogeological risk assessment and engineering design specifications.
2. Y is a lower elevation than *X*. For example, if the compliance limit from a risk assessment is set at 2 m above the site base, an assessment limit for early warning purposes could be set at 1 m above the site base.
3. Assessment tests should be capable of providing timely responses. The use of statistical or other tests is applicable where these can be clearly specified.
4. Level control criteria should be established on a site and cell-specific basis (the above example is only directly applicable to engineered sites with efficient dewatering systems). In some instances, separate criteria may be needed for individual monitoring points.
5. If the compliance limit is breached at any time, the Agency must be informed immediately. Enforcement action will be taken where risks are significant and where no effective corrective measures have been implemented.
6. Response time is measured from the date of measurement (or date of final measurement confirming a breach of assessment limits in the case of multiple measurements).

Table 7.2 Example assessment criterion for leachate quality

Criterion objective To identify an unacceptable deterioration in leachate quality beyond that assumed by risk assessment	
Measurement:	Chloride (Cl) as mg/l; ammoniacal nitrogen (amm-N) as mg/l N
Frequency:	Six-monthly
Monitoring points:	All leachate quality monitoring points in cell A
Compliance limit[1]:	Not applicable
Assessment limit[2]:	Leachate quality concentrations higher than assumed within the site's hydrogeological risk assessment, e.g. Cl concentration should not exceed *Y1* mg/l Amm-N concentration should not exceed *Y2* mg/l List I Substances detected
Assessment test[3]:	Mean Cl or amm-N concentration from all monitoring points exceeds assessment limit on three consecutive surveys.

Contingency action[4]	**Response time[5]**
Advise Agency	One month
Increase survey frequency to quarterly	Three months
Report to Agency on re-appraisal of risks to groundwater and surface water and options for corrective measures	Three months
If risks are acceptable: re-evaluate assessment criteria for groundwaters and surface waters If risks are unacceptable: implement corrective measures	Six months

Example is for illustrative purposes only. Exact details should be site specific.
1. Compliance limits may not be applicable except in relation to quality limits used to monitor co-disposal loading rates.
2. Assessment limits should be set in relation to risk assessment and engineering design specifications.
3. Assessment tests should be capable of providing timely responses. The use of statistical or other tests is applicable where these can be clearly specified.
4. This type of evaluation is unlikely to be subject to immediate enforcement action, but would require an urgent re-appraisal of risk. Subsequent enforcement action could include increased controls on waste input.
5. Response time is measured from the date of measurement that confirms the breach of assessment limit.

Table 7.3 Example assessment criterion for groundwater quality.

Criterion objective To detect an unacceptable deterioration in groundwater quality	
Measurement:	Chloride (Cl) as mg/l; ammoniacal-nitrogen (amm-N) as mg/l N; mecoprop (List I Substance) as mg/l N
Frequency:	Quarterly
Monitoring points:	Single borehole (e.g. BH1)
Compliance limit[1]:	Trigger level as determined by the hydrogeological risk assessment, such as: For mecoprop (List I Substance) – the lower reporting limit that is appropriate for groundwater; For ammoniacal nitrogen and chloride – the most appropriate and most stringent EALs
Assessment limit[2]:	Control[3] levels as determined by the hydrogeological risk assessment and associated risk-base monitoring review, such as: Cl concentration should not exceed *Y*1 mg/l Amm-N concentration should not exceed *Y*2 mg/l Mecoprop (List I Substance)[4] concentration in leachate should not exceed *Y*3 µg/l Exceedence of maximum concentration in leachate used in risk assessment
Assessment test[5]:	Concentration exceeds assessment limit on three consecutive routine surveys

Contingency action[3]	**Response time[6]**
Advise Agency	One month
Increase survey frequency to monthly	One month
Undertake site investigation work in cases of uncertainty	Six months
Report to Agency on re-appraisal of risks and options for corrective measures	12 months
If risks are acceptable: re-evaluate assessment criteria If risks are unacceptable: implement corrective measures	18 months

Example is for illustrative purposes only. Exact details should be site specific.

1. Groundwater Trigger levels should be set for both List I and List II Substances.
2. Assessment criteria should be set in relation to baseline data, risk assessment and engineering design specifications.
3. The breach of a control criterion is unlikely to be subject to immediate enforcement action, but would require an urgent re-appraisal of risk. Subsequent enforcement action could include increased controls on waste input. Potential enforcement action could be taken where Trigger levels are breached, where risks are significant and where no effective corrective measures have been implemented following breaches of either the Control or Trigger levels.
4. Control levels for List I Substances cannot be set and surrogates should be used, such as List I leachate concentrations.
5. Assessment tests should be capable of providing timely responses. The use of statistical or other tests is applicable where these can be clearly specified.
6. Response time should be measured from the date of measurement that confirms the breach of the Control levels and/or the Trigger levels. Response times should be set with consideration for travel times to receptors.

Table 7.4 | Example assessment criterion for a discharge to surface water.

Criterion objective	
To ensure that consent conditions are maintained *(Applicable for a discharge consent where monitoring of the discharge by the operator has been agreed or is required by the Agency)*	
Measurement:	Ammoniacal-nitrogen (amm-N) as mg/l N
Frequency:	Monthly
Monitoring points:	Discharge point
Compliance limit[1]:	Amm-N concentration should not exceed *X* mg/l
Assessment limit[2]:	Amm-N concentration should not exceed *Y* mg/l[3]
Assessment test[4]:	Amm-N concentration exceeds assessment limit on any three occasions in a 6 month period

Contingency action[5]	**Response time[6]**
Advise Agency and initiate repeat sampling and analysis	One day
Report to Agency on results of repeat sampling and analysis	One week
Increase survey frequency to twice weekly	Two weeks
Report to Agency on re-appraisal of risks and options for corrective measures	One month
If risks are acceptable: re-evaluate assessment criteria If risks are unacceptable: implement corrective measures	Three months

All examples are for illustrative purposes only. Exact details should be site specific.

1. Compliance limits should normally be equivalent to consented discharge limits.
2. Assessment limits should be set in relation to risk assessment and engineering design specifications.
3. Y is usually a lower concentration than X.
4. Assessment tests should be capable of providing timely responses. The use of statistical or other tests is applicable where these can be clearly specified.
5. Enforcement action would be taken in accordance with normal practice for controlling consented discharges.
6. Response time should be measured from the date of measurement (or date of final measurement confirming a breach of assessment limits in the case of multiple measurements).

Part 4 Practical Aspects of Monitoring

8.0 Design of monitoring points

8.1 Introduction

This chapter describes some of the technical issues and design criteria to be applied in the location, design, installation and maintenance of monitoring points.

Guidance is presented in this chapter as follows:

Section 8.2 describes a number of general issues applicable to the design of monitoring infrastructure;

Section 8.3 describes issues relevant to identification and referencing of monitoring points;

Section 8.4 describes design specifications for leachate monitoring points;

Section 8.5 describes design specifications for groundwater monitoring points;

Section 8.6 describes specifications for selecting or designing surface water monitoring points.

8.2 General design issues

8.2.1 Design objectives

The design of monitoring infrastructure should only be finalised after completion of the risk-based monitoring review and in the light of the overall monitoring objectives for the site and the monitoring schedules to be implemented (Chapters 4, 5 and 6). This may lead to the abandonment or modification of existing monitoring infrastructure (inherited from site investigations) and the provision of new monitoring points.

Common design objectives are that monitoring points should be constructed to:

- prevent mixing of separate sources of water (e.g. leachate and groundwater, surface water with groundwater or different levels of groundwater within strata);
- use materials that will not influence the measurements being taken;
- accommodate sampling equipment.

Additional design requirements relate to the protection and safety of monitoring points. Monitoring points should be:

- designed to physically survive the effects of use, abuse, weather (including flooding where appropriate) and ground movement, for a specified design lifetime.
  The design lifetime for the monitoring point may be less than that of the site. If this is the case, a maintenance and replacement schedule should be provided in the site operational plan;
- protected from vandalism and unauthorised entry;
- protected from damage by plant and machinery;
- capable of being easily found, and marked to allow identification by personnel unfamiliar with the site;
- protected from ingress of foreign matter (e.g. dust, rainfall, surface water inflow);
- sealed (where necessary) to prevent excessive emission of leachate, landfill gas and other natural gases or artesian water;
- safe for the purpose of monitoring.

Further design objectives specific to different types of monitoring point are given in the appropriate sections below.

8.2.2 Construction quality assurance of monitoring infrastructure

All monitoring installations provided for long-term monitoring within the terms of the site licence should be treated as part of the engineering infrastructure of the landfill site. Poor design and construction of monitoring points can influence and may even invalidate monitoring data. This can lead to misinterpretation of results and the implementation of costly and inappropriate actions. Each point should be designed, supervised and certified in accordance with normal engineering practice. For example, records of borehole constructions should be based on standards in BS5930 Code of Practice for Site Investigations (British Standards Institute, 1999). Health and safety during construction of monitoring points should follow guidance by the Association of Geotechnical Specialists (1992), the British Drilling Association (1981) and the Site Investigation Steering Group (1993).

In practice, this requires the following.

- **a design standard should be agreed with the Agency for each monitoring point type, which should be incorporated into the site Environmental Management and Monitoring Programme;**
- **a competent person should take responsibility for the design, installation and completion of each monitoring installation;**
- **a completion record, log or diagram of each monitoring point should be prepared and certified by a competent person and incorporated into the Environmental Management and Monitoring Programme;**
- **Each monitoring point should be formally registered with the Agency – acceptance of monitoring points by the Agency will be assessed against pre-agreed design objectives;**
- **The continued use of existing monitoring points should be dependent on their suitability for the purpose, and the availability of construction details (see Section 8.5.3 below).**

Defective monitoring installations

The objective of each monitoring point should be stated within the Environmental Management and Monitoring Programme. Where monitoring points are damaged or unable to meet monitoring objectives for any reason, they should be replaced:

- the status of each monitoring point should be reviewed at least annually — where monitoring points fail to meet their objectives and cannot be remediated, a replacement should be provided within a time period agreed with the Agency or as stipulated in the PPC Permit and associated documents;
- all replacement or remediated monitoring points should be certified and recommissioned in accordance with guidance set out above;
- remediation of existing boreholes for monitoring purposes and procedures for sealing abandoned boreholes are set out in Section 8.5.6.

8.3 Identification and accessibility of monitoring points

8.3.1 Definitions and terminology

The following definitions relating to monitoring points are used in this guidance:

Monitoring point: an individual point from which unique sets of monitoring measurements can be obtained.

Permitted compliance point: a monitoring point required by permit or included in the site's environmental management and monitoring programme.

These include wells in which groundwater Control and Trigger levels have been set, and so are an important element of the monitoring and control of the site.

Multiple monitoring points: A number of monitoring points separated vertically within the same construction or at the same location. This includes any number of monitoring points within a single borehole or situations in which surface waters are sampled at different vertical intervals (e.g. a water sample accompanied by a bottom sediment sample).

Clustered monitoring points: A group of individual or multiple monitoring points located near to each other for the purpose of monitoring different vertical intervals in strata, waste or surface water.

8.3.2 Numbering of monitoring installations

A consistent and unambiguous numbering system should be adopted for all monitoring points. The format for numbering will reflect the complexity of the monitoring infrastructure. The following guidelines should be followed.

- every individual monitoring point used to monitor a specific landfill site should have a unique reference number;
- short alphanumeric references are preferable (e.g. 'GW10', 'S5', L13') to enable simple tabulated reports to be prepared and for storage on a computerised database or other recording system;
- re-use of monitoring point numbers to reference replacement monitoring points should be avoided to prevent confusion and ambiguity with historical data records;

- Monitoring points should only be renumbered where this will improve understanding of the monitoring infrastructure or remove ambiguities *Where points are renumbered, any similarity to previous numbering systems should be avoided. An index of new and old numbers should be provided within all future monitoring reports submitted to the Agency until this index is incorporated within a revised version of the Environmental Management and Monitoring Programme and lodged with the Agency.*

8.3.3 Co-ordinates of monitoring points

The location of each monitoring point should be referenced to the co-ordinate system used for mapping the site. Normally, an Ordnance Survey 12-figure National Grid reference (eastings and northings, including prefixes), expressed to an accuracy of at least 1 m should be used.

8.3.4 Identification of monitoring installations

All monitoring points should be capable of being identified unambiguously. For this purpose:

- each individual monitoring point should be labelled externally and internally with its unique monitoring point reference number;
- multiple installations should be identified externally and internally with a unique multiple reference number. Each individual monitoring point should be marked with a separate means of identification (e.g. specific labels, colour coding or an obvious physical distinguishing feature);
- an up-to-date location plan of all monitoring points shall be incorporated into the Environmental Management and Monitoring Programme and annual review report;
- an up-to-date register of all permitted monitoring points should be incorporated within the Environmental Management and Monitoring Programme and annual review report. The register should include the following information:

All monitoring points:

◊ monitoring purpose (e.g. leachate, groundwater, surface water, combined gas and groundwater);

◊ name of strata or water course monitored;

◊ cell number or site area reference (if relevant);

◊ monitoring point reference number;

◊ multiple reference number (if relevant);

◊ cluster reference number (if relevant);

◊ type of monitoring point (e.g. stream, piezometer, standpipe, sump);

◊ any safety or access difficulties;

◊ distinguishing features (e.g. colour);

◊ National Grid Reference (eastings and northings).

Groundwater and leachate monitoring points:

◊ description of datum point used to record water levels;

◊ elevation of datum point (normally as mAOD);

◊ datum height relative to ground level (m);

◊ original depth of constructed installation (m below current ground level or datum level and mAOD);

◊ diameter of internal lining (mm);

◊ depth to top and bottom of screen or slotted interval (m below current ground level or datum level and mAOD).

Surface water monitoring points:

◊ description of datum point used to record water levels;

◊ elevation of datum point (normally as mAOD);

◊ description of location;

◊ a sketch plan or photograph of the monitoring point (if necessary).

Example forms for compiling monitoring point registers are included in Appendix 1.

8.4 Leachate monitoring points

8.4.1 Types of leachate monitoring point

Leachate monitoring points can be classified by their location, which can be:

- within leachate drainage systems;
- within leakage detection layers below basal lining systems;
- at storage lagoons, storage tanks and discharge points;
- within the body of waste.

At any one site, monitoring points may be provided in one or a combination of locations. The largest category at existing landfill sites consists of monitoring points within the body of the waste.

8.4.2 Design objectives for leachate monitoring points

Monitoring points within leachate drainage layers

Specific design objectives relating to monitoring points within leachate drainage layers are:

- to enable an appropriate sample of leachate to be obtained from the base of the site
  where drainage systems are working efficiently, particularly where recirculation of leachate has been successfully established, samples taken from a discharge point within the basal drainage system will be representative of free-draining leachate within the waste mass;
- to determine the volume of leachate discharged from the site
  discharge points from drainage systems can be monitored to record the volume removed and, in some instances, the rate of flow of leachate from discrete parts of the site.

Other design objectives are based on an appreciation of the specific purpose of a monitoring point combined with an understanding of the hydraulic conditions of the landfill and the drainage layer.

Monitoring points installed within drainage systems that are part of a continuous drainage blanket could be used to provide leachate-level measurements above the site base. Non-continuous drainage layers are unlikely to be as reliable, unless there is free movement of leachate through the waste between drainage lines.

Monitoring points within leakage detection layers

The primary design objective relating to monitoring points within leachate-leakage detection layers below landfill liners is:

- to identify and quantify any leachate leakage;
- to enable an appropriate sample of liquid to be obtained for comparison to leachate quality.

Depending on the design of the detection layer, other monitoring objectives may be set, which could include the measurement of water level, flow or discharge rate.

Leakage detection layers provide, in theory, a monitoring facility for detecting any leakage of leachate below the base of an engineered basal lining system. The design of detection layers usually includes a granular material, sometimes with piped drains, sandwiched between low permeability layers. The detection layer should remain dry in the absence of any leachate leakage from the overlying landfill. In practice, water can enter this layer from various sources, including the following.

- from compaction of an overlying mineral lining layer releasing pore water after construction – the quality of this water can often be heavily mineralised and be mistakenly identified as leachate.
- from groundwater upwelling through the secondary basal liner, which can occur seasonally or permanently depending on local conditions.

In both cases, a sample of the pore water from the basal lining materials used should be obtained to allow comparison with any water identified in the detection layer.

Where leakage detection layers are in place and operating successfully, they could provide a rationale for reducing the monitoring effort in groundwater and surface waters provided:

- the detection layer can be hydraulically tested to confirm its integrity;
- at least five years' monitoring data are available from the detection layer and from surrounding groundwater and surface water;
- monitoring data from the detection layer shows no evidence of leachate leakage.

If leakage of leachate into the detection layer is confirmed, an immediate review of risk and the need to modify groundwater and surface water monitoring programmes should be implemented.

Leachate lagoons, storage tanks and discharge points

Specific design objectives relating to monitoring points within surface storage lagoons and at discharge points include:

- to permit an accurate level of fluid within storage facilities to be measured and recorded to an elevation expressed as metres above ordnance datum or by reference to a locally fixed maximum or overspill level;
- to enable a sample of leachate representative of the lagoon quality to be obtained prior to discharge;
- to record discharge volumes from the site as required by the Landfill Regulations, Schedule 3 III, Section 3.

Lagoons may include storage facilities pre- and post-treatment or collection facilities prior to discharge off-site via tanker or sewer.

Monitoring points within the body of waste

Specific design objectives relating to monitoring points within the body of the waste are:

- to permit an accurate level of leachate to be measured and recorded to an elevation expressed as metres above ordnance datum and as metres above the site base;
- to enable an appropriate sample of leachate to be obtained from the waste body.

Other design objectives are based on an appreciation of the specific purpose of a monitoring point combined with an understanding of the hydraulic conditions of the landfill. Some examples are:

- Monitoring points may be designed for multiple use, such as gas monitoring, gas extraction and/or leachate extraction. Multiple usage of monitoring points should only be accepted where it can be shown that these do not conflict with basic monitoring objectives. For example, a leachate extraction point that is frequently pumped will provide a reasonable point for obtaining leachate quality samples, but may not always be satisfactory for level monitoring (Section 6.2).
- Leachate quality may vary with depth. The sampling zone specified in the design objective will depend on whether the monitoring objective is to sample leachate from the base of the site (e.g. for risk assessment of leakage through base) or leachate from higher levels within the waste (e.g. to assess variability in degradation of the waste body).
- Perched leachate levels may be developed in the site, and these may require separate additional monitoring installations.

In some circumstances, it may not be possible to achieve design objectives fully. Some examples are:

- Larger diameter sumps may not yield samples of leachate appropriate to the waste body unless they are regularly pumped.
  It is preferable to use smaller diameter installations (i.e. less than 200 mm) for routine monitoring.
- In high density or deep landfill sites without a leachate collection and basal drainage system, it may prove difficult to provide monitoring points that can unambiguously record the level of leachate lying above the site base. Levels in these monitoring points may be influenced by perched inflows or confining pressures induced by the weight of overlying waste.
  In cases of ambiguity the lack of certainty should be compensated by greater emphasis on the potential pollution pathway – i.e. by increasing the number of points and the frequency of monitoring of groundwater or surface water.

In cases where it is not technically possible to obtain unambiguous leachate monitoring information from a site, these reasons should be stated in the Environmental Management and Monitoring Programme and an alternative monitoring strategy developed in consultation between the operator and the Agency.

8.4.3 Design and construction of leachate monitoring points in the body of waste

Many individual and innovative approaches are used in the design and construction of leachate monitoring points within waste. In general, these fall into two categories:

- monitoring points built during landfilling;
- within leakage detection layers below basal lining systems;

Advantages and disadvantages of each category of monitoring point are summarised in Table 8.1. The optimum approach is to use a combination of both types. Illustrations of design concepts for built and retrofitted leachate monitoring points are included as Figures 8.1 and 8.2. Guidance on the design and construction of these points is presented in Appendices 3, 4 and 5.

Table 8.1 Advantages and disadvantages of built and retrofitted monitoring points for monitoring leachate.

Type of leachate monitoring point	Advantages	Disadvantages
Built	• installed on site base • ability to monitor and extract from basal drainage layers • ability to obtain monitoring data during landfill operations	• substantial foundations needed above basal engineering layers to prevent puncturing and to maintain verticality • susceptible to damage or lateral movement during landfill operations and construction • concrete rings liable to chemical disintegration • can impede capping and restoration
Retrofitted	• can be drilled vertically • annular design and seals can be better controlled • greater density of boreholes can be constructed where needed	• difficult to complete on site base where there is a risk of puncture to basal seals • drilling is potentially hazardous • unpredictable drilling problems can occur installations greater than 30 m deep often need large specialist drilling rigs

When sampling from monitoring points in the waste body there may be a need to dispose of purge water (see Section 9.9). In some cases an appropriate option for disposal is to use a specially constructed purge-water disposal point to enable return of purge water into the waste body directly below the restoration layers. This needs to be installed either at the time of restoration (for monitoring points built during landfilling) or when the monitoring point is constructed (for retrofitted monitoring points). Examples are shown diagrammatically in Figures 8.1 and 8.2.

8.4.4 Construction quality assurance and borehole logs

CQA procedures should be adopted to certify and document each structure prior to formal commissioning of its use and acceptance by the Agency. Detailed construction drawings or borehole logs for each monitoring point should be provided within the environmental management and monitoring programme.

8.4.5 Maintenance and ongoing quality assurance of infrastructure

The depth to the base of all leachate-monitoring points should be recorded at least annually, to check for evidence of silting or blockage. Problems with access to monitoring equipment should also be recorded. This information should be used at the time of the periodic review (see Chapter 10) to assess whether monitoring objectives are being achieved. A monitoring point that is gradually silting-up and is of sufficient diameter may be cleaned by use of a bailer operated with a cable percussion rig, although there is a risk of damage to the linings, particularly if they are pinched or no longer vertical. Smaller diameter boreholes may be cleaned using a surge block and pump. The use of compressed air or a vacuum for cleaning is also possible, but requires a system for full control of the leachate discharge to avoid health and safety risks.

A leachate monitoring point that is silting-up rapidly or has a broken or deformed liner should either be:

- adapted for monitoring a shallower depth range, if this is feasible and meets a monitoring objective; or
- decommissioned and replaced.

The procedure for the decommissioning of redundant monitoring points in waste should be reviewed with the Agency.

Figure 8.1 Examples of built leachate monitoring point designs appropriate for either non-hazardous or inert landfills

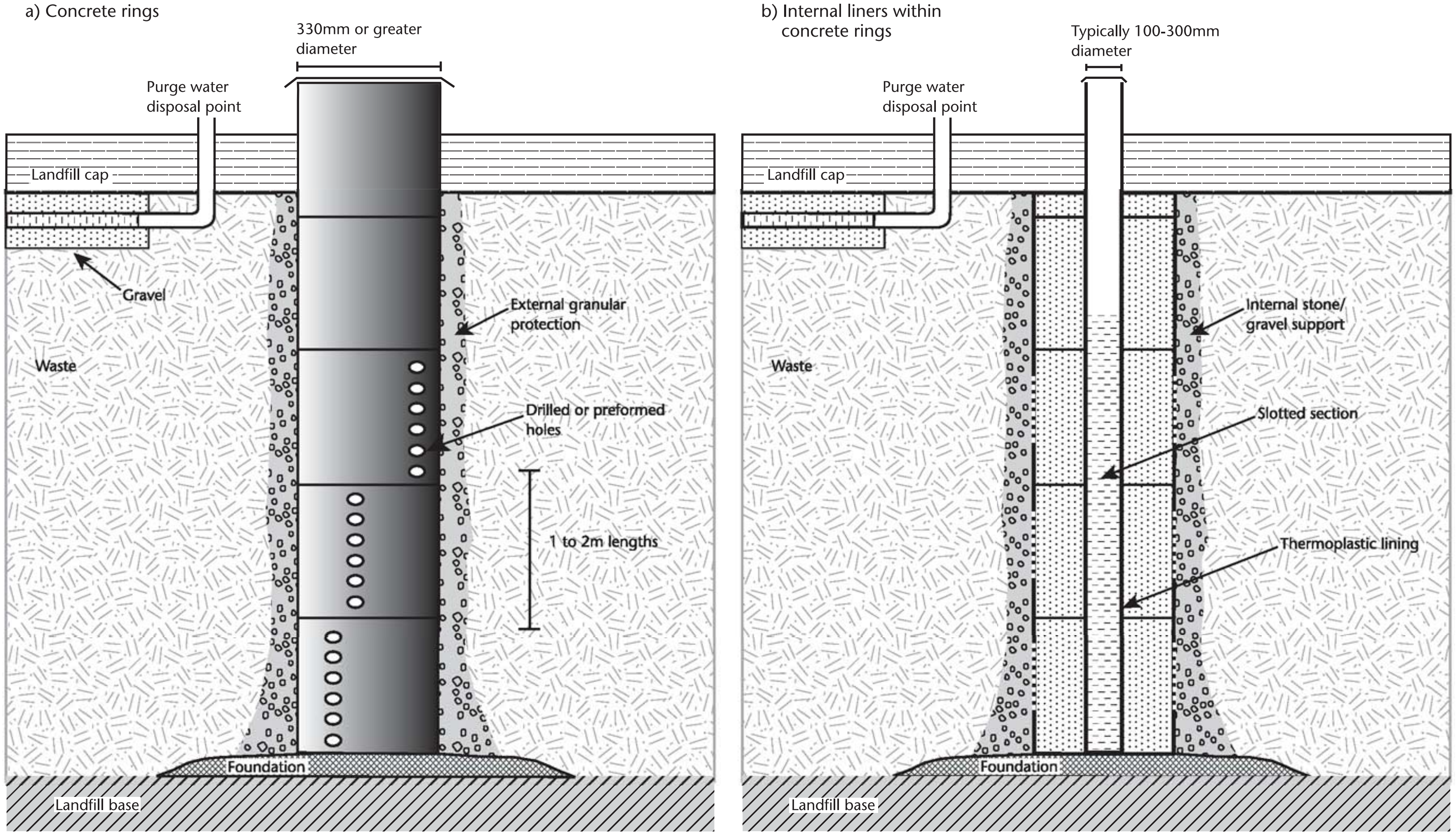
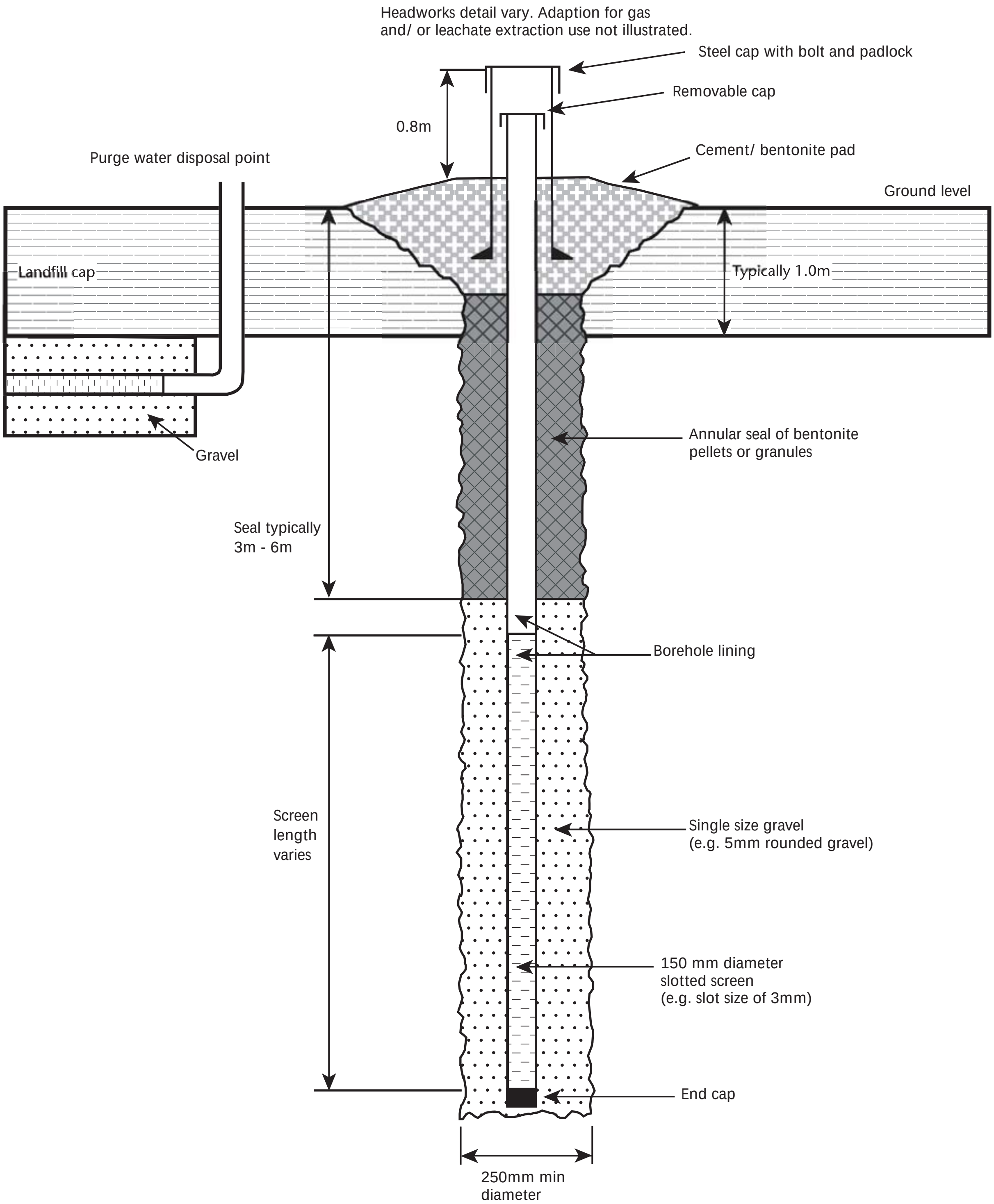


Figure 8.2 Example leachate borehole design completed with a 150 mm diameter lining



8.4.6 Novel or remote monitoring points

Any monitoring-point design that involves indirect monitoring methods (e.g. the use of buried transducers for level monitoring or electrodes for resistivity measurements) or any design that involves monitoring through non-vertical structures (e.g. sampling through inclined side-wall risers) should be used only where such structures can meet the basic monitoring objectives set out above. Any novel monitoring-point designs should be either based on proved technology or be proved in parallel trials with methods that are more conventional until their long-term integrity can be guaranteed.

Resistivity arrays

Resistivity arrays constructed in the unsaturated zone below landfill sites to detect leachate leakage should be designed to be:

- constructed below the whole or specific parts of the landfill where leachate is most likely to be concentrated;
- protected from damage and proved through regular operation and calibration checks to be operational and reliable;
- capable of detecting resistivity variations caused by leachate impact against natural resistivity variations established from a period of seasonal baseline monitoring;
- supported by alternative physical monitoring systems (e.g. a leachate detection layer and/or groundwater monitoring boreholes).

Over-reliance on remote monitoring systems should be avoided.

8.5 Groundwater monitoring points

8.5.1 Types of groundwater monitoring point

Terminology applied throughout this guidance to different types of groundwater monitoring point is as follows:

Well; borehole:
A hole sunk into the ground for abstraction of water or for observation purposes. A well is generally of larger diameter than a borehole and dug rather than drilled. A borehole is often used for monitoring purposes only and may be lined with suitable casing and screened at appropriate depths” [ISO 5667, Part 11 (International Standards Organisation, 1993].

Open or long-screened borehole:
An open borehole or a lined borehole of any diameter that is screened throughout the majority of its length. For the purpose of this guidance a ‘long screen’ is defined as greater than 6 m in length.

This is sometimes referred to as a ‘traditional observation borehole’.

Piezometer:
A tube installed to allow water level measurement and sampling from a specific vertical interval (the ‘response zone’). The response zone consists of a porous or short screened section (i.e. typically less than 6 m in length), or pressure measuring device, isolated by annular seals.

Nested piezometers:
A borehole that contains more than one piezometer separated vertically by seals.

The installation of more than two piezometers in a single borehole for monitoring purposes should not be undertaken other than in exceptional circumstances and in consultation between the operator and the Agency. It is inadvisable to install more than one installation in a borehole without experienced and careful supervision because of the difficulties in obtaining an effective seal. Even if installed correctly, nested installations can give monitoring results that are ambiguous.

Clustered piezometers:
A group of piezometers drilled close together, to monitor separate vertical intervals in the underlying groundwater or waste formations.

These are sometimes referred to as ‘multiple observation boreholes’.

Multi-level sampling devices:
These are proprietary systems, which provide a means of sampling from a number of small diameter ports or short-screened sections separated by vertical seals. Seals are either installed manually (in the manner of nested piezometers) or by the use of packers or other inflating mechanism.

The installation of specialist multi-level systems should be undertaken in consultation between the operator and the Agency. A detailed installation specification, supervision and performance testing is required wherever these types of installations are used.

A schematic diagram to illustrate the principles of the main types of installation is presented as Figure 8.3. A completed piezometer design is illustrated in Figure 8.4.

8.5.2 Design Objectives

Specific design objectives relating to groundwater monitoring points are:

- to 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;
- to enable an appropriate sample to be obtained from the surrounding stratum.

Other design objectives are based on an appreciation of the specific purpose of a monitoring point combined with an understanding of local hydraulic conditions. Some examples are:

- Monitoring points may be designed for combined use as gas-monitoring points. Multiple usage of monitoring points is to be encouraged where these do not conflict with the basic monitoring objectives. However, the basic design of most gas-monitoring points has historically been based on the provision of boreholes with a continuous long-screen. These types of design introduce vertical pathways in layered strata, which invalidate their use for reliable groundwater monitoring and should be avoided (see IWM Landfill Gas Monitoring Working Group, 1998).
- In strata in which groundwater level varies seasonally, the screened section of the borehole should extend below the lowest likely water level by sufficient depth to enable sampling.
- In strata in which vertical flow of water or dispersion is dominant (upwards or downwards), clustered or nested piezometers or longer screened installations may be necessary to effectively monitor contaminant flow.
- In layered strata in which water flow is directed horizontally between low permeability layers, clustered (or possibly nested) piezometers could be required to monitor contaminant flow effectively. In some situations a composite sample may be acceptable (usually across relatively thin layers), in which case a continuous screened section is appropriate.

Figure 8.3 Types of groundwater monitoring point

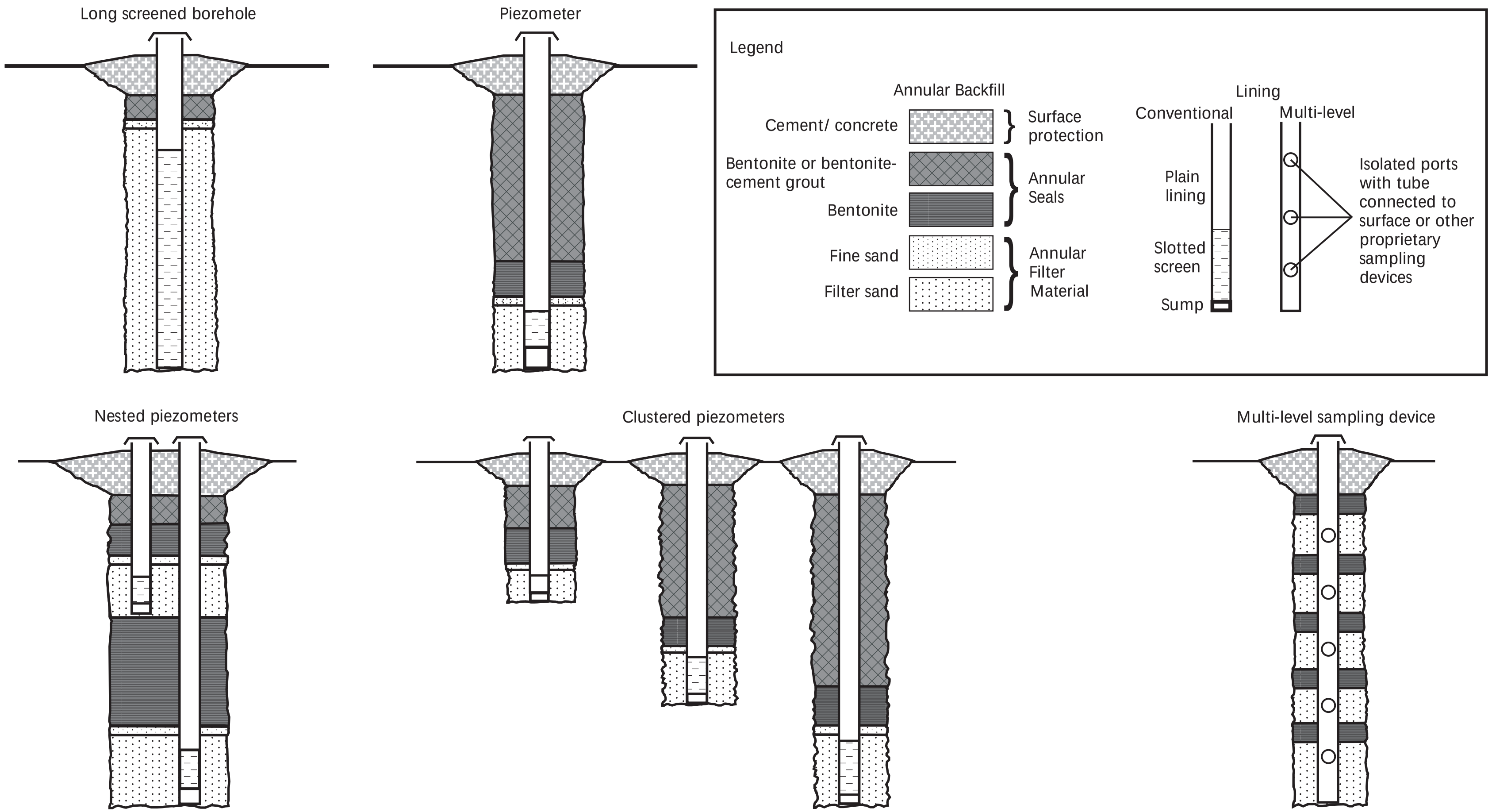
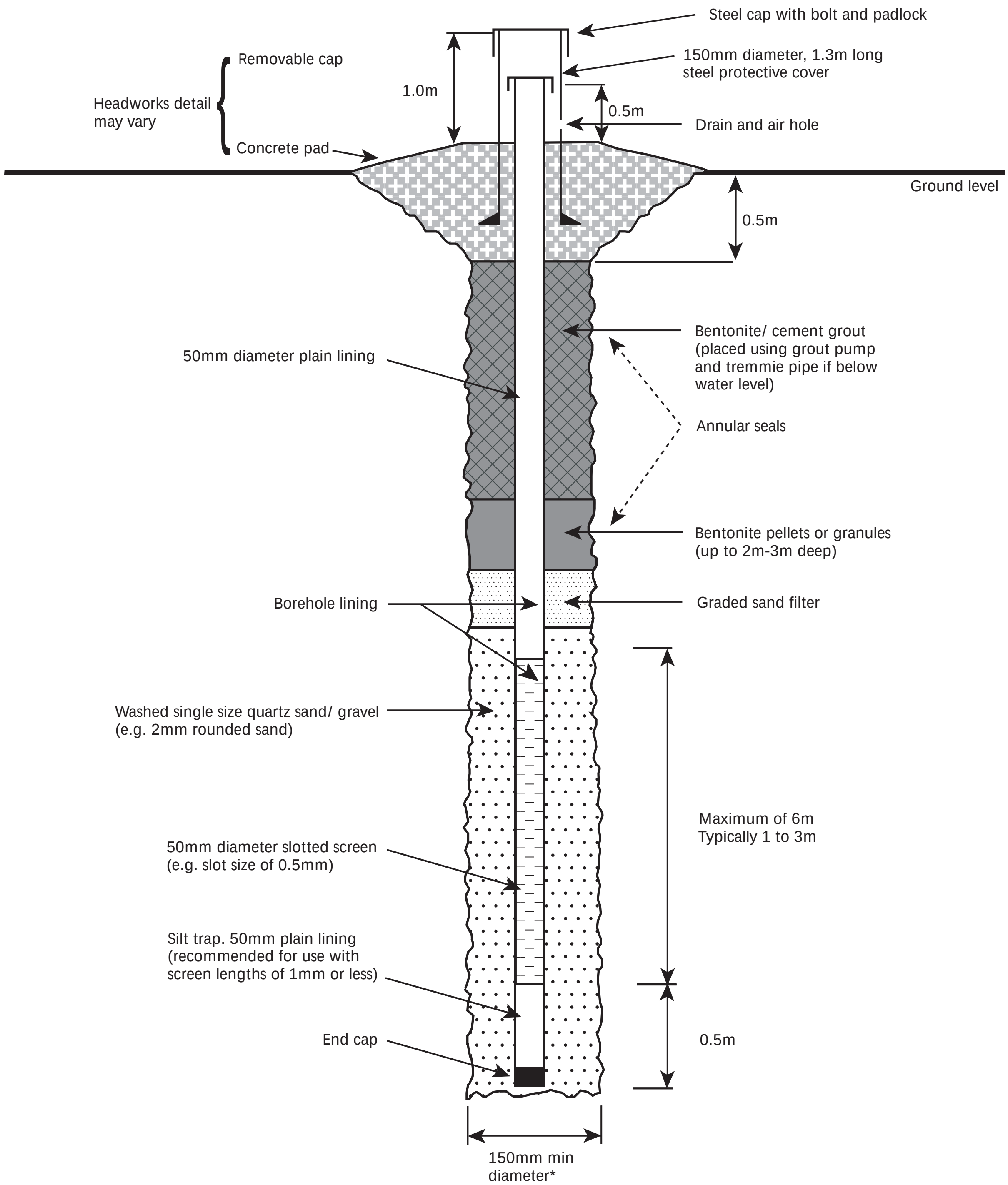


Figure 8.4 Example of a groundwater monitoring borehole (piezometer design) completed with a 50 mm diameter lining



* The borehole diameter should be at least 75mm greater than the lining diameter to allow placement of annular materials.

8.5.3 Design and construction of groundwater monitoring points

Groundwater monitoring points may be established by:

- using existing groundwater discharges and abstractions;
- using existing monitoring points;
- constructing new installations.

Existing structures should only be used if they are capable of fulfilling the monitoring objectives for the landfill site. Borehole logs and well-design details are essential to evaluate the usefulness of any point in relation to groundwater flow that may be potentially contaminated from landfill leachate.

Guidance on the construction of new monitoring borehole installations is provided in Appendices 4 and 5.

Use of existing groundwater discharges and abstractions

Existing groundwater discharges and abstractions include springs, water supply boreholes or wells. In many cases, a groundwater discharge or abstraction is identified as a receptor in the risk assessment. Monitoring receptors directly does not provide sufficient early warning of potential problems and consequently discharges or abstractions are normally only monitored if:

- there is uncertainty associated with the pathway monitoring;
- the discharge is itself on a pathway to another downstream receptor;
- monitoring of the discharge significantly enhances understanding of the hydrogeology of the site.

Large-scale water supply or other abstractions draw water from a large area and are likely to greatly dilute any impacts from landfill contamination, except in cases of gross pollution. Their use as monitoring points is questionable. If abstractions are operating or flowing at relatively low rates, the dilution potential will be less and these points may be suitable for monitoring purposes. Abstraction records should be maintained as part of the routine monitoring of such points.

Use of existing monitoring points

Existing monitoring points may include monitoring points installed for other monitoring purposes by adjacent landowners or the Agency, or for site investigation. Older monitoring points often consist of open or long-screened boreholes, which may be unsuitable for site-monitoring purposes. They may even present a contamination hazard in themselves by providing a direct connection between water-bearing strata. Other monitoring points may consist of piezometer installations, which are more suitable for direct incorporation into a landfill-monitoring programme. In either case, an evaluation against monitoring objectives should be carried out, and one of the following options implemented:

- allow the monitoring point to be used for its existing purpose, but do not incorporate it into the landfill-monitoring programme;
- incorporate the borehole without modification into the monitoring programme;
- modify the borehole construction for incorporation into the monitoring programme;
- abandon the borehole by grouting and capping.

A monitoring point may only be included in the programme if its construction and geological details have been determined from records or geophysical logging. If a long-screened or open borehole is to be modified, this may be done by either:

- backfilling so that it is open only to a few metres of the uppermost aquifer. No vertical pathway to the lower section of the hole should remain, so this option may not be feasible for lined boreholes, unless the liner can be withdrawn and any gravel pack effectively sealed; or
- installation of nested piezometers to permit monitoring at separate vertical intervals. This modification is only possible in larger diameter boreholes (e.g. >200 mm) in which lining has not been installed, and should otherwise be discouraged.

The data already available from an observation borehole should be taken into account when the future of a borehole is decided. A quality or water level trend that covers many years has an obvious value as a baseline against which changes can be measured. There are three choices:

1. not to implement any changes and continue to collect data;
2. modify the borehole to an improved design. Mark the date of change in all databases so that any changes in behaviour can be related to the change in design;

3. drill a new monitoring point to an improved design adjacent to the existing point. Monitor both points for one year to obtain data for correlation between the old and new trends, and then abandon and seal the old borehole.

New groundwater monitoring boreholes

Construction of new boreholes allows monitoring points to be located and designed specifically to meet the monitoring objectives. The method of drilling, lining materials, screen design and sealing method should all be given careful consideration to ensure that the monitoring objectives are met.

Guidance related to drilling and completion of groundwater monitoring points is included in Appendices 4, 5 and 6.

8.5.4 Groundwater borehole cleaning and development

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. Cleaning and development in most monitoring boreholes can be undertaken either on completion of the installation or as part of an extended preliminary sampling survey by simply pumping and surging the borehole for a period of time. It may take the removal of ten or more borehole volumes of water to achieve reasonable cleaning and development of a borehole. Where geotextile wraps are used, lesser volumes of water may need to be removed, depending on the strata sampled. Where strata are predominantly silty or clayey in nature, it may not be possible to achieve a sediment-free discharge. Further guidance is included in Appendices 5 and 6.

8.5.5 Construction quality assurance and borehole Logs

CQA documentation and borehole logs should be produced and collated into the Environmental Management and Monitoring Programme, as specified for leachate monitoring points (Section 8.4.4).

8.5.6 Groundwater borehole maintenance

Most groundwater-monitoring boreholes require periodic maintenance. The most common problem is associated with silt accumulation in the base of a borehole, which can completely block screened intervals. Boreholes may also become blocked through pinching of the lining or by foreign objects. Depths can be checked by comparison with details in borehole logs. If borehole logs do not exist, it may be necessary to carry out a caliper, geophysical or camera survey to help identify construction details (Appendix 7).

Boreholes that are silted can be unblocked by surging (e.g. by the addition of water combined with a pump, such as an inertial pump) or by the use of 'air-lift' methods (i.e. using a pressure jet to blow out the silt, though uncontrolled air-lift methods are not suitable for contaminated groundwater that may present a health and safety hazard). Further details are provided in Appendix 6.

Any boreholes that cannot be rehabilitated should be replaced as soon as possible. The damaged borehole should be sealed and capped to remove a potential pathway for the contamination of groundwater. Procedures for the abandonment or decommissioning of redundant boreholes should be reviewed with the Agency, who can provide separate guidance on this issue (Environment Agency, 1998). In general, abandoned boreholes should be sealed with cement-based grout or bentonite and capped in a manner that prevents any confusion with active monitoring points. The Environmental Management and Monitoring Programme, drawings and monitoring-point register should be amended to document the abandonment clearly.

8.6 Surface water monitoring points

8.6.1 Selection of surface water monitoring points

Factors to be considered in the selection of surface water monitoring points are:

- the appropriateness of the sampling point to meet monitoring objectives;
- the measurements to be made (physical, chemical or biological sampling);
- the sampling method;
- accessibility and safety.

Sampling locations should be chosen to allow access with minimal disturbance of the water at the time of sampling.

Monitoring points in water courses

Monitoring points should be located up- and downstream of discharges from a landfill site.

The downstream monitoring point should be located close enough to the discharge to assess any changes related to the discharge, but far enough downstream to ensure adequate mixing. More than one monitoring point should be chosen downstream of the discharge if information on the extent of impact or recovery is required. The choice of more than one reference point upstream of the discharge increases confidence in the description of reference conditions.

Monitoring points in ponds, lakes and wetlands

Monitoring points should be situated in an area that is sufficiently representative of the water body as a whole. Various factors introduce heterogeneity into water bodies, e.g. inflowing and outflowing water and currents, depth variations, and in deeper waters, stratification of the water. In large bodies of water, more than one monitoring point may be required to reflect lateral and vertical variations in water chemistry.

Monitoring at discharge points

Discharges may be pumped intermittently, be free-flowing through piped outlets or be pond overflows. The monitoring point needs to be chosen such that the sample obtained is sufficiently representative of the quality of the discharge before it is mixed into the receiving water course.

Sediment samples

Sediment samples taken from bottom sediment deposits can sometimes provide a very sensitive means of identifying impacts on surface water by contaminants such as trace metals, which are readily adsorbed onto sediment from flowing water. Care and expertise is required in selecting sampling locations, so that:

- sites which are depositional in nature are chosen, taking account of seasonal patterns of accretion and erosion;
- sampling depth is chosen to reflect recently deposited sediment;
- comparable upstream and downstream sampling sites are chosen.

Consideration should also be given to the relationship between contaminants in solution, in the suspended sediment and in the deposited sediment, so that an appropriate sampling regime can be derived.

Biological samples

Biota sampling requires an understanding of habitats, sampling method and measurement technique. Further guidance is provided in Standing Committee of Analysts (1996).

8.6.2 Objectives for the selection or design of surface water monitoring points

Specific objectives that are applicable to selecting or designing surface water monitoring points are:

- to permit an accurate water level to be measured and recorded to an elevation expressed as metres above ordnance datum;
- to permit an estimate of flow to be measured;
- to enable an appropriate sample for surface water quality measurements.

Other design objectives are based on an appreciation of the specific purpose of a monitoring point combined with an understanding of local hydraulic conditions. For example:

- to enable an appropriate sample for biological quality of surface water to be obtained;
- to enable an appropriate sediment sample to be obtained.

9.0 Monitoring methodology

9.1 Introduction

To ensure data collected by all monitoring personnel are appropriate and collected in a consistent manner, the methodology used for monitoring should be standardised and subject to QC checks. By using standardised procedures and competent personnel, greater consistency in data collection can be achieved. Poor quality or ambiguous data can lead to serious difficulties in interpretation.

Monitoring methodologies should be adopted for each site and based on current good practice and in accordance with the specific monitoring objectives for the site.

Guidance in this chapter is presented under the following headings:

Section 9.2 Objectives of methodology.

Section 9.3 Safety of monitoring personnel.

Section 9.4 Specification and quality control of methodology.

Section 9.5 Physical monitoring measurements.

Sections 9.6 to 9.12 Collection and analysis of water quality samples

Section 9.13 Collection of quality control samples

Section 9.14 Documentation of procedures and results

The Landfill Directive refers to "General Guidance on Sampling Technology, ISO 5667-2 (International Standards Organisation, 1991)" and "Sampling Groundwaters, ISO 5667-11 (International Standards Organisation, 1993; equivalent to BS6068 Section 6.11)".

Further guidance on all these issues and on biological and sediment samples is included in Standing Committee of Analysts (1996) and the *National Sampling Procedures Manual* (Environment Agency, 1998). Other guidance on leachate and groundwater sampling is adapted from research undertaken for the Environment Agency and its predecessors (Blakey *et al*, 1997). Further supporting guidance is referenced in the bibliography.

9.2 Objectives of monitoring methodology

The principal objective of all monitoring methods is to ensure that the measurement is sufficiently reliable for the purpose intended (i.e. that an appropriate sample or measurement is taken). For example:

- if the monitoring objective is to determine the groundwater quality in strata down-gradient of the landfill site, then the analysis results should be sufficiently representative of groundwater in the strata, and should not be excessively influenced by the borehole design, sampling methodology, cross-contamination from other sources, or analytical method.

Similar examples could be cited for leachate or surface water samples.

Reliability is achieved by controlling errors introduced by the monitoring process. To reduce errors to appropriate and known levels, QC procedures need to be used. The following quality objectives should be applied to any monitoring methodology:

- Each sample or measurement at a specific monitoring point should follow a consistent and reproducible procedure.
  This is achieved by using approved and documented monitoring protocols. Records should be kept of conditions at the time of sampling and of any deviations from specified protocols.
- The sample collected or measurement made should not be excessively affected by contamination from surface run-off, contact with the sampling equipment or extraneous matter that may have entered the monitoring structure. Nor should it be affected by the products of reaction with materials used in the construction of the monitoring point.

To avoid unnecessary cross-contamination of monitoring points, any equipment used to directly sample or temporarily store leachate or any other contaminated water should never be used for groundwater or surface water monitoring. Wherever practical, dedicated or disposable monitoring equipment should be used for sampling, particularly for leachates or other contaminated waters. Where this is not practical, decontamination protocols should be used in conjunction with equipment blank samples to determine the effectiveness of the decontamination effort. Where monitoring points are known or suspected to be contaminated, sampling should proceed from least to most contaminated waters.

- A sample that is to be analysed should not be significantly different from its chemical and physical state at the time it was sampled.
  Analytes that are susceptible to contamination or reactions within sample containers should either be measured on site or fixed using a preservative.
- Analytical methods should not be excessively affected by cross-contamination, poor recovery, interference or instrument errors.
  Analytical methods should be chosen that are appropriate for the medium and the sampling objective.
- It should be possible to authenticate all measurements.
  Proper documentation should be produced in the form of field records and chain-of-custody documentation.
- Where measurements are critical for assessment or compliance purposes, the errors associated with monitoring should be quantified.
  This is achieved using QC sampling methods.

A specific objective of all monitoring programmes is to ensure that work is undertaken in a safe manner. This specific issue is dealt with in the following section. The remaining sections of this chapter provide guidance on methodology appropriate to different types of monitoring measurement.

9.3 Safety of monitoring personnel

As a requirement of the PPC Regime, relating to managerial competence and accident prevention, all monitoring points should be selected or designed with the objective of providing clear, safe and unobstructed access for monitoring personnel using designated monitoring equipment.

Monitoring personnel should never be required to undertake monitoring in unsafe conditions. Monitoring points that pose particular difficulties for access or that are unsafe in any way should be identified within the Environmental Management and Monitoring Programme. Any protective health and safety measures needed to access these points should be documented. These points should only be accessed following receipt of instructions and the provision of any necessary training or support by personnel familiar with the hazards.

Specific instances for which health and safety briefings and/or training should be provided, or more than one person should be deployed are:

- where it is necessary to manually lift equipment or remove obstructions greater than 25 kg in weight or are shaped awkwardly for one person to handle safely;
- where access to a monitoring point cannot be achieved easily from a position standing at normal ground level;
- where monitoring points require access within a confined space;
- where leachate sumps or monitoring points are venting landfill gas under pressure and no protective headworks are fitted;
- where leachate monitoring points are located within active landfill areas;
- where stream samples are to be taken from unsafe bank positions or where wading into water greater than 0.5 m deep is required;
- where monitoring requires the use of a boat;
- where monitoring involves the handling of chemical reagents that may be hazardous to health.

The above examples are not exhaustive and a proper health and safety risk assessment of each monitoring point should be implemented. Guidance on sampling safety is provided in ISO 5667 Part 1 (general issues; (International Standards Organisation, 1980), Parts 4 and 6 (surface water) and Part 11 (groundwater; (International Standards Organisation, 1987, 1990)). Where chemical reagents are handled during sampling, samplers should be familiar with Control of Substances Hazardous to Health (COSHH) Assessments[22] and hazard data for these substances.

22 As provided for under the Control of Substances Hazardous to Health Regulations 1989.

9.4 Specification of monitoring protocols

9.4.1 Specification of measurements

Measurement specifications need to be based on an overall understanding of the tolerable uncertainty specified for the measurement (Section 6.3.5), the measurement method and the practicality of implementing and controlling measurements under field and laboratory conditions. Finalising specifications will normally be an iterative and consultative process involving field personnel, the analytical laboratory and site management. It may take several sampling surveys to achieve a workable standard that can be applied routinely to a particular set of monitoring points.

The tolerable uncertainty specified for any measurement (Section 6.3.5) will influence the selection of methods and QC procedures used for the measurement. For example, there is little point in specifying analytical accuracy to parts per billion if the design of the monitoring point is not understood, sampling technique is poor or laboratory methods are incapable of achieving this standard.

A measurement specification should include:

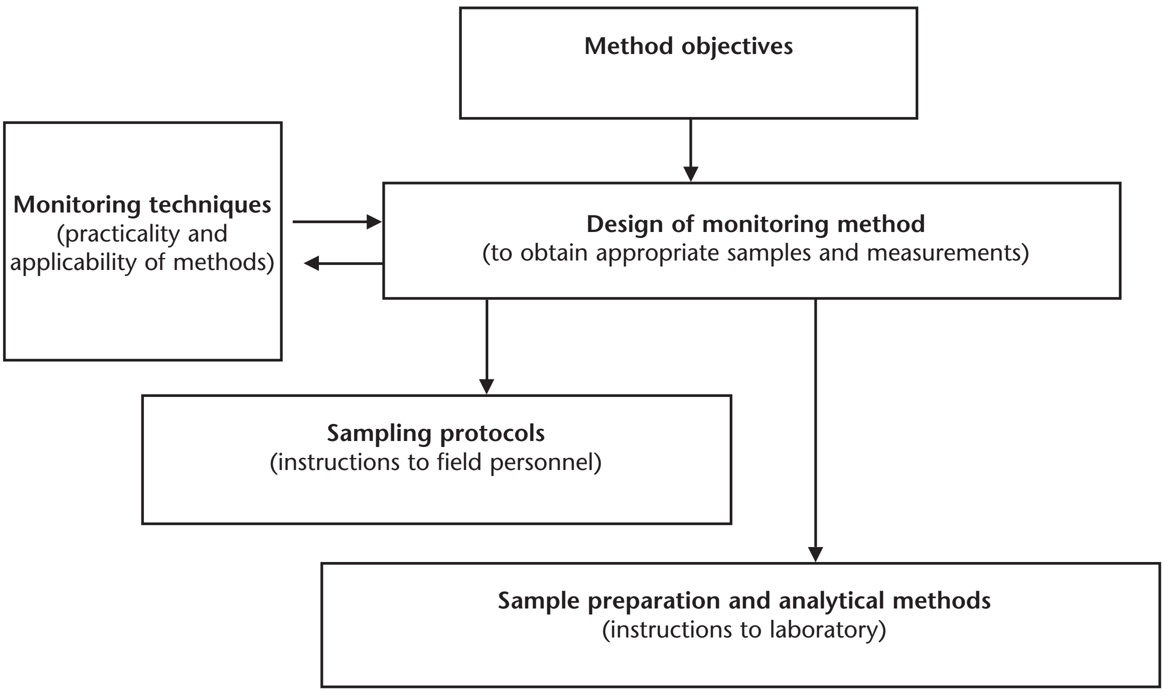
- the measurement method;
- a detailed protocol for sampling and/or measurement and record keeping;
- an appropriate level of QC sampling and measurement.

9.4.2 Monitoring protocols

To present clear instructions to field personnel and analytical laboratories, standardised protocols for monitoring procedures should be specified in the Environmental Management and Monitoring Programme. The elements involved in devising monitoring protocols are illustrated in Figure 9.1, which emphasises the importance of ensuring that procedures are formalised not only with field personnel, but also with the laboratory responsible for analyses of samples. Protocols for field procedures are provided in the *National Sampling Procedures Manual* (Environment Agency, 1998). Example field forms are included within Appendix 8 and a generalised sampling protocol as Appendix 9.

Given the length of time over which some monitoring programmes extend, changes in monitoring protocols are inevitable. Examples include a change in purging method or a change in analytical laboratory, or even a change in sampling and analytical personnel. Changes in protocols should be managed carefully to ensure that the new

Figure 9.1 Elements in preparing monitoring protocols



Derived from Blakey *et al*. (1997), Figure 3.1

protocol meets the monitoring objectives and tolerable uncertainty values specified in the Environmental Management and Monitoring Programme. It may be appropriate, particularly for measurements used for compliance purposes, to take a series of duplicate and other QC sample measurements using the old and new protocols to record the magnitude of change. Without this information, historical data records can sometimes become difficult to interpret and in some instances could result in the validity of an entire baseline record being brought into question.

9.5 Physical monitoring measurements

9.5.1 Preamble

Physical monitoring measurements include observational, water balance, flow and level measurements (see Table 6.4).

9.5.2 Observational records

Observational records include:

- observation of surface water run-off from landfill areas;
- observation of other contaminant sources;
- observation of vermin;
- observation of vegetation.

These observations are part of the normal daily management routine of most operational landfill sites, and significant observations should be logged formally as part of the routine monitoring procedure.

An example form for maintaining observational records is included in Appendix 8. Where appropriate, these should be accompanied by a photographic record.

9.5.3 Water balance measurements

The following sections provide guidance on the measurements that can be taken routinely to allow interpretation of water balance at a landfill site. This group of measurements (listed in Table 6.4) includes:

- rainfall and other meteorological data;
- volume removed;
- volume added;
- volume discharged.

The last three measurements can be grouped together as 'leachate management records'.

Rainfall and other meteorological data

Rainfall records for the majority of sites can be obtained from the Met Office. Site records can be used where these are available, though they should be periodically compared to Met Office records to check consistency. The level of detail will vary from site to site. For example, a statement of mean annual rainfall and effective rainfall for a number of different types of surfaces may be sufficient. At sites where risks are significant, monthly summaries are normally needed.

Leachate management records

Records should relate to cell-by-cell distribution of leachate within the site based on recirculation, pumping or discharge records. Most of these can be collected as part of the normal daily operation of a landfill site.

Records, however simplified, should be maintained (e.g. by counting bowsers or estimating pumping volumes from fixed pumps by recording running hours). Where flow meters are used, these should be calibrated and read as frequently as possible (at least monthly).

Information is best summarised monthly and reviewed annually in comparison with rainfall and water level measurements. Source records should be maintained for checking.

Example summary forms for recording monthly water movements within the site are included in Appendix 8.

9.5.4 Level and flow measurements

Level measurements include leachate level, groundwater level, surface water level and the measurement of the base of the monitoring point (Table 6.4). Guidance on method of measurement and equipment used is included in the National Sampling Procedures Manual (Environment Agency, 1998).

Groundwater and leachate levels

Routine groundwater or leachate level measurements from monitoring points should record the rest water level. If pumping is being carried out from either the monitoring point to be measured or an adjacent monitoring point, this could produce misleading level measurements. When water is pumped from a monitoring point, the water in the lining will fall to a level at which the rate of inflow (i.e. the yield) matches the rate of pumping. This level is the 'pumping water level' (Figure 9.2). Dewatering temporarily occurs if the inflow rate for the entire depth of the monitoring point is less than the pumping rate. When pumping is stopped, groundwater (or leachate) continues to flow into the monitoring point until it reaches the rest water level sustained in the surrounding strata or waste.

The time taken for levels to recover after pumping can vary from being almost instantaneous to hours, days or longer, depending on the permeability of the surrounding strata or waste and the design of the monitoring point. Where pumping is routinely carried out from monitoring points, the following procedure should be followed:

- A recovery test should be undertaken before confirming the suitability of the monitoring point for routine water level measurements. The test should record water levels from the time the pump is switched off for a sufficient period until the rest water level is proved. These data are plotted onto a graph of water level against time. A 'recovery time' is then assigned to the monitoring point and used to govern the timing of all future water level measurements.
- All water level measurements taken at pumped monitoring points are accompanied by a record of the interval between the time the pump was switched off and the time of measurement. This time should be no less than the designated recovery time for the monitoring point.
- Tests should be repeated annually to ensure the efficiency of the monitoring point is sustained.
- Unless the time of recovery is known and properly documented in the Environmental Management and Monitoring Programme, it is unacceptable to use pumped installations for water level measurements.
- Pumped monitoring points in which the recovery time is greater than 24 hours should not normally be used for routine water level measurements.

Pumping from one monitoring point may temporarily lower water levels in adjacent non-pumping monitoring points and give a false impression of the real rest water level. For this reason, recovery tests may also be needed for non-pumping monitoring points affected by nearby pumping.

Ideally, water level measurements should be taken at times or locations unaffected by pumping. In particular, pumped leachate monitoring points should not be used routinely for leachate level monitoring unless there are no practical alternatives (such as providing new monitoring points remote from the leachate pumping points).

Where measurement of water levels in monitoring points affected by pumping is unavoidable (for example, in the vicinity of a major groundwater abstraction, or where leachate levels need to be maintained below compliance levels), a comment should be included in the monitoring records to indicate that pumping is being undertaken.

Base level measurements in monitoring points

Base level measurements can be used as a QC check on the condition of a monitoring point. Measurement of base level should be made:

- at least annually
  as a maintenance check to ensure the screened interval remains unblocked;
- whenever a monitoring point is recorded as 'dry' or 'blocked'
  a comparison can then be made with the constructed base elevation of the monitoring point and informed comment given on the significance of the absence of water;
- whenever the datum point of a monitoring point is damaged or changed
  the depth to base from a defined temporary datum point should be recorded and used as a means of confirming a revised elevation of the datum point. Where this measurement indicates a significant variation from that expected, the new datum should be resurveyed.

In cases where base level measurement is likely to cause an unacceptable increase in suspended sediment in the borehole water, or requires removal of a dedicated pump, the measurement is taken after sampling or between sampling events.

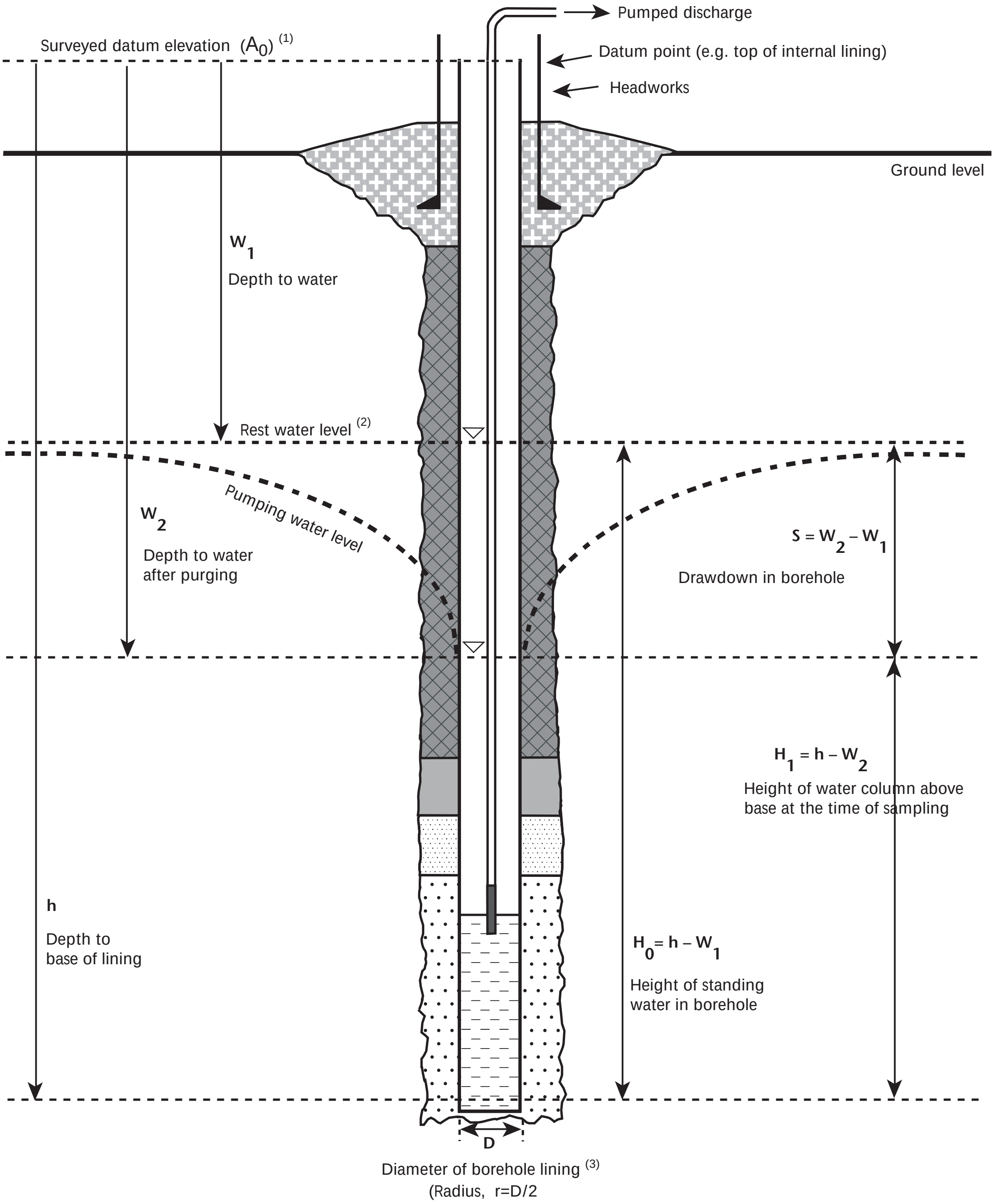
Surface water level measurements

Surface water levels should also be measured relative to ordnance datum to enable comparisons to be made between water bodies and with groundwater level measurements.

Equipment for surface water level measurements is relatively simple and includes:

- fixed boards with scaled measurements;
- electric tapes to measure depth to water from a fixed overhead datum point (e.g. from a bridge);
- levelling equipment (e.g. a surveyor's level and staff) to record levels against a datum fixed adjacent to the water body.

Figure 9.2 Borehole level measurements



(1) Datum levels are normally surveyed relative to Ordnance Datum and expressed in units of m.AOD (metres above Ordnance Datum

(2) Rest water level as m.AOD = A_0 -W_1

(3) Borehole water volume in litres = $\frac{\pi D^2 H_O}{4000}$ $\left(\text{or } \frac{\pi r^2 H_O}{1000}\right)$ (where D (or r) is in mm and H_0 in metres)

9.5.5 Surface water flow measurements

This group of measurements includes:

- surface water flow;
- flows from discharge or abstraction points.

Surface water flow

Flow in rivers and streams can be estimated by:

- direct measurement of velocity
  velocity can be measured using mechanical or electromagnetic current meters, tracers or even floats. Velocity is converted to volumetric flow rate by multiplication by the cross-sectional area;
- measurement of water level above weirs
  a relationship can be developed between water level (stage) and flow, particularly upstream of a regularly shaped constriction, such as a v-shaped or rectangular weir. Once this 'stage–discharge relationship' is known, flow can be calculated from readings of water level.

The choice of appropriate method depends on the stream dimensions, flow rate, available fall and tolerable uncertainty. Further guidance is provided by the Standing Committee of Analysts (1996) and ISO 8363 (International Standards Organisation, 1986).

Flows from discharge or abstraction points

Discharges may be fitted with integrating flow meters, in which flow measurement consists of timed readings of the meter.

When flow is emerging from a pipe or orifice, it may sometimes be measured by timed filling of a container (bucket or drum and stopwatch). This method produces reliable results provided the container is large enough to hold at least 10 seconds of flow. Health and safety considerations, particularly for contaminated discharges, may preclude this method, in which case recourse must generally be made to stream flow measurement methods.

Discharge measurements should be timed to take account of cyclic (e.g. daily) or rainfall-dependent variations in flow.

9.6 Collecting an appropriate water quality sample

9.6.1 General sampling procedure

The general procedure for taking an appropriate sample of leachate, groundwater or surface water is illustrated in Figure 9.3 for which general guidance is given in the remainder of this chapter. Supplementary information is provided in Appendices 8 and 9, including a general sampling protocol and standard forms. More detailed sampling procedures are found in the (Environment Agency, 1998).

9.6.2 Types of sample

Water samples taken for laboratory analysis (or analysed in the field) provide the simplest direct measurement of water quality. Samples are collected in a number of ways for different reasons and may be classified as:

- discrete samples taken at a single point in space and time (sometimes known as 'spot' samples). For example:
  a sample taken from a specific depth in a monitoring point;
  a single sample taken almost instantaneously from a watercourse;
- composite samples that originate from a number of locations or time intervals. For example:
  a sample collected after purging water from a monitoring point with a long screened interval that spans several groundwater flow zones;
  a sample formed by mixing a number of discrete samples such as stream samples taken at several specific time intervals;
- continuous samples, which are usually recorded by use of data loggers and electronic instrumentation
  these types of samples are less commonly used for landfill monitoring.

The quality of surface water bodies can also be assessed indirectly by sampling sediment or living matter. Sample types include the following:

- Sediment samples from the base of surface water courses or ponds.
  Sediment readily absorbs and accumulates trace metals under normal pH and redox conditions. Analysis of trace metal concentrations from sediment samples can sometimes provide an indicator of the long-term accumulation of pollutants carried by a watercourse. This can be a better method of detecting pollution than simple spot sampling of flowing water.

- Biological assay of surface waters.
  Sometimes organisms present in water can be used to provide an overall indicator of water quality and the influence of external environmental impacts. Methods such as in-situ toxicity tests or rapid assessments of indigenous biota can provide an early warning system of contamination and indicate the need for further chemical investigation. Spatial or temporal differences in biotic communities and investigations of individual organisms, e.g. bioaccumulation and biomagnification studies, give a longer term assessment of the environmental impact of contaminants.

Further information on biological and sediment sampling methods is found in Standing Committee of Analysts (1996) and the *National Sampling Procedures Manual* (Environment Agency, 1998). The remainder of this chapter provides guidance on the collection of water quality samples for chemical analysis.

9.6.3 General requirements of sampling equipment

To obtain an appropriate water quality sample, any equipment used for taking samples should be:

- clean and uncontaminated by previous samples prior to use at each monitoring point, or dedicated for use at individual monitoring points;
- constructed of materials that will not significantly absorb or desorb substances to be analysed;
- capable of transferring samples from the monitoring point to the sample container without causing any significant physical or chemical changes in water quality for the range of determinands to be analysed.

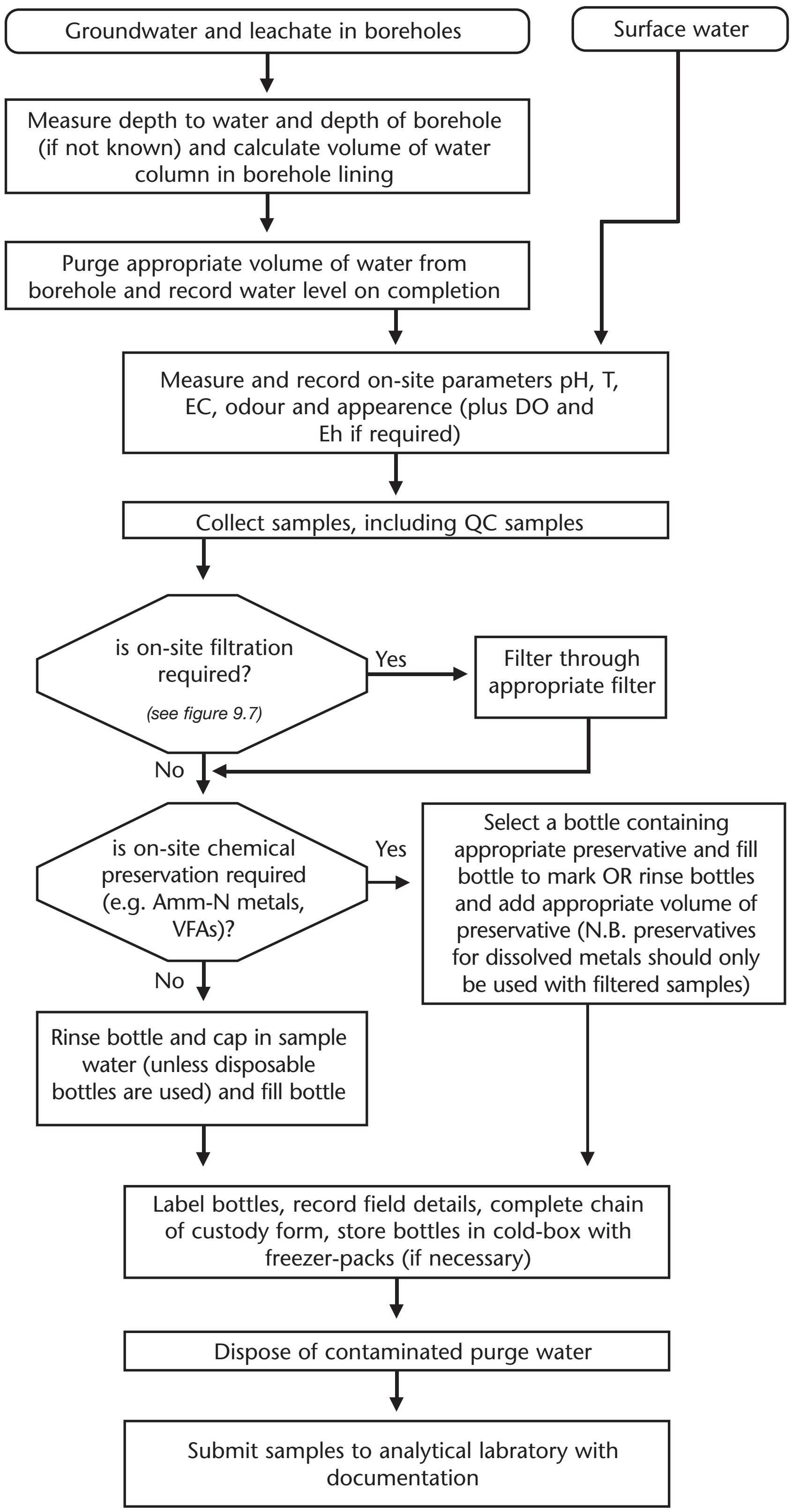
A review of equipment used to purge and sample monitoring points and for the collection of surface water samples is included in Appendix 10.

9.6.4 Factors influencing water quality during sample collection

The quality of a water or leachate sample taken from a sub-surface monitoring point (and to a lesser extent from a surface water body) can be influenced by a number of factors, which are summarised in Table 9.1. The most important of these are the possibility of contamination through poor monitoring-point design and construction (Chapter 8), poor decontamination of sampling equipment (see Appendix 9 for example protocol), unpurged water (Section 9.9) and the influence of sediment collected with sample water (Section 9.11). Other factors, such as type of sample equipment, sample containers, storage conditions and preservation methods, can be important for specific analytes.

The remaining sections of this chapter provide guidance on practical measures that can be taken to minimise sources of error, to ensure that analytical results are as representative as possible of the water being sampled.

Figure 9.3 Procedure for collecting an appropriate water quality sample.



Adapted from Blakey *et al*. (1997), Figure 4.4

9.7 Collecting a sample of surface water

In collecting a surface water sample, the following procedure should be followed:

- Avoid collecting samples from the water surface wherever possible, except where a floating product layer needs to be sampled separately. Submerge sample containers or transfer containers below the water surface to avoid collecting floating debris or other products. If this is not possible, solid materials should be removed from the transfer vessels before pouring into a sample container.
- Where information is required on floating products present on the water surface (e.g. oil or foam) it is necessary to collect two samples – one representative of the floating product layer and one of the sub-surface body of water.
- When collecting from ponds, lakes or wetlands, avoid collecting samples too close to the banks – a sample should be taken as far into the pond as is safe to collect, using an extension rod if necessary.
- When collecting from 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 water. It is preferable to sample direct into sample bottles to avoid cross contamination from sampling containers.
- Take samples from the fastest flowing part of the watercourse. Avoid stagnant parts of a watercourse.
- If determination of suspended solids in a stream is critical, it may be necessary to sample using a 'flow-through' sampling device.

Choice of sampling site is covered in Section 8.6. If the sampling site is at a place where incomplete mixing has occurred[23], two or more samples should be taken at different points across the width of the stream. These samples may be combined to form a composite sample, to give an indication of overall stream quality.

Surface water bodies are subject to cyclic and flow-related quality variations. For example, quality can vary between day and night, and between high and low flow conditions. This should be taken into consideration in deciding timing of sampling.

Further guidance on surface water sampling is given by the Standing Committee of Analysts (1996), in the National Sampling Procedures Manual (Environment Agency, 1998) and ISO 5667 Parts 4 and 6 (International Standards Organisation, 1987, 1990).

23 For example, where it is not possible to place a monitoring point at a sufficient distance downstream of a discharge to allow complete mixing.

Table 9.1 Processes that influence the quality of water samples from boreholes[1]

Process	Sources	General comment	Analytes[2]					
			A	B	C	D	E	F
Inappropriate sampling	Unpurged water standing in a borehole	Selection of most appropriate purging procedure to monitoring point is vital	•	•	•	•	•	•
Cross-contamination	Sample equipment and handling	Equipment used for leachate and other contaminated waters should be segregated from that used for clean groundwaters and surface waters				•	•	•
Aeration/oxidation	Sample collection	Contact with air can result in loss of dissolved gases and volatiles and lead to precipitation of some metals (e.g. iron as iron hydroxide)			•	•		•
Adsorption/dissolution of metals	Silt in water samples	Can be a problem for some trace metals, particularly iron, zinc and manganese				•		
Adsorption/desorption of organics	Materials in sampling borehole	uPVC, nylon, etc., can release trace organic substances from borehole lining and sample equipment					•	
	Materials in sampling equipment	Sampling equipment (including tubes and in-line filters) can affect contaminant concentrations, especially organics		•			•	
Pressure changes	Change in ambient pressure	Gases and some trace volatile organics may be removed from solution						•
	Sample method	Moving parts or surging by sampling equipment causes small pressure changes, which may release gases and volatile organics, cause chemical equilibrium changes or disturb colloidal concentrations			•			•
Temperature changes	Sample storage	Change between sample and analysis						•

1. This table only identifies influences from the sampling process.
Additional influences on quality may occur in the handling and analysis of samples (see Section 9.11.6).

2. Generalised groups of substances influenced
A Major dissolved metals and phosphate
B: COD, BOD, TOC
C: Ammonia, oxidised-nitrogen, alkalinity
D: Trace metals
E: Trace organic compounds
F: DO, Eh, volatile organic compounds (VOCs) and dissolved gases

Based on Blakey *et al.* (1997), Section 3.5

9.8 Unsaturated zone sampling

Sampling of pore water from the unsaturated zone requires the use of specialist sampling equipment. These are not considered in this document to be routine sampling methods applicable to most landfill sites. Background information and details of methods are provided in ISO 5667, Part 18 (International Standards Organisation, 2001) and ASTM standard D4696-92e1 American Society for Testing and Materials (1992).

9.9 Purging and sampling of monitoring points

9.9.1 Preamble

Before commencement of sampling from sub-surface monitoring points, sampling objectives should be balanced against an understanding of the monitoring point design and its hydraulic properties.

Sampling objectives may be:

- to obtain a composite sample
  i.e. a sample drawn from the entire screened or inflow depth of the monitoring point;
- to obtain a discrete or 'spot' sample
  i.e. a sample drawn from a specific depth within the screened or open section of the monitoring point.

Objectives may also relate to the volume of material from which groundwater or leachate is to be sampled. For example, sampling objectives may be:

- to obtain a composite sample sufficiently representative of water quality from a large volume of material surrounding the monitoring point
  i.e. pumping over a prolonged period would be required;
- to obtain a sample of groundwater from the strata immediately adjacent to the borehole or of leachate from waste immediately adjacent to the monitoring point
  i.e. purging prior to sampling should not be prolonged.

To devise an effective sampling strategy, it is often sufficient to know simply the sustainable pumping yield of a monitoring point (see following section). This information can be gathered during preliminary sampling programmes from which a long-term strategy can be developed.

9.9.2 Purging of monitoring points

Purging rationale

Groundwater or leachate that remains in a monitoring point between sampling events can undergo significant chemical changes and may no longer be characteristic of water in the surrounding material. Processes that can alter the composition of standing water include interactions with construction materials, degassing, atmospheric contamination, biological activity, and contamination from dust or other extraneous materials that have entered the monitoring point. These processes can affect the pH, redox potential (Eh), dissolved oxygen (DO), alkalinity and electrical conductivity of the water, in addition to the concentrations of dissolved ions and suspended solids. Leachates 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.

The selection of an appropriate purging procedure is dependent on many factors, including the type of sample to be collected (i.e. a composite or spot sample), the design of the monitoring point, aquifer or waste hydraulics and water chemistry. For example, in high-permeability strata in a long-screened[24] borehole in which the water level lies within the screened interval, purging may prove to be unnecessary. In situations where water is contained in a monitoring point above the screened interval, several times the volume of water in the monitoring point may need to be removed before an appropriate sample can be collected, or alternatively a low-flow pumped sample may be appropriate. In low-yielding strata, the only options may be to sample without purging, or to dewater the monitoring point completely and then take a sample during recovery. Some examples of the effects of purging are given in Figure 9.4. A review of various purging strategies is illustrated in Figure 9.5.

General purging guidance

In the absence of any technical evidence to support a specific purging strategy for a particular monitoring point, the following guidance should be adhered to for leachate and groundwater sampling from sub-surface monitoring points:

- A purging trial should be undertaken to observe the behaviour of field determinands (e.g. conductivity, pH, temperature or other determinands of interest), continuously or at intervals during purging. A sufficient volume

24 That is, where the screen spans more than one groundwater flow zone, or is longer than 6 m (see Section 8.5.1).

(normally at least three 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 a standard purge volume for the borehole.

◊ *A single 'borehole volume' is defined as the volume of water contained within the lining of the monitoring point, excluding the annulus (Figure 9.2). Calculated volumes for some typical lining diameters are shown in Table 9.2.*

- In long-screened boreholes, an alternative purging strategy is to calculate the pumping time required to achieve a high proportion (say 95%) groundwater contribution to the pumped discharge.

◊ *This method requires a knowledge of formation permeability, and the use of formulae derived originally for the test pumping of water supply boreholes (see, e.g., British Standards Institute, 1983).*

- In short-screened boreholes, an alternative is to purge three borehole volumes before sampling.
- This approach may be used as a default standard for a borehole with a short screen and a water level above the top of the screen. In the case of monitoring points that are dewatered before sufficient volume has been removed, two options are available:

◊1. Do not purge. Take a 'grab' sample using a depth sampler or bailer as appropriate. The water in the borehole should be disturbed as little as possible.

◊2. Dewater and then sample after allowing sufficient time for water levels to recover. The water level should recover to levels indicated in Figure 9.5, dependent on sampling objectives and the design of the monitoring point. The disturbance caused may affect some determinands, and the method is not recommended when samples are to be taken for volatile organics.

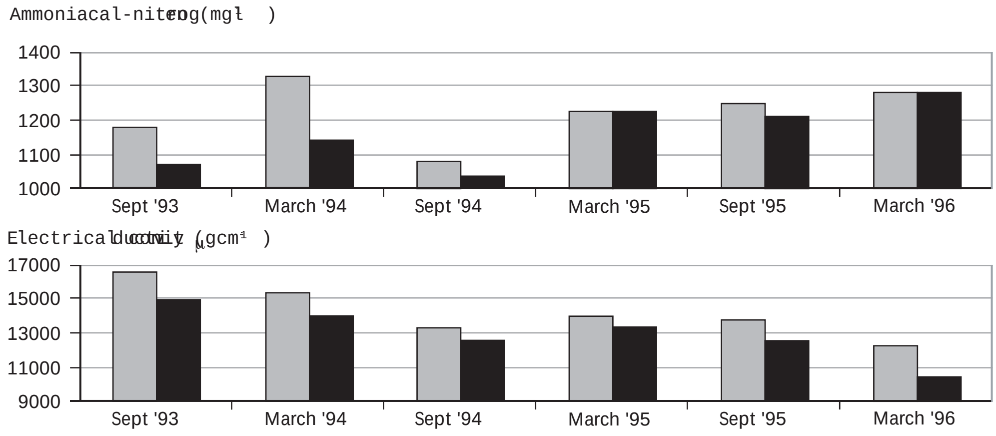
Table 9.2 Standing water volumes in the lining of a monitoring point.

Lining diameter (mm)	Water volume per metre depth (l)	
	One borehole volume	Three borehole volumes
17	0.2	0.7
20	0.3	0.9
25	0.5	1.5
50	2	6
100	8	24
150	18	53
200	31	94
250	49	147
300	71	212
500	196	589
1000	785	2356

Note: Multiply the above volumes by the height of the water column in the borehole (H_0 in Figure 9.2) to obtain the total borehole volume.

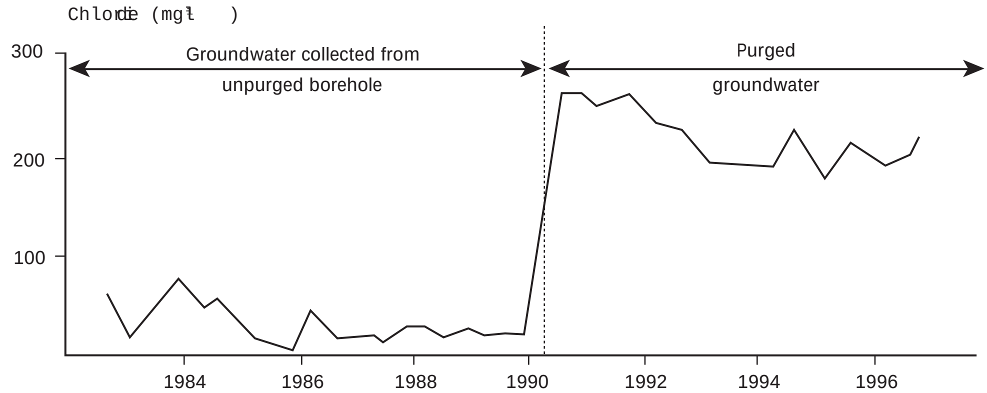
Figure 9.4 Comparison of chemical measurements before and after borehole purging.

a) Comparison between leachate samples from the same borehole collected before and after purging



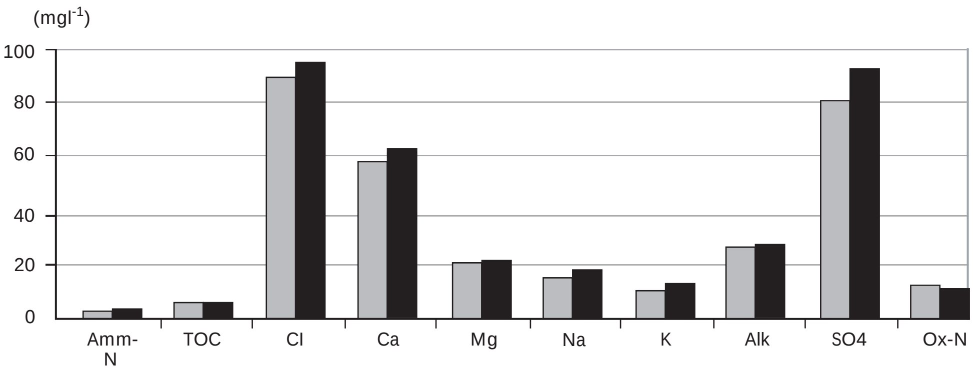
(Data courtesy of Waste Management Section, Shropshire County Council)

b) Illustration of significant discrepancy between unpurged and purged groundwater samples



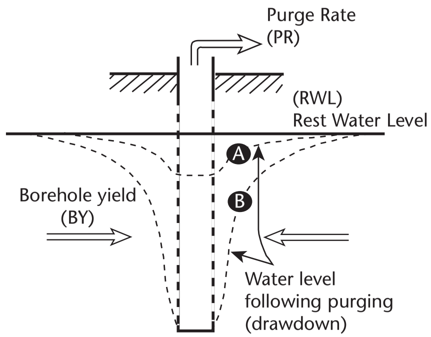
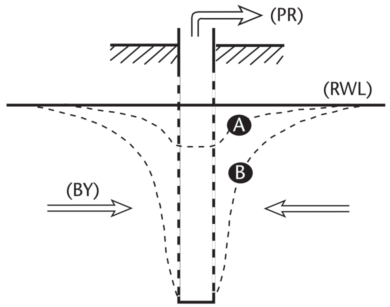
(Data from Environment Agency public register records)

c) Illustration of no significant difference between unpurged and purged groundwater samples collected on the same day



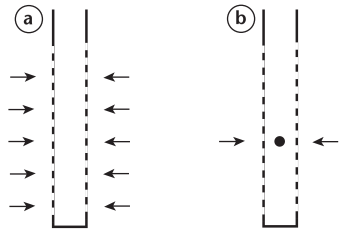
(Data courtesy of Waste Management Section, Worcestershire County Council)

Figure 9.5 Possible borehole strategies related to borehole design and hydraulic properties

BOREHOLE DESIGN	Relationship of Purge Rate (PR) and Borehole Yield (BY)*	Possible purging strategy to achieve sample objective: ⓐ COMPOSITE SAMPLE	ⓑ SPOT SAMPLE
• Open and long-screened boreholes (see 8.5.1) • Water level below. within or close to top of screen 	Ⓐ PR < BY	❶ or ❹ use of alternative strategies (e.g. ❷ ❺ ❻ ❼ should be justified in comparative trials against ❶ or ❹	❻ or ❼ if spot sample required from water level. ❺ in homogenous high permeability formations.
	Ⓑ PR > BY	❻ , ❼ or ❸ (allow water level to recover by at least 50% before sampling).	❻ or ❼ if spot sample required from water level.
• Short-screened boreholes/ piezometers • Water level above top of screen (see 8.5.1) 	Ⓐ PR < BY	❶ or ❷ use of alternative strategies e.g. ❹ ❺ ❻ ❼ should be justified in comparative trials against ❶ or ❷	❺ or ❻ in homogeneous high permeability formations. ❶ , ❷ or ❹ if screen is very short (e.g. <3m)
	Ⓑ PR > BY	❻ or ❸ (allow water level to recover by at least 50% before sampling).	❻ or ❹ if screen is very short (e.g. <3m)
unknown design ?	ANY	❶ or ❸	Not possible. (insufficient knowledge)

Notes: *Purge rate is less than Borehole Yield if water level stabilises during pumping. This is prefered to minimise turbulence. Consideration must be given to the possibility of mixing caused by lowering of the sampler. (<: 'less than', >: 'greater than')

SAMPLE OBJECTIVE



a) **Composite sample** – mixed sample representative of entire screened interval/ open borehole.
b) **Spot sample** – sample representative of groundwater at a specific depth.

PURGING STRATEGY

Replacement of water in borehole lining above screen

❶ Stability of chemical determinands.[1,2]
❷ 3x borehole volume[2].
❸ Dewater and recover.

Replacement of water in screened section only

❹ Low flow[3] timed purge based on hydraulic properties[4].

Sampling of water in screened section (assumed to be in continuity with aquifer)

❺ Low flow[3] pumped sample[5].
❻ Depth sample.
❼ Surface sample.

Notes

1. Field measurements or specific contaminants are monitored during an experimental purging trial to demonstrate acceptable purge volume for routine use.
2. Pump intake located as near the top of water column as practical.
3. Pumping must not include mixing in the borehole. Rates are tyically <0.5l/min. and much lower in low permeability formations.
4. Pump intake located at the top or within well screen.
5. Also reffered to as 'micropurging'. Pump must be dedicated or installed at least 24 hours in advance.

Other purging strategies, particularly those that involve purging smaller volumes of water (e.g. the use of a single purge volume for leachate monitoring points) are acceptable where:

- details of monitoring point construction are logged and presented in the Environmental Management and Monitoring Programme;

  and either

- trials have been undertaken to compare results from the proposed strategy with results from one of the default strategies given above;

  or

- where a number of monitoring points at the same site are very similar in design and environmental setting, it may be acceptable to carry out trials on a representative number of monitoring points to develop a generalised purging strategy for similar monitoring points.

Problems with purging

Particular difficulties associated with purging include the following:

- In larger diameter or deep monitoring points, unless the monitoring point is being pumped for other reasons it will often be difficult to purge even one borehole volume of water because of the large volume of water to be removed (Table 9.2).
- In waste and fine-grained formations, purging can draw fines towards the monitoring point, which can enter the lining of the monitoring point and lead to a high suspended solids content in samples. This effect occurs particularly when the design of the screen and/ or annular filter pack is not appropriate for the formation.

In these instances, a purging trial as described above should be carried out on at least one occasion. Future samples taken without purging should only be analysed for those determinands that remain unaltered (i.e. typically within a 15% variation). Where appropriate samples for determinands critical to assessment or compliance cannot be collected without purging, two options are available:

- extended purging prior to sampling
  i.e. for large-diameter monitoring points use a high purge rate over an extended period to obtain the necessary purge volume. For silting boreholes use a low purge rate over an extended period, to avoid silting;

- construction of a replacement monitoring point
  the use of a more appropriate monitoring-point design should help to overcome the problems encountered.

If, during purging trials, measurements fail to stabilise within three to five borehole volumes, consideration should be given to the cause of this. Possibilities include:

- contamination derived from construction materials
  if these cannot be remedied, and determinands are critical, a replacement monitoring point may be required;

- dependence of purge volume on purge rate
  in some cases reducing the purge rate may reduce the volume necessary to achieve stabilisation — however care is needed at lower purge rates to detect true stabilisation, as the process is slower;

- instrument error
  readings may fail to stabilise because of instrument drift, which should be checked by adequate calibration procedures;

- real variations in the water body

  for example, if the monitoring point is located near a boundary between waters of different quality (e.g. the margin of a pollution plume). In this case, purging strategy should be derived from a careful consideration of the monitoring objective.

Where analytical results from unpurged samples have not been correlated against purged samples, the results should be treated with caution. Unpurged samples may be suitable for providing preliminary information for other purposes (e.g. prior to discharge to a treatment system).

Collection and disposal of purge water

Uncontaminated groundwater can usually be pumped onto ground surface or to a soakaway, drain or ditch during purging. An exception to this is when large volumes of water are removed over a prolonged period. In this case, the Agency should be informed in advance and their advice sought on the safe disposal of water. With contaminated groundwater or leachate, the choice of disposal option should be governed primarily by the need to minimise any health risks to monitoring or other personnel from unnecessary contact with contaminated purge water, and the need to avoid unnecessary cross-contamination of samples.

Options for disposal of contaminated groundwater or leachate (in order of preference) are as follows.

- remove directly to a leachate/waste water collection and disposal system *the preferred option for situations in which leachate disposal systems are present on-site or for serious contamination of groundwater by List I or other dangerous substances;*

- dispose directly onto open areas of waste
  this is feasible at operational landfill sites — the disposal area should be sufficiently remote from the sampling point to avoid the possibility of recirculation of purge water;
- for leachate monitoring points within a landfill, dispose within the waste body via a leachate monitoring point, abstraction well or purge water disposal point (see Section 8.4.3)
  this can be achieved by either pumping directly to the disposal point or by collecting in containers at ground surface (e.g. plastic bins) and then pumping or siphoning to disposal on completion of sampling. This is the preferred option for small-diameter monitoring points for which no alternative disposal facilities are available, but the health and safety of personnel should not be compromised to achieve this;
- collect in containers at ground surface for removal and suitable disposal
  this option may be feasible for small purge volumes.
- Sample without purging
  this option may be feasible where comparative trials have shown that the difference between purged and non-purged samples does not exceed the tolerable uncertainty of the determinands to be analysed and where there are no safe options for disposal of purge water.

9.9.3 Purging and sampling equipment

Choice of equipment to purge and sample monitoring points is dependent on:

- the volume of water to be removed;
- the diameter of the monitoring point;
- the depth of pumping water level below ground;
- the requirement not to excessively alter sample quality.

The most common types used for groundwater and leachate are:

- depth samplers
  e.g. bailers and discrete depth samplers;
- pumps
  e.g. suction, peristaltic, inertial and electrical submersible pumps; gas lift pumps and bladder pumps;
- in-situ samplers
  dedicated or proprietary multi-level sampling systems using peristaltic, gas lift or inertial pumps to retrieve samples.

Further information on sampling equipment, including advantages and disadvantages of each, is included in Appendix 10. Groundwater may also be sampled from an abstraction borehole or spring, and details of methodologies for these situations are given in the *National Sampling Procedures Manual* (Environment Agency, 1998).

9.10 Field measurements of water quality

Measurements of water quality can be taken on site during the sampling of monitoring points using a range of techniques, including:

- measurements using field instruments, for example temperature, pH, electrical conductivity (EC), DO and Eh;
- measurements using chemical test kits and ion-specific probes, for example, titration and colorimetric methods.

Field instruments can be used conveniently to monitor changes in water quality during purging of boreholes. They should also be used to obtain analyses of determinands that are liable to change in the time between sample collection and analysis at a laboratory. Where field measurements are taken for the latter purpose, measurements should be made immediately prior to sample collection (and after purging). These data should be recorded carefully for future comparison with laboratory measurements, to provide a record of changes in sample condition between field and laboratory. Examples of changes that can occur include:

- change in pH through the loss of carbon dioxide from the sample;
- change in conductivity because of precipitation or dissolution of solids.

A strategy for undertaking field measurements for routine landfill monitoring parameters is illustrated in Figure 9.6, and should be used in conjunction with guidance in the following sub-sections.

9.10.1 Measurement using electronic meters and probes

Measurements of determinands such as pH, Eh, DO, EC and temperature are recorded using electronic meters and probes. All of these need calibration prior to use. QC records of calibration should be maintained for each individual instrument as part of normal field survey records. Specific issues that arise from each field measurement are as follows.

- Eh should be measured in the field because of potentially rapid changes in the oxidation state of all waters during transport to laboratories. The measurement can be affected when the sample is exposed to the atmosphere, and should be taken in flowing water, a flow-through cell or using a down-hole sonde during pumping. Measurements taken in beakers are unlikely to be appropriate. The use of any probes in oily environments (e.g. leachates) is problematical and Eh measurements are normally only undertaken on groundwaters and surface waters.
- The comments for Eh also apply to DO measurements taken in the field. As an alternative for relatively uncontaminated water, a sample can be fixed in the field, and analysed in a laboratory, using the Winkler method.
- Temperature, pH and EC are best recorded in flowing water, flow through cells or in down-hole sondes (during pumping if necessary), though reasonable measurements can also be obtained in beakers of standing water[25]. For routine monitoring purposes, analysis of pH and EC can reasonably be undertaken in the laboratory. Temperature should always be recorded in the field.

The use of down-hole sondes can, in some circumstances[26], enable an appropriate measurement to be taken without the need for purging.

Protocols for the above measurements are included in the *National Sampling Procedures Manual* (Environment Agency, 1998).

9.10.2 Measurement using chemical test kits and ion-specific probes

A number of proprietary test kits and ion-specific probes are available for carrying out field measurements. These have obvious advantages in providing rapid analysis and can lead to the improved management of water bodies at immediate risk from leachate egress in sensitive locations. An approved calibration protocol and QC sampling procedure, which define the accuracy of the field method against comparative laboratory methods, should always accompany the use of any field analytical measurements.

9.11 Preparation and Handling of Water Samples for Laboratory Analysis

9.11.1 Consistency in Sampling Procedures

Sample handling procedures between the time a sample is removed from a monitoring point until it arrives at the laboratory need to be controlled. Decisions need to be made on matters such as:

- whether or not suspended solids are to be included in the analysis;
- how samples should be preserved, if at all;
- whether or not the sample containers and conditions during transport significantly influence the quality of the sample.

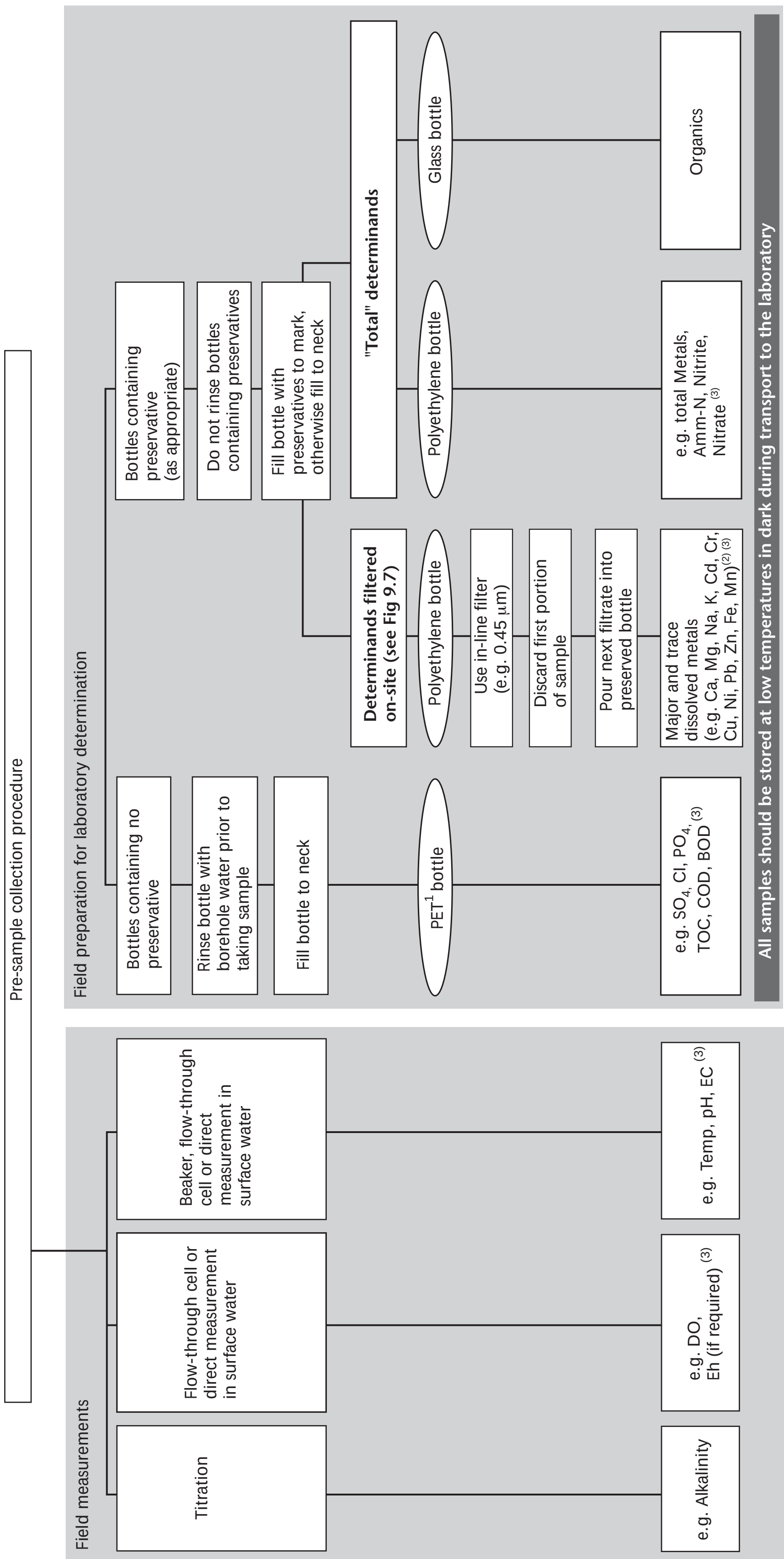
Many of these issues are subject to ongoing technical debate, and guidance presented in the following section reflects the need for a flexible approach.

The most important feature in sampling is that of consistency. Once an acceptable strategy for sample handling has been adopted for a site, it should not be changed without good reason. If the procedures used prove to be inappropriate, it may be necessary to introduce a period of overlapping sampling programmes using the old and new procedures, to compare results and allow correlation with the historic data record. Without this overlap, elements of the entire historic data record for a site could be invalidated.

25 In low ionic strength waters (which exhibit low electrical conductivity), it may be difficult to obtain a stable pH reading. This problem can be overcome to some extent by using specialist electrodes.

26 That is, when water in the screened length is considered sufficiently representative, and the sonde does not cause excessive disturbance of the water column.

Figure 9.6 Example procedure for field measurements and preparation of water samples



Notes:

(1) Polyethylene terphthalate.

(2) If on-site filtration is not carried out, samples for these determinands should be collected in bottles not containing preservatives.

(3) See Tables 6.5 and 6.6 for key to chemical abbreviations.

Adapted from Blakey *et al*. (1997), Figure 3.4

9.11.2 Sample filtration

The decision as to whether to filter samples at the time of collection is not straightforward. Field filtration is not normally necessary for obtaining samples for organic analyses and is best avoided for this purpose. Samples for inorganic substances are normally filtered when dissolved, rather than suspended or total, forms of a substance are to be analysed (e.g. for metal concentrations or phosphates). Filtration may also be required to separate leachate or other waters from materials that may have entered the monitoring point accidentally. When groundwater-monitoring boreholes are installed in clays and silts, purging can create a hydraulic gradient capable of carrying particulate matter into the borehole. If this is not removed by filtration, these soil particles can produce high levels of organic and inorganic analytes within the sample.

In surface waters (and some groundwaters) the suspended solids content is mobile, and filtration may not be appropriate. In leachates, suspended solids may be important in relation to the design of treatment or disposal systems, but it is the dissolved constituents that are more appropriate to understanding biodegradation processes and the potential impact from leachate egress.

If filtering is required, a choice must be made as to whether this should be carried out at the time of sampling, or in the laboratory. Changes, which may occur in an unfiltered sample because of the continued presence of suspended solids, introduce additional uncertainty to the final result.

An example of a strategy that could be followed, to decide the need to filter in the field or not, is presented as Figure 9.7. This strategy assumes that field filtration is preferable to maintain consistency in sampling procedures and to minimise uncertainty in reported results. Where field filtration is not considered desirable, and the objective of sampling is to determine dissolved constituents, comparative analyses of field filtered and unfiltered samples should be undertaken. The difference between results for each analyte should be compared with the tolerable uncertainty to determine the acceptability of the procedure.

Care must be given to the choice of filter used. Filters can add or remove dissolved components of the water. Filter-media test documentation should be examined and QC sampling undertaken to evaluate these effects. Filter pore size can significantly affect results. Therefore, standardisation is vital for all measurements for which comparison is required. Any assessment or compliance limits set for filtered determinands should include specification of the filter pore size.

Manufacturer's instructions on filter use should be followed carefully. In particular, it is recommended normally that a minimum volume of sample water should be passed through the filter and discarded prior to sample collection, to reduce the effects of sample alteration by the filter.

The addition of preservatives to 'fix' dissolved constituents in samples prior to analysis should only be undertaken on filtered samples. Ideally, filtration should be carried out using in-line filters and under pressure rather than vacuum.

Guidance on sample filtration requirements for common analytes is included in Figure 9.6.

9.11.3 Sample preservation

Biological and chemical processes may occur in water samples with sufficient rapidity to significantly modify some components of the sample chemistry within a few hours (or even minutes) of sampling. Details of maximum delay before analysis for specific analytes are given by the Standing Committee of Analysts (1996) and in the *National Sampling Procedures Manual* (Environment Agency, 1998). Constituents that are critical for assessment purposes may need to be preserved in the field prior to submission to a laboratory, depending on feasible delivery times. Where preservation is undertaken on-site, this should be planned alongside the chosen filtration strategy (Figure 9.7). Preservation of samples can be undertaken by one or more of the following methods:

- Using chemical preservatives
  The preparation of sample bottles with chemical preservatives should always be undertaken by the laboratory responsible for analyses. The analyst should always be consulted, particularly when planning surveys that require field preservation, and a procedure agreed in advance. This should be incorporated into the Environmental Management and Monitoring Programme.
- By maintaining samples at low temperatures
  Many determinands remain stable for several days after sampling as long as they are stored at low temperature. Ideally, and in critical cases, the temperature should be between 2 and 4°C, which requires the use of portable fridges. Cool boxes with freezer packs can be used to achieve a temperature of about 12°C, which may be sufficient for short periods while samples are transported to the laboratory. Unfiltered and unpreserved samples should, as a minimum, be cooled,

and should be submitted to a laboratory within 24 hours of sampling.

9.11.4 Selecting and filling sample containers

The choice of sample container may have important implications for sample stability and the prevention of contamination from, or adsorption onto, the container wall. The sample bottle usually needs to be prepared for sampling prior to fieldwork and the type of bottles used should be agreed in consultation with the analytical laboratory. Ideally, the laboratory should supply appropriate containers for sampling. An example of types of containers that could be used for different analytes is included in Figure 9.6.

All containers used for sampling should be leak-proof. Typical material types are:

- Glass bottles
  Preferred for most organic determinands, dissolved gas and isotope analyses. Amber glass reduces photochemical reactions. A smooth rigid bottle is important when sampling dissolved gases and trace organics to prevent the trapping of atmospheric gases during sample collection. Glass bottles should contain an inert seal, such as polytetrafluoroethene (PTFE), in the cap.
- Polyethylene terphthalate (PET) bottles of food grade standard
  Usually chosen for inorganic analyses and organic indicator analyses, such as TOC and COD.
- Polyethylene and polypropylene containers
  Used for most inorganic analyses. They are light, robust and inexpensive and can be supplied with wide necks for easy filling.

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). Further guidance on containers and filling requirements is provided by the Standing Committee of Analysts (1996) and in the *National Sampling Procedures Manual* (Environment Agency, 1998).

9.11.5 Sample labelling

Labelling should either be carried out in advance, or immediately after sampling. As a minimum, samples labels should carry the following information:

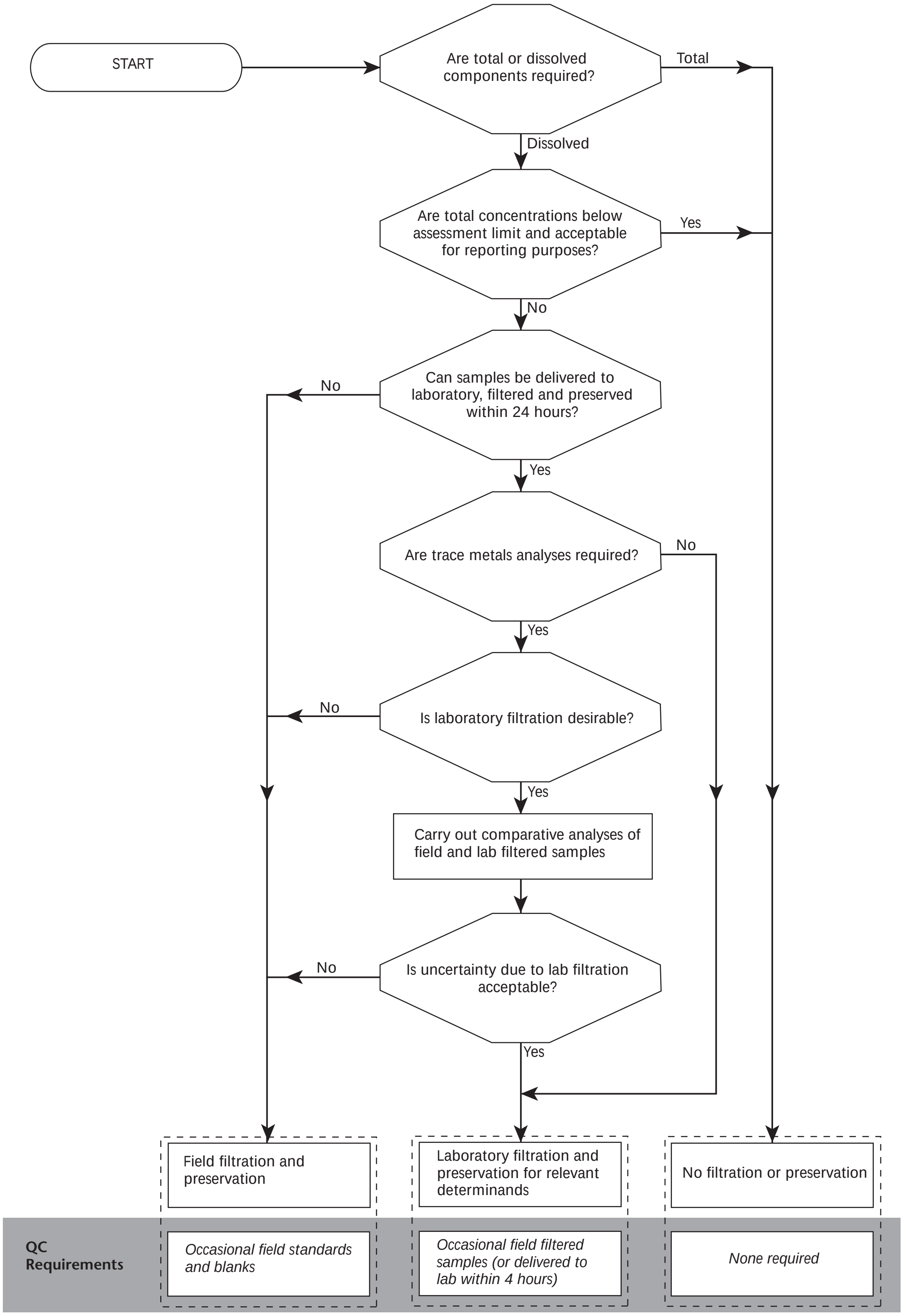
- unique monitoring point reference;
- depth of sample (where appropriate);
- sampling date and time;
- sampler identification.

9.11.6 Sample storage and transportation

Care should be taken to ensure that no appreciable contamination of the samples occurs during storage after sampling, and also during transportation back to the laboratory facility. The main factors to affect sample stability are time of storage, temperature, light and pressure changes:

- samples should be delivered to the laboratory as soon as possible after sampling — ideally on the same day and preferably within 24 hours of sampling;
- samples should be exposed to minimum light by storage in a covered box;
- the samples should always be stored at a lower temperature than that at which they were sampled and preferably in an insulated cool box with freezer-packs, or in a fridge — this is particularly important for those samples that have not been chemically preserved;
- samples should be packed to avoid movement and breakage during transport;
- highly contaminated samples, such as leachate, should be stored separately from relatively clean water samples;
- agitation of the sample during transport can encourage some of the chemical processes outlined in Figure 9.1, particularly if the sample has a high suspended solids content, or includes air — in most cases these chemical changes will be insignificant, but for some trace or volatile analytes, the differences could be significant (in some cases, specific QC effort may be needed to quantify handling and storage effects);
- health and safety arrangements for handling and transport of samples should be established with monitoring personnel, the courier and the receiving laboratory.

Figure 9.7 Filtration and preservation strategy for dissolved components of water and leachate samples.



Notes: In all cases a written procedure should be agreed in consultation with the laboratory and included in the site monitoring plan. This will include consideration of appropriate filter pore size.

9.12 Laboratory analyses

9.12.1 Preamble

Close liaison with analytical laboratories, whether these are in-house or at external facilities, is vital to ensure consistency in sample handling and the production of appropriate analytical data. Laboratory personnel need to be familiar with the analytical objectives of the monitoring programme, while sampling personnel should be aware of the issues that affect analytical accuracy. The following sub-sections provide guidance on:

- laboratory accreditation;
- laboratory procedures to be agreed (i.e. sample handling, analysis and reporting).

9.12.2 Laboratory selection, contract and accreditation

The performance standards required of the laboratory are determined by the monitoring objectives, tolerable uncertainty, and Agency requirements. These should be conveyed to the laboratory and incorporated into any contract made.

The laboratory should have a documented procedure and performance specification for each analysis, confirming that it is appropriate for the purpose required. This should include specification of the matrix (clean water, contaminated water, leachate) for which the analytical method is designed.

The laboratory should have a quality manual, which details policies covering at least all the remaining sections of this chapter (Sections 9.12 to 9.14 inclusive).

Ideally, the quality manual should describe the following:

- the quality policy;
- the quality system;
- organisation and management;
- auditing and review arrangement;
- equipment;
- calibration;
- analytical methods;
- sample handling;
- records;
- analytical reports;
- sub-contracting;
- complaints and queries;
- an analytical QC procedure.

Preferably, the laboratory chosen should operate a quality management system of at least the standard demanded by the United Kingdom Accreditation Service (UKAS). The advantage of using accredited laboratories is that the accreditation body carries out audits to prove that the laboratory is conforming to the standard agreed in the contract with the operator.

A laboratory that is certified to BS EN ISO 9001 or 17025 meets most of the requirements outlined in this sub-section.

9.12.3 Sample handling, analysis and reporting

Procedures for handling and preparing samples are critical and can significantly influence the final analytical results of a number of key determinands (e.g. dissolved metals, COD, BOD and TOC). The following procedures should be agreed in writing with the laboratory and included in the Environmental Management and Monitoring Programme:

- sample reception and registration
  arrangements for samples delivered, documentation to be exchanged with laboratory to preserve chain of custody and special arrangements for out of hours delivery, if appropriate;
- arrangements for continued preservation of samples
  e.g. refrigeration of samples delivered in cool boxes;
- sample preparation and preservation procedures
  a specification of sample preparation and preservation methods for each analyte and matrix should be produced (procedures will vary depending on whether filtration and preservation has been carried out in the field or is to be undertaken in the laboratory);
- analytical methods
  a specification of analytical methods should be agreed with the laboratory, and where non-standard methods are used these should be documented, particularly if analyses are submitted to other laboratories (further detail on the specification of analytical methods is provided in Appendix 12);
- reporting requirements
  this will include specification of the information required in reports, reporting times and format of digital and tabulated data;

- QC information to be reported
  all laboratories operate a variety of internal and third party QC methods and those to be reported should be agreed in advance.

9.13 Quality control sampling

9.13.1 Introduction

The collection and analysis of QC samples provides a means to determine whether or not sampling or analytical procedures have affected analytical results significantly. An effective QC sampling programme is an essential part of QA. Without it, it may not be possible to distinguish whether monitoring is measuring real changes in the water system or simply recording variations caused by sampling and analytical procedures. This particularly applies to constituents of water that could be gained from sources unrelated to the sampled water or lost from the sample during handling and transit.

This section provides general guidance on determining the number and types of QC samples required at different stages in monitoring programmes. Further details are provided in Appendix 11.

9.13.2 Types of error: accuracy and precision

Each stage of the monitoring process, from monitoring-point construction through sampling, handling and analysis to final reporting of results, can introduce errors of two kinds (Figure 9.8).

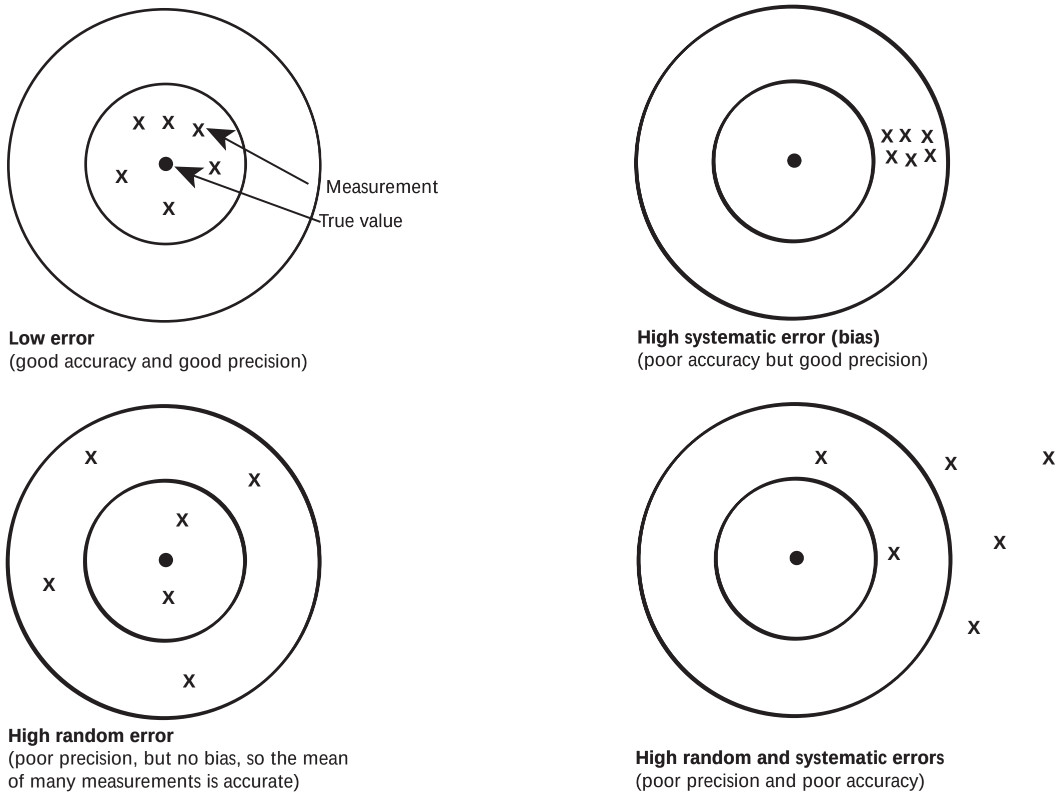
- Errors that arise from random variation
  These arise from variations in the behaviour of the sampling and measurement systems. These variations may or may not be evenly distributed around the actual measurement value. When such errors and/or variations are small relative to the measurement value, precision is high.
- Systematic errors (biases)
  These are variations that consistently bias the measurement in one particular direction (e.g. increased concentrations of substances caused by cross-contamination, or loss of substances induced by volatilisation during sampling). It is rarely possible to determine all sources of bias. It may be possible, through inter-laboratory comparisons, to evaluate relative bias between laboratories. Likewise, comparisons between field and laboratory analyses can be made. If systematic errors are small, the mean of a sufficient number of samples is close to the true mean (i.e. accurate).

For an individual sample, *accuracy* is good when both random and systematic errors are small.

The error caused by random fluctuations can be measured by appropriate replications of both sampling and measurement processes. Bias is difficult to estimate in absolute terms, as there is no satisfactory way of finding the 'true' value. However individual sources of bias can be investigated by the use of standards of known (or zero) measurement value.

Both systematic and random errors can be reduced to some extent by the use of carefully designed, standardised sampling and measurement protocols, as described earlier in this chapter (see Section 9.4). However, some errors will remain, and it is the function of QC sampling to evaluate these.

Figure 9.8 Illustration of random and systematic errors (precision and accuracy)



9.13.3 Determining the number of QC samples

The number of QC samples to be collected during a sampling survey depends on the following:

- The measurements (analyses) being made
  Those that are susceptible to effects relating to sampling, sample handling, sub-sampling and sample preservation and/or storage (e.g. pH, ammonia, trace metals, volatile or semi-volatile organic compounds) may require a greater QC effort. Analyses that are more difficult to undertake require greater analytical QC.
- The number of water samples to be taken
  At the outset of a monitoring programme, or where monitoring procedures are significantly changed, QC samples should make up at least 10% of the total number of samples taken on each survey. For complex sampling (e.g. characterisation of trace concentrations of VOCs), a greater proportion of different types of QC samples would be expected.
- The maturity of the monitoring programme
  The QC effort should be greatest at the outset of a monitoring programme. Once procedures have been established, and QC has shown that procedures are under control, relaxation of the proportion of QC samples would be reasonable.

9.13.4 Types of QC sample

Each stage of the sampling, handling and analysis process introduces errors. Distinguishing the contribution to total error from each individual source requires a substantial number of different types of QC sample [see, e.g., ISO 5667 Part 14 (International Standards Organisation, 1998) for sampling, and ISO 13530 (International Standards Organisation, 1997) for analysis]. The approach recommended in this guidance is to use QC sampling to determine overall errors initially. If these are unacceptable, more detailed QC sampling is required to locate the sources of the errors.

Standard laboratory practice incorporates QC procedures to distinguish errors that arise from the analytical process. For routine sampling surveys the QC sampling effort should consist of the following three types of QC sample:

- Sampling duplicates
  These are used to quantify errors that arise from random variations in the entire sampling and analytical process. Sampling duplicates should ideally be taken following the main survey sample, after repeating the entire sampling process (including purging wherever practicable).

- Field standards
  These are used to quantify both systematic and random errors for selected analytes that arise as a result of the sample handling and analysis process (i.e. excluding the sample collection process).

  Field standards are laboratory-prepared water samples with a known concentration of specific analytes. A standard sample for each relevant analyte is passed through the same sampling equipment used to collect the main survey samples (as far as practical), and thereafter treated in exactly the same way as the main samples. An analysis of the QC sample can then be compared to the known standard concentration. This procedure detects both gains and losses of analyte, and is particularly relevant for analytes such as ammoniacal-nitrogen, trace metals, TOC and volatile organics.

- Field blanks
  These are used to detect systematic and random gains (but not losses) over an entire analytical suite.

  Field blanks are a form of field standard, and consist of a laboratory-prepared sample of pure water treated in the same way as described for a field standard above. This QC sample is analysed for the same suite as the main survey samples.

Other QC samples may be needed to justify the choice of a specific sampling procedure. For example:

- where laboratory filtering is used routinely, occasional field-filtered samples should be analysed for comparison;
- where samples have been proved to be acceptable without purging by comparative trials and a no-purge sampling protocol is routinely used, the collection of occasional purged samples may be appropriate.

If the sampling and measurement errors estimated from any of the above QC samples are excessive in relation to the tolerable uncertainty (Section 6.3.5), either:

- further QC sampling should be introduced to identify the sources of errors in the sampling and analytical process;

or

- this specific part of the sampling or analytical protocol should be modified if a specific part of the process can be identified as the major source of error.

9.13.5 Strategy for determining quality control effort

QC effort ideally should be concentrated during the period of initial characterisation monitoring, so that the major sources of error in the sampling process are eliminated as soon as possible in a monitoring programme. Routine monitoring surveys can be carried out with less intensive QC effort.

A QC strategy based on the collection of the three QC samples specified above is illustrated in Figure 9.9 and described below. For more sensitive analyses (e.g. VOCs) additional types and quantities of QC samples are needed:

- QC samples need to be taken for each sampling protocol (i.e. separate QC samples are needed for leachate, groundwater and surface water sampling procedures[27]).
- At the commencement of a new monitoring programme, or if sampling procedures are changed, at least 10% (and a minimum of four per sampling protocol) of all samples analysed from a monitoring survey should be accompanied by QC samples (sampling duplicates, field standards and field blanks).
- Standard samples need only be used for specific indicator parameters that are liable to be affected by sample collection, transport and storage procedures. For routine sampling surveys at biodegradable sites, this should include ammoniacal-nitrogen and TOC. Other standards for trace constituents may be required where these are defined in the Environmental Management and Monitoring Programme as being key indicators for monitoring purposes.
- QC samples can be reduced to a minimum of 5% of samples if an evaluation of QC results after the initial characterisation period shows the total sampling and measurement error to be within acceptable margins (in relation to the tolerable uncertainty).
- If an evaluation of QC results after four consecutive surveys of 5% QC sampling shows the sampling and measurement errors to be within acceptable margins, QC sampling can be reduced to an occasional basis for indicator measurements. All ongoing characterisation monitoring should include at least 5% QC samples.
- In circumstances where excessive sampling and measurement errors are persistent, other types of QC sample should be introduced to identify and remove the cause [see ISO 5667 Part 14 (International Standards Organisation, 1999)].

27 Where protocols are carried out in parallel (e.g. in the case of Agency audit monitoring), both should be subject to QC samples, for example *separated duplicate samples* (see Glossary).

- Once a QC sampling programme has matured, results should be routinely reviewed both during validation checks following each survey and, more critically, on an annual basis (Chapter 10). Where persistent sampling and measurement errors are identified the proportion of QC samples should be increased until the cause is identified and removed.

9.13.6 Reporting of QC sample analyses

Field QC sample analyses should be processed by the laboratory in the same way as all other samples. The laboratory should not be able to identify any sampling duplicates. The responsibility for reviewing the significance of these results lies with the person responsible for the sampling programme.

On receipt of analytical results from the laboratory, all QC sample results should be isolated from and dealt with separately from other monitoring data. QC results should be identified clearly in any paper or computer records to avoid confusion with routine monitoring data.

The results of an effective QC sampling programme ensure that:

- mistakes and spurious data can be traced;
- measures can be set in motion to deal with unacceptable sampling and analysis errors;
- the validity of the data can be substantiated;
- the sampling and measurement uncertainty (error) can be quoted with results.

Procedures for data handling and reporting are outlined in Chapter 10.

9.14 Documentation

The responsibility for ensuring that the correct procedures are followed for sample collection, preservation, handling and analysis should be clearly defined in the Environmental Management and Monitoring Programme. The documentation of all procedures in the field and laboratory is of vital importance, so that the entire monitoring process can be audited.

Examples of forms for documenting field methods and chain of custody of samples are included in Appendix 8.

9.14.1 Field records

Paper records should be maintained and document the following procedures:

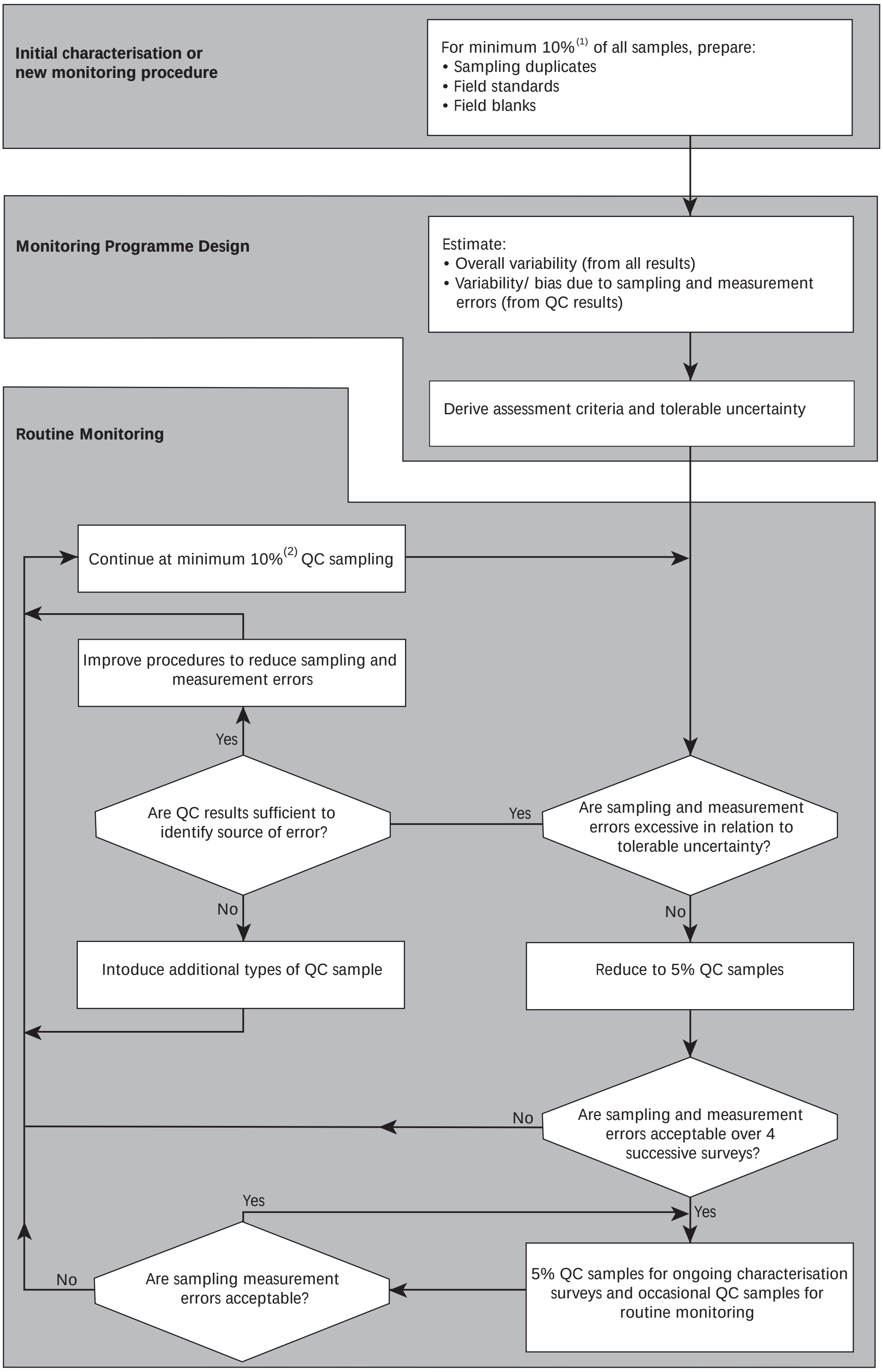
- field equipment calibration;
- purging of monitoring points;
- sample observations;
- field instrumentation measurements.

9.14.2 Laboratory submission records

Each bottle submitted to a laboratory should be labelled uniquely in a form agreed with the analytical laboratory (some laboratories provide bottles with pre-printed labels). Documents submitted to the analytical laboratory should include:

- sample analysis instructions form;
- a chain of custody form.

Figure 9.9 Strategy for collecting QC samples.



Notes: (1) % sample requirement must include at least 4 QC sample sets per sampling protocol during the initial characterisation period.

(2) must include sufficient QC samples to cover all sampling protocols where excessive errors have been identified.

10.0 Data management and reporting

10.1 Introduction

This chapter describes the principles that underline the control and interpretation of data generated by landfill monitoring programmes. There are a number of management tasks involved with data, illustrated in Figure 10.1, for which guidance is provided under the following headings:

Section 10.2 data management principles;

Section 10.3 quality control;

Section 10.4 data collection;

Section 10.5 collation of monitoring data and preliminary storage;

Section 10.6 data validation;

Section 10.7 data storage and archiving;

Section 10.8 data presentation, review and interpretation;

Section 10.9 reporting.

Although focusing on monitoring of leachate, groundwater and surface water, the guidance given in this chapter has application to other environmental monitoring programmes.

10.2 Data management principles

10.2.1 General principles

A monitoring programme at a small-scale landfill operation may generate only modest volumes of data, which can be kept on paper or as simple computer records and submitted to the Agency in total. Data from many non-hazardous or larger scale landfill operations may need to be collected from a number of monitoring points over many decades. There is a need to control and maintain an accurate and reliable long-term data record effectively, particularly as this forms part of the process to obtain a certificate of completion. Data handling and reporting for these sites are important issues.

Data held in a data management and reporting system should be:

- quality assured:
  - ◊ raw data must be preserved;
  - ◊ integrity of data must be preserved as it is processed;
  - ◊ data quality must be checked and the results of quality checks fed back into the monitoring programme;

◊ the system must enable auditing to trace sources of data back to original records;

- collated logically:
  - ◊ data must be stored in a form that can be manipulated readily for interpretative purposes;
  - ◊ systems need to be in place that can collate data efficiently to meet the requirements of response times incorporated into assessment criteria, and reporting dates agreed with the Agency.

10.3 Quality assurance

Through the use of assessment and compliance criteria, such as Control and Trigger levels, monitoring forms part of the overall QC check on the performance of a landfill against its design specification. Costly or far-reaching management or regulatory decisions may rely on monitoring data, and accordingly the need for reliable data cannot be overstated. QA and QC procedures are also a requirement of the PPC Regime. Consequently, QA is achieved by:

- stating quality objectives in the Environmental Management and Monitoring Programme;
- stating and implementing QC measures that achieve the objectives;
- documenting the results of QC checks, to preserve evidence of data quality.

10.3.1 Stating quality objectives

Quality objectives (such as specifying the tolerable uncertainty of monitoring measurements — Section

6.3.5) should be an integral part of the overall monitoring programme objectives given in the Environmental Management and Monitoring Programme.

For larger sites, or for companies that operate several sites, it may be appropriate to document QA procedures within a separate QA plan.

10.3.2 Achieving quality control

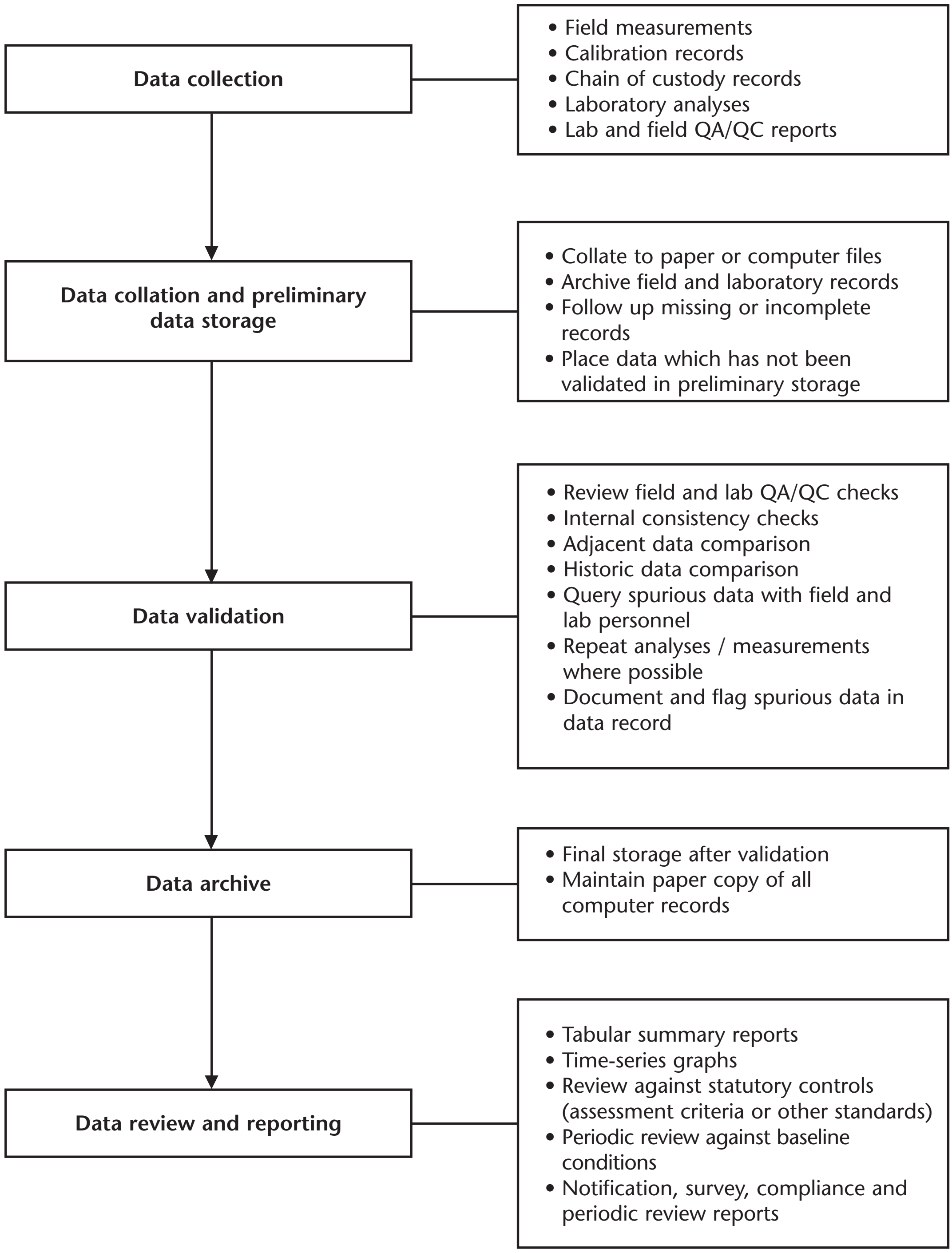
Adherence to good QC practices improves confidence in presented data. QC of monitoring data should be accomplished in two ways:

- minimisation of uncertainty at the time of measurement and sampling
  this is achieved by appropriate monitoring programme design, and standardised good practice in data collection and handling (i.e. by the adoption of sampling and handling protocols);
- estimation of sampling and measurement uncertainty at the time of reviewing results of measurements
  this is achieved by an assessment of QC samples and by checking monitoring data.

10.3.3 Documenting quality control

All QC checks should be documented within routine survey reports (Section 10.9). Where changes to records are necessary, an audit trail that documents the rationale and steps taken in reaching this conclusion should be maintained.

Figure 10.1 Stages in the management of monitoring data



10.4 Data collection

In the context of the overall quality management of data, the quality of data collection can be managed by:

- the use of competent personnel
  staff should be trained and familiar with data gathering, its use and application;
- the use of sampling and handling protocols to ensure care and consistency in methods used
  protocols include provision for QC sampling to provide a check on quality of sampling and handling procedures;
- the use of standardised recording procedures
  e.g. checklists and forms for data entry, including procedures for documenting data gathered using automated logging equipment;
- the use of accredited (e.g. UKAS) and quality-assured laboratory analyses
  the use of accredited procedures does not always guarantee competence in analyses. Clarification on methodology and matrix covered by any accreditation procedure should always be sought from laboratories, particularly when analysing for leachate.

10.5 Collation of monitoring data and preliminary storage

10.5.1 Types of data

Data collation is the process of gathering and ordering incoming data into a format suitable for preliminary storage. Where incoming data are in electronic form, a paper copy of the unprocessed data should always be kept available for reference.

Data arising from monitoring programmes include:

- data related to monitoring infrastructure, compliance and other standards
  e.g. monitoring-point construction details, site details, assessment and compliance standards and environmental quality standards — these data may not change with each monitoring survey, but are nonetheless required whenever ongoing monitoring data are reviewed, and should be readily available for this purpose;
- data related to specific monitoring surveys
  e.g. field and laboratory measurements and records, chain of custody records and observational notes.

10.5.2 Preliminary data entry and storage

Data can be stored using either paper or computer systems. Whichever is used, the process of preliminary storage must include:

- a system for cross-referencing all transcribed data to original field records or laboratory certificates;
- a means of indicating where data have been altered or omitted – examples where this sometimes occurs include comments, numeric data with varying numbers of decimal places (reflecting varying analytical precision) or determinations that are less than detection limit[28] ;
- a means of indicating whether or not data have been validated;
- archiving of all original field, laboratory and other relevant paper records.

Personnel responsible for data collation should be familiar with the Environmental Management and Monitoring Programme (preferably having visited the site and its monitoring facilities).

10.6 Data validation

10.6.1 Preamble

Data validation involves checking data for simple errors and inconsistencies and remedying these wherever possible. This should be followed up by acting to reduce the chance of similar errors occurring again.

Validation rules must be formulated with care to avoid rejection of data that, though extreme, are not erroneous. This particularly applies where validation rules are incorporated within computerised systems.

The person responsible for data validation should have an understanding of the meaning of the data and have access to the following records:

- the newly entered data, including records of validation rule breaches recorded during data collation and preliminary storage;
- the original data records;
- all historic monitoring data;
- the Environmental Management and Monitoring Programme.

[28] The approach adopted for 'non-detects' should be consistent, and also risk based. Substitution with zero may be acceptable in low-risk situations; but when detection limits are significant in relation to assessment limits, allowance must be made for the range of values that could be represented by the non-detect, and an alternative value, such as the LOD or 2/3rds LOD, may be appropriate.

10.6.2 Validation checks

A number of simple validation checks can be carried out on data. These include:

- internal data checks
  applying tests to a suite of data collected from a single monitoring point from one specific monitoring survey;
- external data checks
  applying tests by comparison to other related data.

Specific validation checks include internal and external data checks.

Internal data checks

- simple errors
  e.g. transcription errors, incorrect sample identification and missing data;
- logical checks
  e.g. data outside valid range;
- chemical or biological data checks
  e.g. chemical ratio checks, major ion balance calculation and field–lab comparisons.

External checks

- comparison with QC sample analyses;
- comparison with historic analyses from the same monitoring point;
- comparison with analyses from similar monitoring points;
- evaluation of other sample attributes

e.g. adherence to sampling and handling protocols, and any notable departures from normal procedure.

10.6.3 Handling anomalous or erroneous data

Where anomalous or erroneous data are identified these should be dealt with by:

- confirming values against original field records or laboratory certificates;
- referring unresolved queries to the laboratory or field monitoring personnel;
- undertaking repeat measurement or analysis.

A written record of the above procedures should be maintained. It may not always be possible to carry out repeat analyses or measurements because of the time delay between collection and collation of results. However, where questionable data have been identified and are important for compliance or critical to the performance of the landfill, repeat sampling should be undertaken immediately.

If erroneous or questionable data remain on file after inquiry, they should be treated as follows.

- data identified as questionable should be included on the data record for the site, but flagged with an explanatory comment;
- data that are demonstrably erroneous should be removed from the validated data record for the site, and the empty record should be flagged with reference to the validation record and include an explanatory comment;
- If data are identified as erroneous after being submitted to the Agency, formal notification should be given in writing to the Agency along with a technical justification for removing or amending the erroneous data from file records and the public register.

10.7 Storage and archiving of validated data

Working data that have been validated should be stored in a permanent but accessible location, where it is available for regular review. Validated data should be clearly distinguished from data that are not yet quality assured. This distinction may be achieved by transfer of data to separate permanent storage, or it may be achieved by flagging the data and retaining it in the same storage location.

The likely duration of the monitoring programme should be taken into account when specifying storage and archiving facilities. Data have to be stored for the lifetime of the site, which may be many decades. Data should be ordered and handled appropriately to ensure its survival for at least this length of time.

Where data are stored on computer, they should be regularly backed up and back-up media stored in a secure place. Additionally, a paper copy of all validated data should be produced for long-term storage to allow for the possibility of degradation or loss of electronic archive media. Archived paper copies of validated data should be distinguishable from the unvalidated source data.

10.8 Data presentation, review and interpretation

10.8.1 Introduction

Following validation and storage, monitoring data must be periodically evaluated against:

- compliance conditions
  failure to meet a compliance condition in the site permit (e.g. a maximum leachate level or groundwater Trigger level) may lead to prosecution;
- assessment criteria
  breach of assessment criteria (e.g. a groundwater Control level) should be addressed by the implementation of appropriate contingency measures within the specified response time;
- monitoring programme objectives
  failure to meet a monitoring programme objective (e.g. the number of monitoring points becomes insufficient through damage) should be addressed by implementing measures to achieve the objectives.

10.8.2 Data presentation

The exact format of data reported from the data management system is dependent on the volume of data generated by monitoring programmes, and on their application. In general, data should be presented in simple tabular format accompanied by graphic representation where this aids in understanding information.

Specific information requirements to be provided from monitoring programmes are as follows.

- monitoring performance summaries:
  - ◊ to compare actual monitoring tasks undertaken against those planned;
  - ◊ to summarise results of QC checks, highlighting where quality problems have arisen and any conclusions that can be drawn from such checks;
- leachate monitoring data:
  - ◊ to present leachate level data relative to ordnance datum and relative to the base of the site (data for individual cells should be grouped together and include reference to cell base levels, and assessment and compliance levels, where these are established);
  - ◊ to present leachate quality data (data for individual cells should be grouped with reference to any assessment limits);
- groundwater monitoring data:
  - ◊ to present groundwater levels relative to ordnance datum (data for each separate groundwater body should be grouped together);
  - ◊ to present groundwater quality data (data for separate groundwater systems should be grouped together with reference to any established both Control and Trigger levels);
- surface water monitoring data:
  - ◊ to present surface water level and flow data (data should be grouped by sub-catchment and, where appropriate, compared to rainfall data);
  - ◊ to present surface water quality data (data should be grouped by sub-catchment, with upstream and downstream monitor points clearly indicated, together with reference to any established compliance limits or assessment criteria);
- consented discharge points:
  - ◊ show relevant results of monitoring of any consented discharges or other contaminant sources, with reference to consented limits.

In each case, consideration should be given as to whether the monitoring is providing appropriate data that meet the objectives of the monitoring programme they are designed to satisfy.

Data prepared by operators for submission to external parties (e.g. the Agency, or an outside specialist) are often presented in summary tables. However, data presented in this form rarely meet the criteria outlined above, except for sites with limited monitoring and low volumes of data. Summary data can often be prepared more effectively in graphic format. Formats that are particularly encouraged include the following:

- Time-series charts (e.g. Figures 10.2, 10.3)
  Plotting data as a time series enables trends to be visualised and compared and may allow a degree of prediction based on extrapolation of trend lines. Inclusion of control data (such as maximum leachate level, base level of cell, assessment and compliance limits) can add further value to the charts.

  Further interpretation of time-series charts (particularly in relation to assessment criteria) can be provided by the presentation of control or cusum charts (see Figure 7.2).
- Spatial plots (e.g. Figure 10.4)
  Where the spatial distribution of data is significant (mainly for groundwater level and quality data), the use of spatial plots is encouraged. An important use is to demonstrate the location and extent of groundwater

contamination. For operations that involve large volumes of spatially related data, the use of geographic information systems (GIS) may be appropriate.

Guidance on other interpretative graphic methods can be found in standard texts[29]. It is envisaged that further guidance on interpretative data presentation techniques will be developed by the Agency in the light of ongoing research and experience.

10.8.3 Data review and interpretation

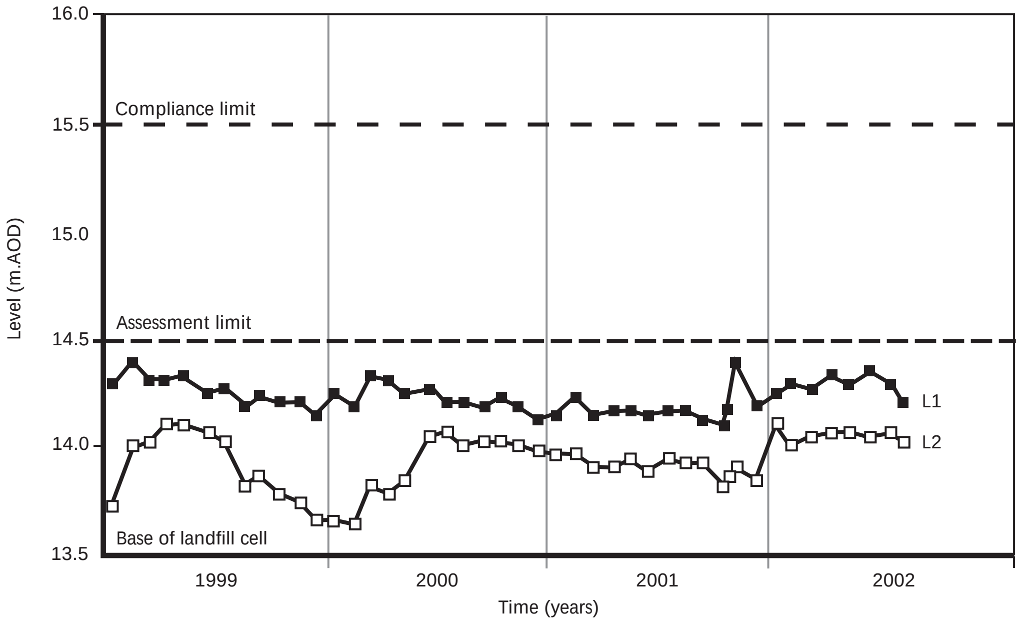
A number of specific review tasks should be implemented on validated data:

- comparison of actual against specified monitoring schedules
  any missing data should be identified with comments and recommendations for retrieving this information in future surveys (e.g. a replacement monitoring point may be needed);
- evaluate significance of QC data
  this includes a periodic assessment of laboratory and field QC data to determine whether data quality meets the monitoring programme objectives — both quantitative and qualitative QC data may be presented in tabular or graphic form to assist in this task.
- application of assessment tests
  assessment criteria response times dictate the maximum duration of the period between monitoring and review, but it is to the operator's advantage to review data speedily to provide the earliest possible warning of any difficulties;
- a review of the conceptual site model (i.e. current understanding of the hydrology and hydrogeology of the site)
  to ensure that monitoring objectives are still being met in the light of this understanding. For example, it may emerge from data that groundwater flow direction is not the same as it was thought to be at the time of site investigation, so that alternative or new down-gradient monitoring boreholes may need to be provided.

[29] For example, Mazor (1991) and Hem (1975) for graphic presentation of water-quality data; Gibbons (1997) on statistical methods applied to groundwater data.

Figure 10.2 Examples of presentation of leachate and groundwater level records using time-series charts

a) Leachate levels in a landfill cell



b) Groundwater levels

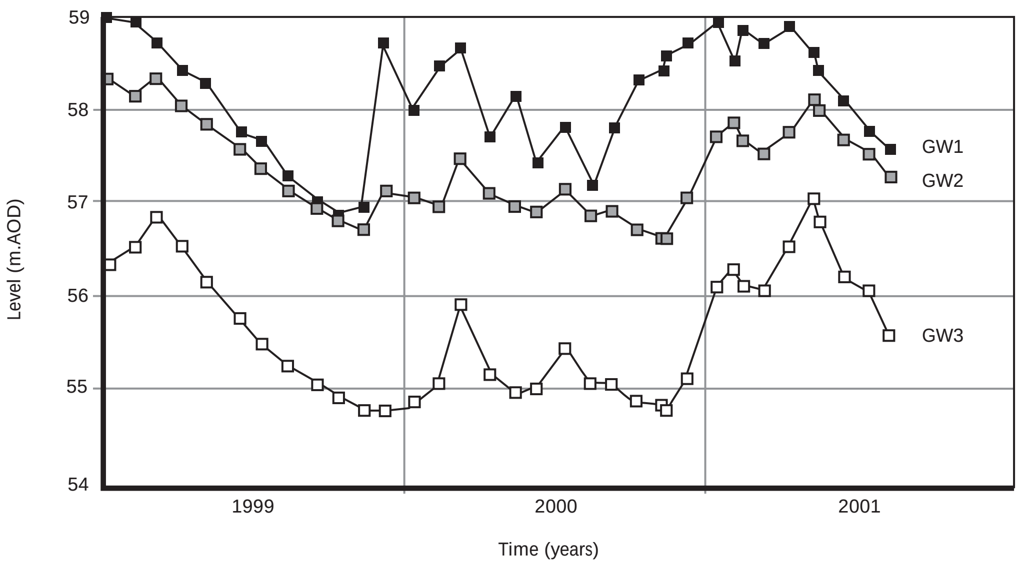


Figure10.3 Examples of presentation of water quality data for a single monitoring point using time-series charts

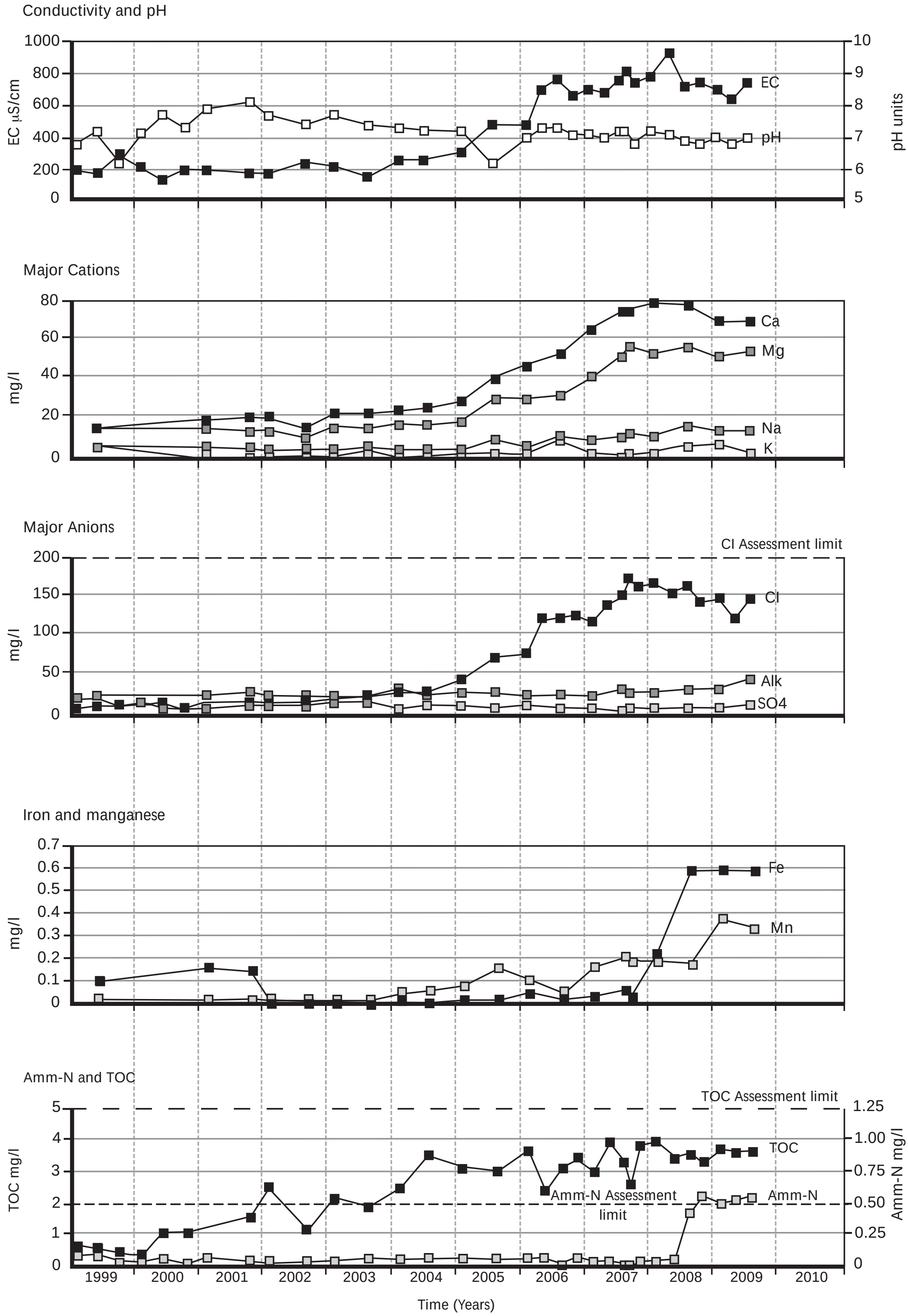
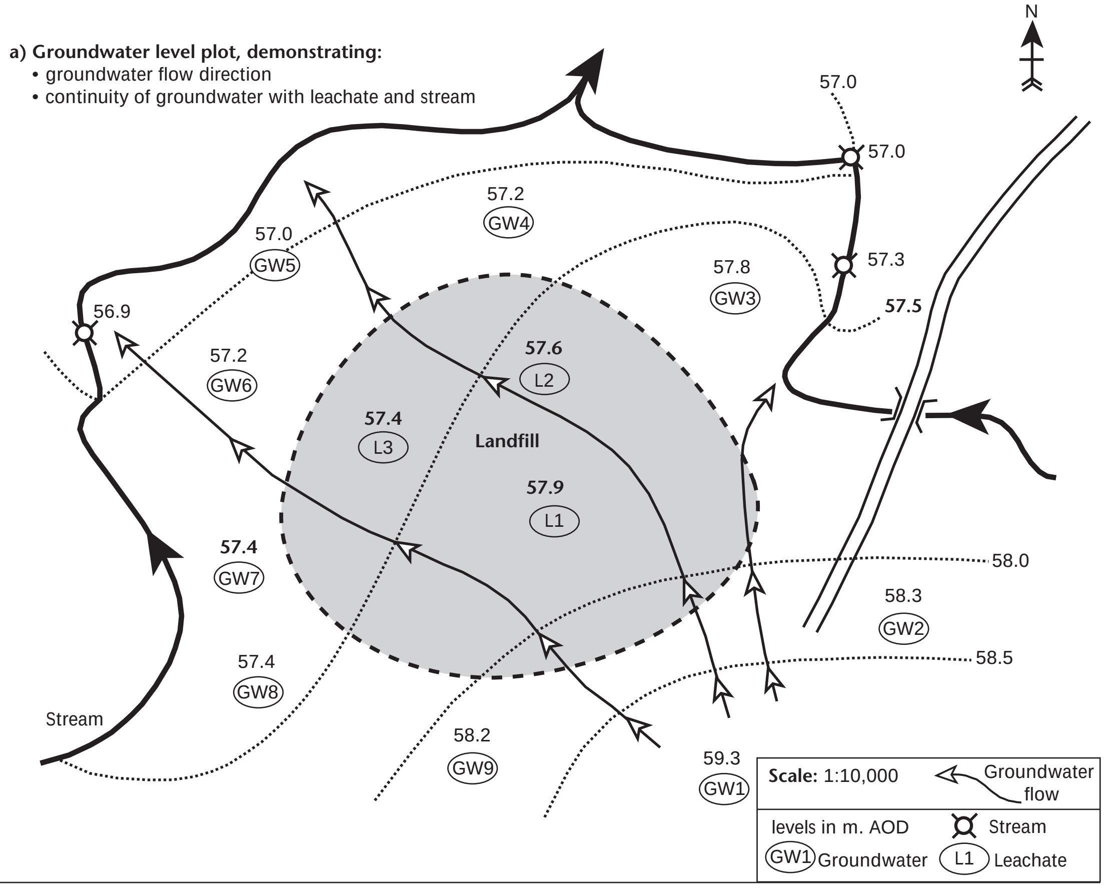
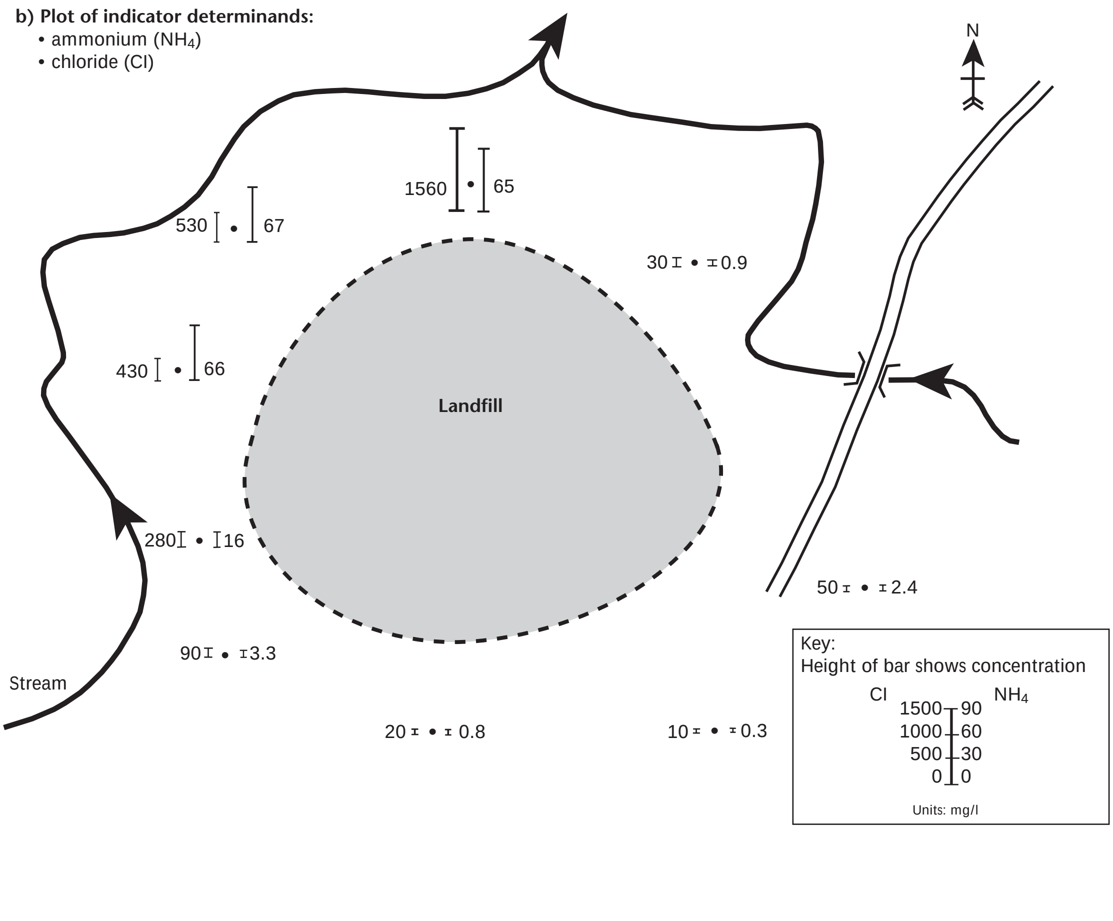


Figure 10.4 Examples of spatial presentation of data.





10.9 Reporting

10.9.1 Introduction

Article 12 of the Landfill Directive requires landfill operators, at least once per year, to report all monitoring results to the Agency to demonstrate compliance with permit conditions and increase knowledge on waste behaviour in landfills.

The purpose of reporting is to provide a formal channel for communication of the results of monitoring to site management and the Agency and for lodging on a public register. Wherever possible, data records should be provided to the Agency electronically in a format agreed between the site operator and the Agency. All reporting should be succinct, backed up by necessary and sufficient data, which should be quality assured, and appropriately presented. In particular, data and reports submitted to the Agency should be:

- submitted on time
  timescales may be stipulated by the licence condition, although in all cases timely submission of data and reports is essential to ensure informed discussion of their significance before any action is taken;
- quality assured
  any erroneous data submitted to the Agency can lead to unnecessary, time consuming and costly exchanges;
- collated and presented in a consistent format
  while the detailed format of data submitted will vary from site to site and for different types of data, simple tabular and time-series or control chart graphic summaries are preferred, with clear comparisons with any established compliance limits or assessment criteria;
- accompanied periodically by interpreted reports
  the content and layout of reports should be standardised in a format agreed between the operator and the Agency to highlight key issues of compliance or departures from baseline conditions. The frequency of reporting should be related to pathway travel times or anticipated rate of change of concentration (e.g. immediate report of surface water contamination versus annual summary of leachate quality).

10.9.2 Reporting tasks

The format and type of monitoring reports will vary depending on the complexity of monitoring programmes. Typically, the following types of reports can be used:

- notification reports
  these are issued to provide notice of a breach of assessment criteria or compliance conditions, or other potential or actual polluting incidents — the report should include notification of the contingency measures required or implemented;
- routine survey documentation
  these are prepared primarily to provide detail and comment on results from individual monitoring surveys, and include QC and validation records and any changes made to data as a result of these procedures;
- compliance reports
  these are prepared for submission to the Agency to include data and comment relating primarily to compliance with permit conditions;
- review and data submission reports
  these are prepared to periodically assess all monitoring results to date against the monitoring objectives for the site. In most cases, these reports should form the principle means of collating and submitting routine monitoring data to the Agency.

Actions that arise from these reports include the need to periodically update the Environmental Management and Monitoring Programme and, if required, the risk-based monitoring review. It is likely that the Environmental Management and Monitoring Programme will need updating at least annually during the operational stage of landfilling. The risk-based monitoring review will need to be updated whenever compliance limits or assessment criteria are changed, or where a material change in the site or surrounding environment requires this.

An example schedule for reporting to site management and the Agency is presented in Table 10.1.

10.9.3 Notification reports

Notification reports should be seen as the prime means of disseminating information for which action is required by site management and/or the Agency. Notification reports should be issued when breaches in assessment criteria or compliance limits have occurred or if any other potential or actual instances of pollution arise from the landfill. These reports should provide clear, concise information and carry a recommendation for action (or advise of action taken). Timescales for issuing reports may be specified by permit condition, but in all cases reports should be issued within a time frame agreed between the operator and the Agency. Reports should be issued to both site management and the Agency and should include:

- date and time of issue of report;
- name, position and contact information for person issuing report;
- date and time of monitoring surveys or observations that confirm the breach of a compliance limit or assessment criterion, or an actual pollution incident;
- pollution incident recorded or assessment criteria breached;
- contingency action required or implemented;
- an indication of the urgency of response needed by management and/or the Agency.

Attached to the report should be other information that helps clarify the seriousness of the incident. For example:

- a tabular summary of relevant data;
- a time-series graph of data, including assessment and compliance limits;
- any other relevant observations.

In instances where assessment criteria or compliance limits are breached regularly and action is being implemented by the site operator (e.g. where leachate level control measures are underway or where the source of contamination to groundwater is being investigated), alternative ongoing reporting procedures should be agreed between the site operator and the Agency to avoid unnecessary duplication of notification reports.

10.9.4 Routine survey documentation

Routine survey documentation is concerned primarily with conveying to site management confirmation of work undertaken, results obtained and the quality of results. Whether this information is compiled into a formal report, or is simply collated for internal review, is a matter for the operator and is typically dependent on the size of the organisation. Whichever method is adopted, the documentation must be available for inspection by the Agency on request.

The documentation should include:

- survey results
  summarised in tables;
- details of data validation
  documentation and comment on QC tests and breaches and any actions taken to remedy them (recommendations for ensuring excessive errors identified by QC are not repeated);
- comment on any breaches in assessment or compliance criteria
  including a statement of any assessment or contingency actions undertaken or recommendations for such action.

10.9.5 Compliance reports

Compliance reports are the formal means of submitting routine compliance data, required by PPC Permit conditions, to the Agency.

For sites that pose low risk, the function of compliance reports may be fulfilled by annual review reports (see next section). For sites where risks are greater, a selected range of information may need to be submitted on at least a quarterly basis (e.g. leachate levels, water-quality data related to discharges or data for locations close to or in breach of assessment criteria). Where immediate changes to monitoring schedules are proposed, these should be reported in compliance reports.

For sites that fail to issue notification or compliance reports as required, enforcement action may be taken by the Agency. Enforcement would follow procedures set out in the relevant Agency's Enforcement and Prosecution Policy. Enforcement procedures could include either a modification of permit conditions or the serving of a notice requiring information.

10.9.6 Review reports

A review report should be prepared at least annually, as required by the Landfill Directive, and should be submitted within three months of the end of the monitoring year. The report should include tabular and graphic presentation of indicator monitoring measurements, including all those used for assessment criteria. The main purpose of this report is to inform site management and the Agency of the environmental performance of the landfill site, as well as the performance of the monitoring programme. Recommendations for improving the

Table 10.1 Example schedule of reporting tasks.

<table>
<tr><th rowspan="2">Report and content</th><th colspan="2">Timescale for reporting to:</th></tr>
<tr><th>Site management</th><th>Agency</th></tr>
<tr><td>Notification reports:
breaches of assessment criteria
contingency implemented</td><td colspan="2">Within response time specified in assessment criteria</td></tr>
<tr><td>Routine survey documentation:
QC and data validation records
tabulated results
comment on breaches of assessment criteria
comment on unusual or notable data
changes needed to monitoring infrastructure or procedures</td><td>Before next routine survey</td><td>Not normally required, but must be available for inspection</td></tr>
<tr><td>Compliance reports:
details of compliance and assessment monitoring programmes
tabulated compliance and assessment data
comment on breaches of assessment criteria, and action taken
changes needed to monitoring infrastructure or procedures</td><td colspan="2">At least quarterly for sites that pose high risks to receptors and at other intervals to be agreed between Agency and site operator

(NB: any changes to monitoring infrastructure or procedures should be agreed with the Agency prior to implementation)</td></tr>
<tr><td>Review reports:
review of site development and monitoring infrastructure changes since the previous report
review of changes to risk assessment and Environmental Management and Monitoring Programme since the previous report
review of monitoring programmes completed against planned schedules
collation of monitoring data
review of monitoring data
conclusions and recommendations</td><td>Annually</td><td>Annually – to be submitted within three months of end of reporting year</td></tr>
<tr><td>Environmental Management and Monitoring Programme: see Chapter 5 for contents</td><td colspan="2">Annually during operational stage — to be submitted within six months of the end of the reporting year to the Agency
As necessary following restoration, with a minimum review interval of five years</td></tr>
<tr><td>Risk-based monitoring review</td><td colspan="2">As necessary following breaches of assessment criteria</td></tr>
</table>

monitoring system should be made and discussed with the Agency.

Data provided to the Agency with these reports should include all monitoring data collected since the previous submission of a review report. All data should be collated into tabular formats. Computerised data records, where available, should be provided electronically in a format agreed with the Agency.

10.9.7 Update of Environmental Management and Monitoring Programme and risk-based monitoring review

The periodic (annual) review should include an assessment not only of the performance of the landfill, but also of the performance of the monitoring programme itself. This should allow informed recommendations to be made to update details in the Environmental Management and Monitoring Programme or the risk-based monitoring review. This process is illustrated in the flow chart of the monitoring process, Figure 3.2.

Updating the risk-based monitoring review should be a relatively rare occurrence, normally in response to the re-evaluation of risks following a breach in assessment criteria or following a periodic risk-assessment review. Where this is updated, the risk-based monitoring review should be completed prior to updating the Environmental Management and Monitoring Programme.

Interim changes to the risk-based monitoring review or changes required to monitoring infrastructure or monitoring programmes might be made at any time (e.g. following breach of an assessment criterion, or damage to a monitoring point). These changes, and any other changes proposed in the annual review report, should be formalised by the production of an updated Environmental Management and Monitoring Programme within six months of the end of the monitoring year.

Updating the risk-based monitoring review

Examples of situations that require the risk-based monitoring review to be updated include:

- leachate level or quality different to design values;
- evidence of leachate leakage above design rates;
- evidence of previously unknown leachate migration pathways;
- new source–pathway–receptor linkage identified (e.g. through a new abstraction borehole being installed, or land redevelopment).

Updating the Environmental Management and Monitoring Programme

Examples of situations that require the Environmental Management and Monitoring Programme to be updated include:

- any alteration to the risk-based monitoring review;
- inability to obtain an appropriate sample from a monitoring point (e.g. through blockage or contamination).

Elements of the Environmental Management and Monitoring Programme most likely to be subject to periodic revision include:

- the register of monitoring points (Section 8.3.4);
- the monitoring-point location plan (Section 8.3.4);
- monitoring schedules (Chapter 6);
- specifications for assessment and compliance criteria (Section 7.2);
- statistical baseline data summaries (Section 5.2).

Other parts of the Environmental Management and Monitoring Programme may require less frequent revision. To facilitate updates, the use of a loose-leaf format with dated pages is to be encouraged.

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Glossary of terms and abbreviations

This glossary defines terms as they are used in this document. Some terms may have broader meanings outside this guidance. Within definitions, words in *italics* are themselves defined elsewhere in the glossary.

Acceptable release rate/acceptable leakage rate A designed leakage rate for leachate egress through an engineered landfill lining system based on a quantitative assessment of risk.

Accuracy The closeness of the result of a measurement to the true value.

Acetogenic/acetogenic phase The initial period during the decomposition of refuse in a landfill, when the conversion of organic polymers, such as cellulose, into simple compounds, such as acetic and other short-chain fatty acids, dominates, and little or no methanogenic activity takes place.

Analyte A specific compound or element of interest undergoing chemical analysis.

Annulus The ring-shaped space in a borehole between the borehole lining and the borehole wall.

Annular seal A seal that occupies the *annulus* to prevent vertical movement of water.

Appropriate sample A sample collected and analysed using standard protocols, which is *fit for it's purpose*.

Aquifer A permeable geological stratum or formation that is capable of both storing and transmitting water. A *confined aquifer* is where an upper layer of low permeability confines groundwater in the aquifer under greater than atmospheric pressure. An *unconfined aquifer* is where the upper surface of a saturated zone forms a water table within the water-bearing stratum. See *groundwater system*.

Aquifer classification Classification given to water-bearing strata by the Agency and published in groundwater protection policy documents (e.g. major aquifer, minor aquifer, non-aquifer).

Aquitard A geologic stratum or formation of low permeability that impedes the flow of water between *two aquifers.*

Assessment The process of evaluating the significance of a departure from baseline conditions by reference to an adverse trend in data or the breach of a specified limit (e.g. a *Control level* for groundwater quality).

Assessment criterion A test of the significance of a deviation from baseline conditions, which if breached would trigger a series of pre-planned actions (e.g. a *Control level* for groundwater quality).

Assessment limit A predetermined 'early warning' limit value of a measurement, used in some assessment criteria (e.g. a *Control level* as a specified limit for groundwater quality).

Assessment monitoring An investigative monitoring programme initiated in response to anomalous data or as an action following breach of an assessment criterion.

Attenuation A decrease in contaminant concentration or flux through biological, chemical and physical processes, individually or in combination (e.g. dilution, adsorption, precipitation, ion exchange, biodegradation, oxidation, reduction). See also *natural attenuation*.

Background See *baseline*.

Baseline Measurements that characterise physical, chemical or other distinctive properties of groundwater and surface water unaffected by leachate contamination.

Baseline or background concentration/level The value and variability of a measurement in the absence of a landfill.

Bias The tendency of sampling measurements to be reported consistently to one side of the true result. *A systematic error* caused by the sampling and/or analytical process.

Blank sample A laboratory-prepared sample of reagent-grade water or pure solvent used as a quality control sample. See also field blank.

Borehole A hole sunk into the ground by drilling for abstraction of water or leachate or for observation purposes. A borehole may be lined with suitable casing and screened at appropriate depths.

Borehole development The process of cleaning out a borehole following its construction, to remove fine material within and immediately around the screened section of the borehole.

Construction quality assurance (CQA) A certifiable management system that provides assurance that construction works are completed as specified. See *quality assurance*.

Catchment The area from which water drains to a specified point (e.g. to a reservoir, river, lake or borehole). See also *landfill catchment*.

Catchment drawing See *landfill catchment drawing*.

Characterisation monitoring Monitoring using a broad range of measurements to characterise a water by recording as many measurable properties (e.g. physical, chemical and biological) as practicable.

Compliance The process of achieving, and the achievement of, conformity with a regulatory standard.

Compliance limit A regulatory limit established in the regulatory permit or associated documents or discharge consent. A *Trigger level* is a compliance limit for groundwater quality.

Composite sample A sample taken over a range of locations or time intervals. For example, a sample taken over an extended depth range in a borehole or surface water, or a sample formed by combining a number of *discrete samples*. Synonymous with *integrated sample*.

Conceptual model A simplified representation or working description of how the real (hydrogeological) system is believed to behave based on qualitative analysis of field data. A quantitative conceptual model includes preliminary calculations for the key processes.

Conduit flow Groundwater flow in formations in which flow is almost entirely channelled through discrete solution channels or discontinuities.

Consented discharge A *discharge* of *effluent* controlled by a discharge consent or groundwater authorisation issued by the Agency.

Conservative contaminants *Contaminants* that can move readily through the environment with little reaction or degradation (e.g. chloride).

Contamination/contaminant The introduction of any substance to water at a concentration exceeding the *baseline* concentration. A contaminant is any such substance.

Contingency action plan A predetermined plan of action to respond to a breach of an *assessment criterion* or *compliance limit*.

Continuous sample A sample taken continuously over an extended period of time.

Control chart A graphic statistical method for evaluating changes in monitoring data.

Control Level A test of the significance of a deviation from baseline groundwater conditions, used to determine whether a landfill is performing as designed and regarded as an early warning system to enable appropriate investigation or corrective measures to be implemented (see *contingency action plan*). Control level specifically relates to groundwater and is directly comparable to assessment criterion (Environment Agency, 2003b).

Controlled waters Defined by the Water Resources Act 1991, Part III, Section 104. All rivers, canals, lakes, groundwaters, estuaries and coastal waters to three nautical miles from the shore.

Cusum chart A type of *control chart* that exaggerates small permanent shifts from a baseline mean value.

Design leakage See *acceptable release rate*.

Detection limit The lowest concentration of a substance that can be measured reliably to be different from zero concentration.

Determinand The subject of any measurement or analysis.

Development See *borehole development*.

Diffusion Migration of dissolved substances within a fluid through random movement of particles. Significant when flows are low.

Dilution Reduction in concentration brought about by the addition of water.

Discharge A release of leachate or water into another water body.

Discrete sample A sample taken from a single point in space and time (sometimes known as a *spot sample*).

Dispersion Groundwater – irregular spreading of solutes because of heterogeneities in groundwater systems at pore-grain scale (microscopic dispersion) or at field scale (macroscopic dispersion).

Surface water – spreading of substances through the receiving water by means of differential flow rates and turbulence.

Down-gradient In the direction of decreasing water level (i.e. in groundwater this follows the *hydraulic gradient***).**

Duplicate sample A second sample prepared in the same way as a primary sample. There are several types of duplicate sample (see Appendix 12). See also *sampling duplicate*.

Effective porosity The amount of interconnected pore space, through which fluids can pass, expressed as a percent of bulk volume.

Effective rainfall Total rainfall minus actual losses through *evaporation* and *transpiration*. Effective rainfall includes both surface run-off and that which percolates into the ground below the soil zone.

Effluent A waste fluid discharged or emitted to the external environment. See also *trade effluent*.

Environmental assessment level (EAL) A water quality standard that is defined by either UK Regulations [e.g. Water Supply (Water Quality) Regulations 1989], EU Directives (e.g. Drinking Water Directive 80/778/EEC) or another relevant source (e.g. ADAS water-quality standards for water used for irrigation and livestock watering).

Environmental Management and Monitoring Programme A reference document that details the design, management and implementation of a monitoring scheme for a landfill. Incorporates the management and monitoring of leachate, groundwater, surface water, landfill gas, etc. (see Section 3.7).

Environmental quality standard (EQS) A water quality and biological standard for a surface watercourse.

Error The total error is the difference between an experimental result and the 'true' value at the time of sampling. The total error is made up of a combination of *systematic* and *random errors* that result from the sampling and measurement process.

Evaporation The process by which water passes from a liquid to a vapour.

Evapo-transpiration The total water transferred to the atmosphere by *evaporation* from the soil or water surface, and *transpiration* by plants.

Example schedules Tables of monitoring measurements and sample frequency illustrative of monitoring needs for a landfill in a particular setting. Provided as a model against which site-specific schedules can be compared.

Field blank/standard A *blank* or *standard* sample prepared in the laboratory and taken to the sampling site, from where it is treated in exactly the same way as the sample. Used to detect combined errors in sampling and analysis.

Fissure flow Groundwater flow in rock or clay formations in which water movement is primarily through fissures.

Fit for purpose (Describing a process or measurement.) Yielding a result that is within the *tolerable uncertainty*.

Geological formation An assemblage of rocks that have some characteristics in common, whether of origin, age or composition. Normally now used to refer to an identifiable rock unit within a particular area.

Groundwater In this document the definition used is that given in the EC Groundwater Directive (80/68/EEC) as "all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil".

This definition specifically excludes water contained in the unsaturated zone.

'Ground waters' have also been defined legally as "any waters contained in underground strata" [Water Resources Act 1991, Part III, Section 104(d)]. In this instance, the definition includes both the unsaturated and saturated zones below ground level. Throughout this document, reference to groundwater is based on the EC definition.

Groundwater system A saturated groundwater bearing formation, or group of formations, which form a hydraulically continuous unit.

Hazard A property or situation that, in particular circumstances, could lead to harm.

HDPE High-density polyethylene – a plastic material.

Head (hydraulic head) The sum of the elevation head, the pressure head and the velocity head at a given point in a water system. In practical terms, this is the height of the surface of a column of water above a specified datum elevation.

Hydraulic conductivity A coefficient of proportionality that describes the rate at which a fluid can move through a medium. The density and kinematic viscosity of the fluid affect the hydraulic conductivity, so this parameter is dependent on the fluid as well as the medium. Hydraulic conductivity is an expression of the rate of flow of a given fluid through unit area and thickness of the medium, under unit differential pressure at a given temperature. See also *permeability*.

Hydraulic gradient The change in total *head* (of water) with distance in a given direction. The direction is that which yields a maximum rate of decrease in head.

Hydrogeology The study of water in rocks.

Hydrology The study of water at ground surface.

Index/Indices A multivariate statistic that combines a number of monitoring measurements to produce a numeric value which can be used to represent variability in measurements.

Indicators Measurements specified as part of a *routine monitoring programme*, and are used as indicators of leachate contamination or for compliance purposes.

Inert waste Wastes that do not undergo any significant physical, chemical or biological transformations.

Infiltration The entry of water, usually as rain or melted snow, into soil or a landfill.

Initial characterisation monitoring An initial period of intensive *characterisation monitoring* carried out to provide sufficient data to define the normal pattern of variation in a broad suite of measurements.

Integrated sample (Term not used in this guidance.) Synonymous with *composite sample*.

Intergranular flow Groundwater flow through interconnected pore spaces in a soil or rock formation.

Inorganic Any substance that is not *organic*.

Ion An element or compound that has gained or lost one or more electrons, so that it carries a charge.

Ionic balance See major *ion balance*.

Landfill catchment/Landfill catchment drawing A drawing or drawings that encompass the up-gradient groundwater and surface water *catchment* areas containing the landfill site, and the area down-gradient of the site that could potentially be influenced by leachate discharges from the landfill site.

Landfill leachate The liquid that results from the percolation of water and liquid waste through solid waste.

List I and II Substances As defined by EC Groundwater Directive 80/68/EC.

Major ion One of several principle *ions* that together account for the majority of dissolved ions in a water sample.

Major ion balance A calculation to show the relative amounts of positive and negatively charged ions reported in laboratory results for a solution. All solutions are neutral, so the sum of positive ions should be equal to the sum of negative ions.

Measurement See *monitoring measurement*.

Methanogenic/methanogenic phase An advanced stage of anaerobic decomposition of refuse, when methane is produced in significant quantities.

Minimum reporting value The lowest concentration of a substance that is reported in the results of an analysis. It is not necessarily the *detection limit*.

Mixing depth The depth of groundwater into which leachate that escapes from a landfill site is mixed. Used for dilution calculations.

Monitoring A continuous or regular periodic check to determine the on-going nature of the potential hazard, emissions and conditions along environmental pathways, and the environmental impacts of landfill operations, to ensure that the landfill is performing according to design (adapted from Waste Management Paper 26, 1986).

The general definition of monitoring includes measurements undertaken for compliance purposes and those undertaken to assess landfill performance.

Monitoring infrastructure The total of all monitoring points and services used for a monitoring programme.

Monitoring measurement An individual measurement taken from a single monitoring point on a single occasion.

Monitoring point An individual point or structure from which unique sets of monitoring measurements can be obtained.

Natural attenuation Natural processes that reduce the concentration of *contaminants* in groundwater and surface water

Organic (compound) Any substance containing carbon–carbon bonds, or methane or its derivatives.

Pathway The route by which contaminants are transported between the source of landfill leachate and a water *receptor*.

Permeability A measure of the rate at which a fluid will move through a medium. The permeability of a medium is independent of the properties of the fluid. See also *hydraulic conductivity*.

Piezometer An instrument for measuring hydraulic pressure. The term is commonly applied to a tube installed to allow water level measurement and sampling from a specific vertical interval (the 'response zone'). The response zone consists of a porous or short screen (i.e. typically less than 6 m in length), or pressure-measuring device, isolated by *annular seals*.

Pollution Defined in the Environment Protection Act 1990 Section 29(3) as "pollution of the environment due to the release or escape (into any environmental medium) from

(a) the land on which controlled waste is treated

(b) the land on which controlled waste is kept,

(c) the land in or on which controlled waste is deposited,

(d) fixed plant by means of which controlled waste is treated, kept or disposed of,

of substances or articles constituting or resulting from waste and capable (by reason of the quantity or concentrations involved) of causing harm to man or any other living organisms supported by the environment".

Also defined in the PPC Statutory Instrument as

"emissions as a result of human activity which may be harmful to human health or the quality of the environment, cause offence to any human senses, result in damage to material property, or impair or interfere with amenities and other legitimate uses of the environment"; and 'pollutant' means "any substance, vibration, heat or noise, released as a result of such emission which may have such an effect".

Also defined in the EC Groundwater Directive 80/68/EC in relation to groundwater as "the discharge by man, directly or indirectly, of substances or energy into groundwater, the results of which are such as to endanger human health or water supplies, harm living resources and the aquatic ecosystem or interface with other legitimate uses of water".

Pollution Prevention and Control (PPC) regime Refers to the provisions of the Landfill Regulations (England and Wales) 2002 and minor modifications to the Pollution Prevention and Control Regulations 2000, both made under the PPC Act 1999. These implement the EU Integrated Pollution Prevention and Control Directive in England and Wales.

Precision The repeatability of a measurement. The closeness of each of a number of similar measurements to their arithmetic mean.

Protocol A standardised procedure for carrying out a monitoring task, such as sampling, handling, analysis or data management. (Use of a protocol can help to ensure consistency and repeatability.)

Purging The process of removing water that is unrepresentative of the surrounding strata or waste from a borehole, prior to sampling.

Quality assurance (QA) A management function, involving all those planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality.

Quality control (QC) The operational techniques and activities that are used to fulfil requirements for quality. Includes methods for minimising errors (such as use of appropriate *protocols*) and methods for detecting errors (such as check measurements, e.g. QC sampling).

QC sampling The preparation and analysis of samples for the purpose of detecting errors introduced by the monitoring process. Examples of QC samples include *duplicates, blanks, standards and* **s***piked samples*.

Random error Error caused by random variation in the performance of the sampling and measurement process.

Receptor A groundwater or surface water resource, amenity or abstraction point.

Recharge The amount of water added to the groundwater system by natural or artificial processes.

Regulation 15 Regulation 15 of the Waste Management Licensing Regulations 1994, for the purposes of implementing Council Directive 80/68/EC on the protection of groundwater against pollution caused by certain dangerous substances, makes provision for the method of dealing with applications for licences in respect of waste activities that could lead to a discharge into groundwater of substances in lists I and II of that Directive.

Remediation The process of improving the quality of a polluted body of water or an area of land, either by carrying out works on the pollutant source or by treatment of the affected water or land.

Representative sample An ideal water sample that retains the chemical and physical characteristics of the in-situ water.

Resistivity The electrical resistance offered to the passage of a current, usually expressed in ohm-metres. The reciprocal of conductivity.

Resistivity array A permanently installed grid of electrodes used to measure *resistivity* on a periodic basis as a means of monitoring changes in the electrical properties of strata.

Risk A quantitative or qualitative combination of the probability of a defined *hazard* causing an adverse consequence at a *receptor*, and the magnitude of that consequence.

Risk assessment The process of identifying and quantifying a risk, and assessing the significance of that risk in relation to other risks.

Risk-based monitoring review A review document using the results of site investigation and *risk assessment* to rationalise monitoring priorities for a landfill.

Risk inventory A tabular summary of risk to receptors from a landfill for the purpose of prioritising monitoring effort.

Routine monitoring Monitoring that is undertaken once *initial characterisation monitoring* has been completed, and consisting of ongoing *characterisation*, together with *indicator* measurements. Routine monitoring continues until an impact is detected (leading to *assessment monitoring*) or completion monitoring is implemented.

Run-off Rain or melted snow that drains from the land surface.

Sampling duplicate A sample taken immediately following another sample by repeating the entire sampling procedure. Both samples are then treated identically. Used to determine total *random errors* in the entire sampling and analysis process.

Sampling protocol A *protocol* for carrying out a specific sampling task.

Saturated zone (phreatic zone) The zone in which the voids of the rock or soil are filled with water at a pressure greater than atmospheric. The water table is the top of the saturated zone in an unconfined groundwater system. In general, flow on a macro scale is horizontal and typically faster than for unsaturated zone flow. Flow rates between different types of strata vary over several orders of magnitude.

Significant deviation The amount of deviation from the norm that would give cause for concern.

Site manual The accumulated design, planning, licensing and operational documentation for a landfill (see Waste Management Paper 26 26B).

Spiked sample A water sample to which a known amount of a specific *analyte* has been added.

Spot samples Groundwater – a sample taken from a specific depth in a borehole.

Surface water – a sample taken almost instantaneously from a specific location in a surface water, or from a discharge.

Synonymous with *discrete sample*.

Stabilisation In relation to landfill, this is the degradation of organic matter to stable products, and the settlement of fill to its rest level.

Standard sample A quality control sample in which the concentration of a specific or group of chemical constituents is known. See also *field standard*.

Surface water Any accumulation of water on the ground surface, which includes ponds, lakes, wetlands, drains, ditches, springs, seepages, streams and rivers.

Systematic error Error introduced by the sampling and measurement process that consistently causes *bias* of the result in one direction.

Time-series A graphic representation of data arranged sequentially by date.

Tolerable uncertainty The degree of uncertainty that is acceptable without compromising the purpose of the measurement.

Trade effluent Fluid discharged or emitted to the external environment (including sewers) under the control of a trade effluent authorisation.

Section 141 of the Water Industry Act 1991 states: "trade effluent means (a) any liquid either with or without particles of matter in suspension in the liquid which is wholly or partly produced in the course of any trade or industry carried on at trade premises; and (b) in relation to any trade premises means any such liquid which is so produced in the course of any trade or industry carried on at those premises, but does not include domestic sewerage."

See also *effluent*.

Transpiration The transfer of water from the soil to atmosphere by plants.

Trigger levels Defined as levels at which significant (adverse) environmental effects have occurred. Such effects would be consistent with the most stringent *environmental assessment limit* (EAL) for a groundwater receptor being breached. A Trigger level specifically relates to groundwater and is directly comparable to a *compliance level*.

Turbidity Cloudiness in water caused by the presence of suspended and/or colloidal organic and inorganic solid material.

Uncertainty The interval around the result of a measurement that contains the true value with high probability. Uncertainty is caused by undetected or unpredicted errors in the sampling and measurement process, together with unpredicted natural variation.

Up-gradient In the direction of increasing *hydraulic head* (i.e. in groundwater this is moving up the *hydraulic gradient*).

Unsaturated zone (vadose zone) The zone between the land surface and the water table. The pore space contains water at less than atmospheric pressure, as well as air and other gases. Saturated bodies, such as perched groundwater, may exist in the unsaturated zone. Also called the vadose zone.

Overall flow, on a macro scale, is downward (gravity driven); moisture content is low and water normally flows slowly in close contact with the rock matrix.

Water balance An evaluation of all the sources of supply, storage and corresponding discharges of water – e.g. within a landfill site or an entire surface water catchment area.

Water body A continuous mass of water with similar characteristics, which can be represented on a map or plan. For example, groundwater within a specific stratum, water in a lake, water in a stream course.

Water quality objective A chemical and or biological objective for a body of water such as to be fit for a particular use – e.g. abstraction for potable supply or for a target organism, such as freshwater fish.

Well A hole sunk into the ground for abstraction of water or leachate or for observation purposes. A well is generally of larger diameter than a borehole and dug rather than drilled.

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Appendix 1:

Example monitoring point construction forms and registers

A1.1 Monitoring point construction record sheet for wells and boreholes

An example form for a single monitoring point in a borehole is provided as Table A1.1a, which could be used for most groundwater or leachate monitoring points. A continuation form (Table A1.1b) is provided to record details of multiple installations within a single borehole. The forms should be used in association with other records, such as borehole logs, and could be used as a basis for transferring information to a database.

Descriptions of information and examples applicable to each heading are given below.

Heading information

Field	Description (with explanatory text)	Examples
Borehole reference number	Borehole reference number *For boreholes that contain a single monitoring point, this will usually be the same as the 'Mon. Point Ref No'* *For boreholes that contain multiple installations, this will usually be the same as the 'Multi Ref' number.* *This should be an alphanumeric number unique at a particular site (avoid use of the characters: *, /, \, -, _, brackets and spaces).*	*BH1, GW1, L1*
Site Name	Name of landfill site. *It is preferable to use the name stated on the permit unless some other name is commonly used.*	*Mountain Top Landfill Site*
Site Operator	The named permit holder and/or landfill operator.	*ABC Landfill Co.*
Environment Agency Permit Number	Permit or Licence Reference Number.	*WCC 123456*
No of Mon Points in Borehole	Total number of monitoring points in borehole.	*1, 2, etc.*
Sheet __ of __	Sequential and total no of sheets used for this borehole record. *A continuation sheet (Table A1.1.b) completed for multiple monitoring points within a single borehole.*	*Sheet 1 of 3*

Group ID information

Field	Description (with explanatory text)	Examples
Multi Ref	Multiple monitoring point reference number. *The same reference number is used to link more than one monitoring installation within a single borehole or built structure. (Leave blank if not applicable.)*	*BH1*
Cluster Ref	Cluster reference number. *A reference number used to group together a number of boreholes or wells drilled close together to monitor different vertical intervals. (Leave blank if not applicable.)*	*CL1*
Cell Ref	Landfill cell reference number. *A reference number used to group together a number of monitoring points within a single hydraulically separate landfill cell. (Leave blank if not applicable.)*	*Cell 1*
Area Ref	Site area descriptive reference. *Name or code used to group monitoring points geographically.*	*N (Northern site catchment)* *SWB (South-western boundary)*

Monitoring point ID information

Field	Description (with explanatory text)	Examples
Vertical Sequence (from top)	Sequence of monitoring points in borehole from ground level downwards.	*1, 2, 3 etc*
Mon Point Ref No.	Monitoring point reference number. *This should be an alphanumeric number unique at a particular site (avoid use of the characters: *, /, \, -, _, brackets and spaces).*	*GW1, L1*
EA WIMS Ref No	Environment Agency database reference number. *(If available from Environment Agency.)*	*19373a01*
Mon Type	Type of monitoring installation.	*LS (Long-screened borehole)* *Pz (Piezometer or short-screened borehole)* *C (Concrete ring)*
Mon Use	Purpose of monitoring points. *(Leachate, groundwater, gas, or some combination of these.)*	*G (Gas monitoring only)* *GW (Groundwater only)* *GGW (Combined gas and groundwater monitoring)* *L (Leachate monitoring)* *GL (Combined gas and leachate monitoring)*
Response Zone	Name of zone being monitored.	*WB Base of waste* *WP Perched level in waste* *GP Perched groundwater* *GR Regional groundwater* *AQ1 Aquifer 1 (Chalk)*
Details on Sheet No	Sheet number with monitoring point completion details. *For multiple monitoring points within a single borehole.*	*1, 2, 3, etc.*

Example

Construction record

Field	Description (with explanatory text)	Examples
SI BH Ref	Reference number of borehole at time of construction. *Use BH Ref No if separate number not used. Do not leave blank.*	*BH1*
Hole Dia (mm)	Diameter of borehole in mm.	*150*
Hole Depth (mbgl)	Depth to base of borehole recorded in borehole logs. *Expressed as metres below ground level.*	*18.35*
Date Completed	Date of completion of borehole.	*15/6/01*
Contractor	Name of company undertaking construction.	*Mon Well Specialists Ltd*
Supervisor	Name of company and competent person responsible for design and supervision.	*XY Consultancy, AB Smith*
Construction Method	Brief description of methodology used.	*Rotary hollow stem auger* *Cable tool percussion* *Rotary with air flush using down-the-hole hammer* *SimCas/Odex*

Ground survey at time of construction

Field	Description (with explanatory text)	Examples
Surveyor	Name of company and competent person responsible for survey	*YZ Surveyors, CD Jones*
National Grid Reference – Prefix	100 km Ordnance Survey Prefix	*SO*
National Grid Reference – Eastings and Northings	12-figure OS grid reference *Surveyed to at least 1 m accuracy. The first number of the easting and northing identify the 100 km grid square. A full 12-figure reference is essential to incorporate information reliably into GIS mapping systems.*	*12 figure grid reference for Worcester City Centre:385000 255000* *Using the 100 km prefix, this can also be expressed as:* *SO 85000 55000*
Datum Point Description	Simple description of datum point used for water level measurements.	*Top of external casing* *Top of internal lining*
Height of Datum (magl)	Difference in height between datum point and ground elevation. Expressed as metres above ground level. A '+' or '–' symbol should be included to indicate height above (+) or below (–) ground level.	*+ 0.35, 0.07*
Datum Elevation (mAOD)	Surveyed elevation of datum point. Expressed as metres above Ordnance Datum.	*95.42*

Lining completion record
(Use continuation sheet to record details of multiple monitoring point within a single borehole)

Field	Description (with explanatory text)	Examples
Lining Material	Type of lining material used. *Use code or description.*	*uPVC* *HDPE*
Lining Dia (mm)	Internal diameter of borehole lining expressed in mm	*50*
Depth to Base of Lining (mbgl)	Depth to base of internal lining (or base of unlined borehole). *As recorded on original borehole log expressed in metres below ground level.*	*15.67*
Top of Lining above Ground Level (magl)	Height of borehole lining material above ground level. *Use negative number if level is below ground level.*	*0.53, −0.06*
Screen Description and Size	Type and size of screen used. *Use code or description.*	*0.5 mm slotted uPVC* *2 mm slotted uPVC with 250 μm sock*
Top of Screen (mbgl)	Depth to top of screened interval expressed in metres below ground level.	*12.36*
Base of Screen (mbgl)	Depth to base of screened interval expressed in metres below ground level.	*15.36*
Screen Length (m)	Length of screened interval in metres (i.e. difference between top and base of screen)	*3.0*
Annular Filter Description and Size	Use code or description for type and size of annular filter material.	*1–2 mm rounded quartz sand and gravel* *6 mm pea gravel*
Top of Filter (mbgl)	Depth to top of filter material surrounding screen expressed in metres below ground level.	*11.85*
Base of Filter (mbgl)	Depth to base of screened interval surrounding screen expressed in metres below ground level	*18.35*
Filter Length (m)	Length of annular filter interval in metres (i.e. difference between top and base of filter). This is also known as the response zone.	*6.5*
Annular Seal Description	Use code or description for type and size of annular seal used.	*Bentonite pellets/cement-bentonite grout/coated bentonite pellets*
Top of Seal above Filter (mbgl)	Depth to top of annular seal material above filter expressed in metres below ground level.	*9.75*
Base of Seal above Filter (mbgl)	Depth to base of annular seal material above filter expressed in metres below ground level. (Should normally be the same value as 'top of filter'.)	*11.85*
Seal Length (m)	Length of annular seal interval in metres (i.e. difference between top and base of seal)	*6.5*

Headworks

Field	Description (with explanatory text)	Examples
Headworks Description	Type and size of headworks used. *Use code or description*	*200 mm dia. raised steel cap* *Manhole cover*
Top of Headworks (magl)	Height of headworks above ground level. *Use negative number if level is below ground level.*	*0.65, −0.04*

Dedicated monitoring equipment

Field	Description (with explanatory text)	Examples
Describe Equipment:	Brief description of any dedicated monitoring equipment within monitoring point.	*Pressure transducer for water level measurements* *Dedicated pump (specify type)*

Access and safety

Field	Description (with explanatory text)	Examples
Describe special requirements for access or safety precautions	Notes describing any exceptional access or safety requirements for monitoring specific boreholes.	*Walking access only over fence and 100 m into field* *Strong venting of landfill gas, awkward height for sampling* *Gas protective masks and goggles needed*

Construction QC checks

Field	Description (with explanatory text)	Examples
Dated	Date details confirmed and filed in company records.	*31 July 2001*
Name of Competent Person	Name of competent person responsible for check.	*JJ Jones*
Position	Position of named competent person.	*Monitoring manager* *External consultant or contractor (xyz Company Ltd)*
Initials	Signed initials of competent person.	*JJJ*
Borehole Log (Y/N)	Circle 'Y' if a log recording drilling and geological details is available; 'N' otherwise.	-
Lining Details (Y/N)	Circle 'Y' if a log recording lining details is available; 'N' otherwise.	-
QC Checks (Y/N)	Circle 'Y' if information on logs has been QC checked; 'N' otherwise. *Person responsible for QC checks should fill in details in this section.*	-

Construction QC checks (continued)

Field	Description (with explanatory text)	Examples
EA Registered (Y/N)	Circle 'Y' if monitoring point details have been submitted to the Environment Agency; 'N' otherwise. *Date should be date of submission*.	-
EA Approved (Y/N)	Circle 'Y' if monitoring point details have been formally approved by the Environment Agency. *Date should be date of formal approval.*	-

Additional Fields on Table A1.1b (Borehole Multiple Record)

Field	Description (with explanatory text)	Examples
Drop Tube Information (if any): (Leave fields blank if none)		
Tubing Material	Type of lining material used. *Use code or description.*	*Nylon, uPVC, HDPE*
Tubing Dia (mm)	Internal diameter of sample tubing expressed in mm.	*6*
Depth to Base of Tubing (mbgl)	Depth to base of drop tube recorded as depth below ground level.	*8.57*

Table A1.1a Example borehole construction record sheet

Borehole Construction Record		Borehole Reference Number:
Site Name:	Environment Agency Permit Number:	
Site Operator:	No of Mon Points in Borehole:	Sheet __ of ___

Group ID References

Multi Ref	Cluster Ref	Cell Ref	Area Ref

Monitoring Point ID Information

Vertical Sequence (from top)	Mon. Point Ref No	EA WIMS Ref No	Mon Type	Mon Use	Strata	Details on Sheet No.
1.						1
2.						
3.						
4.						
5.						
6.						
7.						

Construction Record

SI BH Ref:	Hole dia (mm)	Hole depth (mbgl)
Date completed:	Contractor:	Supervisor:
Construction method:		

Ground Survey at Time of Construction

Surveyor:	Ground Elevation (mAOD):
Easting (m)	Northing (m)
Datum point description:	
Height of datum (magl)	Datum elevation (mAOD)

Lining Completion Record (use continuation sheet for multiple monitoring points in a single borehole)

Lining material	Lining dia (mm)	Depth to base of lining (mbgl)	Top of lining above ground level (magl)
Screen description and size	Top of screen (mbgl)	Base of screen (mbgl)	Screen length (m)
Annular filter description and size	Top of filter (mbgl)	Base of filter (mbgl)	Filter length (m)
Annular seal description	Top of seal above filter (mbgl)	Base of seal above filter (mbgl)	Seal length (m)

Headworks

Headworks description	Top of headworks above ground level (magl)

Table A1.1a Example borehole construction record sheet (continued)

Dedicated Monitoring Equipment	Access and Safety
Describe equipment:	Describe special requirements for access or safety precautions:

Construction QC Checks

		Dated	Name of Competent Person	Position	Initials
Borehole Log	Y / N				
Lining Details	Y / N				
QC Check	Y / N				
EA Registered	Y / N				
EA Approved	Y / N				

Table A1.1b Multiple monitoring point details

Borehole Multiple Record Sheet		**Borehole Reference Number:**
Site Name:	Multi-Ref (if different to Borehole Reference Number):	
Site Operator:	Ground Elevation at time of construction (m.AOD):	**Sheet __ of ___**

Monitoring Point Datum Description / Identification

Vertical Sequence (from top)	Mon. Point Ref No	Datum Point Description / Identification Markings
1.		
2.		
3.		
4.		
5.		
6.		
7.		

Monitoring Point ID and Survey Information

Vertical Sequence (from top)	1	2	3	4	5	6	7
Mon. Point Ref No							
Height of Datum (magl)							
Datum Elevation (m.AOD)							

Drop Tube Information (if any)

Tubing material (description):							
Tubing dia (mm)							
Depth to base of tubing (mbgl)							

Table A1.1b Multiple monitoring point details (continued)

Lining Information (if any)

Lining material (description):							
Lining dia (mm)							
Depth to base of lining (mbgl)							
Top of lining above ground level (magl)							
Screen (description and size):							
Screen dia (mm)							
Top of screen (mbgl)							
Base of screen (mbgl)							
Screen length (m)							
Annular filter (description and size):							
Top of filter (mbgl)							
Base of filter (mbgl)							
Filter length (m)							
Annular seal (description):							
Top of seal above filter (mbgl)							
Base of seal above filter (mbgl)							
Seal length (m)							

Construction QC Checks (See Front Sheet)

A1.2 Monitoring point surveying and monitoring history record sheet for wells and boreholes

An example form is provided as Table A1.2. This form collates surveying and monitoring history information for each individual monitoring point. Where datum or positional information is updated for any reason (e.g. correction of previously estimated information, because of damage, or because of vertical extension), it is essential that proper records of these changes be maintained.

The following provides descriptions of information and examples applicable to each heading.

Heading information

Field	Description (with explanatory text)	Examples
Sheet __ of __	Sequential sheet number for individual monitoring point.	*1 of 3*
Mon Point Ref	Monitoring point reference number. *This should be an alphanumeric number unique at a particular site (avoid use of the characters: *, /, \, -, _, brackets and spaces).*	*BH1, GW1, L1*
EA WIMS Ref No	Reference number of monitoring point on Environment Agency database (if available).	*19373a01*
Site Name	Name of landfill site. It is preferable to use the name stated on the permit unless some other name is commonly used	*Mountain Top Landfill Site*
Site Operator	The named permit holder and or landfill operator.	*ABC Landfill Co.*
Environment Agency Permit Number	Permit or Licence Reference Number.	*WCC 123456*

Reference elevations from original construction logs

See Tables A1.1a and A1.1b for description of each detail. All details can be converted to mAOD using figures provided in Tables A1.1a and A1.1b. Subtract each detail expressed as mbgl from 'Ground Elevation' to record mAOD values.

Surveying records

Field	Description (with explanatory text)	Examples
Date of Datum Change	Date from which changes in survey details should be used. Since a survey may be carried out some time after this change has occurred, it may mean some water level records have to be amended back to this date.	*2/1/01*
Date of Survey	Date when ground survey was carried out.	*15/2/01*
Surveyed by	Name of company and competent person responsible for survey.	*YZ Surveyors, CD Jones*
National Grid Reference – Prefix	100 km Ordnance Survey Prefix	*SO*
National Grid Reference – Eastings and Northings	12-figure OS grid reference *Surveyed to at least 1 m accuracy. The first number of the easting and northing are the 100 km grid. A full 12-figure reference is essential to incorporate information reliably into GIS mapping systems.*	*12-figure grid reference for Worcester City Centre:* *385000 255000* *Using the 100 km prefix, this can also be expressed as:* *SO 85000 55000*
National Grid Reference – Status	Code indicating reliability of positional survey.	*S (Surveyed)* *GPS (GPS record)* *E (Estimated from OS Plan)* *U (Unknown)*
Datum Point Details – Description	Simple description of datum point used for water level measurements.	*Top of external casing* *Top of internal lining*
Datum Point Details – Elevation (mAOD)	Surveyed elevation of datum point. *Expressed as metres above Ordnance Datum.*	*95.42*
Datum Point Details – Relative to GL (magl)	Difference in height between datum point and ground elevation. *Expressed as metres above ground level. A '+' or '−' symbol should be included to indicate height above (+) or below (−) ground level.*	*+ 0.35, −0.07*
Datum Point Details – Ground Elevation (mAOD)	Ground elevation. *Expressed as metres above Ordnance Datum.*	*95.07*
Datum Point Details – Status	Code indicating reliability of level survey.	*S (Surveyed)* *E (Estimated)* *U (Unknown)*
Base of Lining (mbd and mbgl)	Depth to base of internal lining (or base of unlined borehole). *Recorded from dip measurements taken after the datum point has changed. Expressed as metres below new ground level and metres below new datum point.*	*18.67*
Initials	Initials of competent person responsible for updating information.	*AB Jones*

Depth changes arising from change in datum point

See Table A1.1 for descriptive details. The first record line should be for records taken from the original borehole log. Other lines are for when the datum level has changed. It is important to know depths when undertaking sampling programmes. The most recent figures from this table can be used for updating the Site Monitoring Point Register (Table A1.3).

The 'Date of Datum Change' is taken from the Surveying Records Table (above).

Details recorded as metres below ground level (mbgl) are metres below the new ground level (if changed). This is calculated by subtracting the elevation of the detail from the ground elevation on the date of datum change.

Details recorded as metres below datum (mbd) are metres below the new datum level. This is calculated by subtracting the elevation of the detail from the datum elevation on the date of datum change.

Monitoring History

This table records significant dates relating to the collection of data for specific sets of monitoring measurements.

Monitoring History

Field	Description (with explanatory text)	Examples
First Record	Date of first monitoring measurement.	*31 July 2001*
Initial Characterisation Completed	Date when initial characterisation record completed.	*31 December 2002*
End of Baseline (if reached)	Date recording when a specific monitoring data record is last used as a baseline record. *For data unaffected by landfill operations this record will remain blank. For leachate data this field will remain blank.*	*31 December 2035*
No of Baseline Data Records	Total number of data records throughout baseline period. *Leave blank unless baseline is completed.*	*16,250*
Last Record (if disused)	Date of last monitoring record. *This field should be filled-in for points that are no longer monitored for whatever reason.*	*3 September 2004*
Comments	Any significant comments relating to monitoring history. *This could include the reference number of a new monitoring point that may have replaced this one, or some significant influence on monitoring data.*	*Monitoring point replaced by GW99* *Water chemistry affected by road salting* *Groundwater level affected by dewatering from adjacent quarry in 1999 and 2000.*

A1.2 Example monitoring point surveying and monitoring history record

Monitoring Point Surveying and Monitoring History		**Sheet ___ of ___**
Site Name:	Environment Agency Permit Number:	Monitoring Point Ref:
Site Operator:		EA WIMS Ref. Number:

Reference Elevations (from original construction logs and ground survey at the time of construction)

			Response Zone					
Date	Base of Borehole mAOD	Base of Filter mAOD	Base of Liner mAOD	Base of Screen mAOD	Top of Screen mAOD	Top of Filter mAOD	Top of Seal mAOD	Inits

Surveying Records

Date of Datum Change	Date of Survey	Surveyed by	National Grid Reference				Description	Datum Point Details				Base of Lining		Inits
			Prefix	Easting (6-figs)	Northing (6-figs)	Status		Elevation	Relative to GL	Ground Elevation	Status	From new dip measurements		
				m.	m.			mAOD	magl	mAOD		mbd	mbgl	
Original:														

Depth changes arising from change in datum point

Date of Datum Change	*Base of Borehole*		*Base of Filter*		*Base of Liner*		*Base of Screen*		*Top of Screen*		*Top of Filter*		*Top of Seal*		*Inits*
	mbgl	*mbd*	*mbgl*	*mbd*	*mbgl*	*mbd*	*mbgl*	*mbd*	*mbgl*	*mbd*	*mbgl*	*mbd*	*mbgl*	*mbd*	
Original:															

Monitoring History

Monitoring Measurements	*First Record*	*Initial Characterisation Completed*	*End of Baseline (if reached)*	*No of Baseline Data Records*	*Last Record (if disused)*	*Comments*
Water levels						
Water quality						
Gas						

A1.3 Monitoring point register for wells and boreholes

An example form that summarises the main information required on a monitoring point register is provided as Table A1.3. This information can be extracted from individual monitoring point forms such as Tables A1.1 and A1.2, which should contain more specific detail for each monitoring point. The following provides descriptions of information and examples applicable to each heading.

Heading information

Field	Description (with explanatory text)	Examples
Page __ of __	Sequential page number for each register	*1 of 3*
Site Name	Name of landfill site. *It is preferable to use the name stated on the permit unless some other name is commonly used.*	*Mountain Top Landfill Site*
Site Operator	The named permit holder and/or landfill operator.	*ABC Landfill Co.*
Environment Agency Permit Number	Permit or Licence Reference Number.	*WCC 123456*
Mon Point Ref:	Monitoring point reference number. *This should be an alphanumeric number unique at a particular site (avoid use of the characters: *, /, \, -, _, brackets and spaces).*	*BH1, GW1, L1.*
Register Revision Number	Sequential number for updated registers.	*Rev 1, Rev 2, Rev 3.*

Data Requirements

Field	Description (with explanatory text)	Examples
Mon Point Ref:	Monitoring point reference number. *This should be an alphanumeric number unique at a particular site (avoid use of the characters: *, /, \, -, _, brackets and spaces).*	*GW1, L1*
Access & Safety (Note)	Footnote number describing any exceptional access or safety awareness details. *Leave blank otherwise.*	*1, 2, 3*
Multi Ref	Multiple monitoring point reference number. *The same reference number is used to link more than one monitoring installation within a single borehole or built structure. (Leave blank if not applicable.)*	*BH1*
Cluster Ref	Cluster reference number. *A reference number used to group together a number of boreholes or wells drilled close together to monitor different vertical intervals. (Leave blank if not applicable.)*	*CL1*
Cell Ref	Landfill cell reference number. *A reference number used to group together a number of monitoring points within a single hydraulically separate landfill cell. (Leave blank if not applicable.)*	*Cell 1*
Mon Use	Purpose of monitoring points. *(Leachate, groundwater, gas, or some combination of these.)*	*G (Gas monitoring only)* *GW (Groundwater only)* *GGW (Combined gas and groundwater monitoring)* *L (Leachate monitoring)* *GL (Combined gas and leachate monitoring)*
Mon Type	Type of monitoring installation.	*LS (Long-screened borehole)* *Pz (Piezometer or short-screened borehole)* *C (Concrete ring)*
National Grid Reference – Prefix	100km Ordnance Survey Prefix	*SO*
National Grid Reference – Eastings and Northings	12-figure OS grid reference. *Surveyed to at least 1 m accuracy. The first number of the easting and northing are the 100 km grid. A full 12-figure reference is essential to incorporate information reliably into GIS mapping systems.*	*12-figure grid reference for Worcester City Centre:* *385000 255000* *Using the 100 km prefix, this can also be expressed as:* *SO 85000 55000*
National Grid Reference – S	Status code indicating reliability of positional survey.	*S (Surveyed)* *GPS (GPS record)* *E (Estimated from OS Plan)* *U (Unknown)*

Data Requirements (continued)

Field	Description (with explanatory text)	Examples
Datum Point Details – Description	Simple description of datum point used for water level measurements.	*Top of external casing* *Top of internal lining*
Datum Point Details – Elevation (mAOD)	Surveyed elevation of datum point. *Expressed as metres above Ordnance Datum.*	*95.42*
Datum Point Details – S	Code indicating reliability of level survey.	*S (Surveyed)* *E (Estimated)* *U (Unknown)*
Datum Point Details – Relative to GL (magl)	Difference in height between datum point and ground elevation. *Expressed as metres above Ordnance Datum.*	*+ 0.35, −0.07*
Depth of lining – From BH Log	Depth to base of internal lining (or base of unlined borehole). *Recorded from original borehole log. Expressed as metres below new ground level and metres below new datum point.*	*15.67*
Depth of Lining – From Dip	Depth to base of internal lining (or base of unlined borehole). *Recorded from most recent dip measurement expressed in metres below ground level. Any significant difference between this measurement and the borehole log should be explained as a footnote.*	*15.67*
Lining ID	Internal diameter of borehole lining. *Expressed in mm.*	*50*
Screen – Top	Depth to top of screened interval. *Expressed in metres below ground level.*	*12.36*
Screen – Base	Depth to base of screened interval. *Expressed in metres below ground level.*	*15.36*
Response Zone	Name of zone being monitored.	*WB Base of waste* *WP Perched level in waste* *GP Perched groundwater* *GR Regional groundwater* *AQ1 Aquifer 1 (Chalk)*
Access and Safety Notes:	Footnotes that describe any exceptional access or safety requirements for monitoring specific boreholes. *Numbers correspond to those under 'Access & Safety' column.*	*1. Walking access only over fence and 100 m into field* *2. Strong venting of landfill gas* *3. Awkward height for sampling* *4. Gas protective masks and goggles needed*

QC checks

Field	Description (with explanatory text)	Examples
Compiled by:	Name of person responsible for updating register.	*JJ Jones*
Checked by:	Name of person responsible for quality control or managing of monitoring programmes.	*SS Smith*
Position:	Position of named person.	*Monitoring manager* *External consultant or contractor* *(xyz Company Ltd)*
Dated:	Date register completed.	*31 July 2001*

A1.4 Monitoring point register for surface waters

An example form is provided as Table A1.4. Information requirements different to those on Table A1.3, with applicable examples, are given below.

Data requirements

Field	Description (with explanatory text)	Examples
Water/leachate body	Name identifying water or leachate body being monitored.	*River Thames* *Northern ditch* *Pond A* *Leachate storage lagoon 1*
Area Ref	Name or code used to group monitoring points geographically.	*N (Northern site catchment)* *SWP (South-western boundary)*
Mon Use	Purpose of monitoring points. *Either leachate or surface water.*	*SW (Surface waters)* *LCH (Leachate)*
Mon Type	Type of monitoring installation.	*FS (Flowing water course)* *Dr (Field drain discharge)* *Spr (Spring)* *Pd (Sample from pond or lagoon surface)*
Description of Monitoring Point Location	Exact location for sampling. *Refer to plan or photo if necessary.*	*10 m upstream of discharge (access ramp on north side)* *Inflow to manhole 2 (see plan ABC/123)*

Table A1.3 Example monitoring point register for Boreholes and wells

Monitoring Point Register (Boreholes and Wells)														Page _ of _					
Site Name						Environment Agency Permit Number:								Register Revision Number:					
Site Operator:																			
Mon Point Ref	Access & Safety (Note)	Multi Ref	Cluster /Cell Ref	Mon Use	Mon Type	National Grid Reference				Datum Point Details				Depth of Lining		Lining ID	Screen		Strata
						Prefix	Easting (6-figs)	Northing (6-figs)	S	Description	Elevation	S	Relative e to GL	From BH Log	From Dip		Top	Base	
							m	m			mAOD		magl	mbgl	mbgl	mm	mbgl	mbgl	
Access and Safety Notes: 1.										Compiled by:			Position:			Dated:			
										Checked by:			Position:			Dated:			

Table A1.4 Example monitoring point register for surface water monitoring points

Monitoring Point Register (Surface Waters)														Page _ of _
Site Name					Environment Agency Permit Number:									Register Revision Number:
Site Operator:														
Mon Point Ref	Access & Safety (Note)	Water/leachate body	Area Ref	Mon Use	Mon Type	National Grid Reference				Datum Point Details				Description of Monitoring Point Location
						Prefix	Easting (6-figs)	Northing (6-figs)	S	Description	Elevation	S	Relative to GL	
							m	m			mAOD		magl	

Access and Safety Notes:
1.

Compiled by: Position: Dated:

Checked by: Position: Dated:

Appendix 2:

Datum point identification and measurement

A2.1 Introduction

To express water level measurements to an accuracy of 1cm requires that a datum point be established on or near to each monitoring point. Ground level should not normally be used as a datum point unless this is a hard fixed surface with a distinguishing point of measurement. In general, a datum point should be:

- clearly identified in documentation and unambiguously distinguishable on the monitoring point
  e.g. the top of the internal lining of a borehole or the top of external headworks.
- surveyed by a competent person on final completion of the installation to a minimum accuracy of 0.5cm and expressed in units of metres relative to Ordnance Datum level.

A2.2 Surface water datum points

Where measurements of surface water level are taken, the datum point should be either:

- an identifiable feature adjacent to the water body from which local levels can be resurveyed subsequently;
- an identifiable feature above the water body from which taped measurements can be taken;
- a fixed level board or other identifiable scaled feature within the water body.

A2.3 Datum points for built leachate monitoring points

For monitoring points that are raised with the landfill, a permanent datum point cannot be fixed accurately until the structure is completed. This requires the use of temporary datum points and careful record keeping of structural changes.

A temporary datum point can be fixed at the base of the structure and then estimated by maintaining a record of the height of each raised section added. Alternatively, the base itself can be used as a temporary datum point. However, both situations can easily lead to erroneous results. For example:

- Silt or other obstructions may block the base of the structure. (In this case any leachate-level measurements that use the base as a datum would be recorded artificially low.)
- The number and height of raised sections of the monitoring point can be misrecorded easily.
- Built structures may become inclined during construction through waste, which requires corrections to be made for the degree of inclination; these are unlikely to be sufficiently accurate.

The consequences of underestimating the datum level are to record water levels lower than their true value. Conversely, any overestimate of datum level results in water levels being recorded higher than they should be.

In the absence of a surveyed datum level, the potential for error can be minimised by confirming the depth to base of a built structure each time there is a change in datum. Where siltation of the base has occurred or where the monitoring point has become blocked for any reason, this check is not always satisfactory. An improvement in maintaining an accurate record of datum levels for built structures is possible by keeping clear records (see Table A1.2).

In summary, the following guidance is offered:

- The foundation of all monitoring points should be surveyed prior to commencement of infilling around the structure and expressed in metres above ordnance datum to an accuracy of 0.5 cm. This has the added benefit of confirming the base elevation of the structure in relation to the level of the site base, which is necessary for leachate-level control.
- The top of each raised monitoring point should be surveyed at least annually during its construction and expressed in metres above Ordnance Datum to an accuracy of 0.5 cm.
- Whenever there is a change in datum level, the depth of the structure should also be measured for comparison to the original surveyed base level. If any major discrepancies suggest the base may have become blocked, contingency actions may be necessary to reinstate the monitoring point. In these circumstances it is advisable to survey the datum level of the monitoring point accurately to confirm the need or otherwise for contingency measures.
- Where leachate levels are reported within databases or on paper records, the status of the datum point level measurement should be recorded as 'Estimated', unless the datum point has been surveyed accurately (see, for example, Table A8.4).

A2.4 Datum points for groundwater monitoring points

Most groundwater boreholes, once completed and surveyed, should not undergo any significant movement. However, there will be occasions when datum points are moved – for example through damage or the need to extend pipework vertically to accommodate re-profiling of surrounding land.

It is important to keep track of datum level changes for boreholes for the same reasons as those outlined above for built leachate-monitoring points. In particular, the final two points are re-iterated:

- Whenever there is a change in datum level, the depth of the structure should also be measured for comparison to the original surveyed base level. For any major discrepancies that suggest blockage of the screened interval, the datum level should be resurveyed as soon as possible.
- Where water levels are reported within databases or on paper records, the status of the datum point level measurement should be recorded as 'estimated' unless it has been surveyed accurately (see, for example, Table A8.4).

Appendix 3:

Leachate monitoring points during landfilling

A3.1 Types of built leachate monitoring points

Built leachate monitoring points are structures that are raised progressively above a foundation within the landfill body at the same time as waste is landfilled. Examples of two different design concepts are presented in the main guidance document as Figures 8.1 and 8.2.

The design of these structures is very varied within the industry, but can be categorised into three main types.

- Stacked ring structures.
  Typically 330 mm to 1 m diameter thermoplastic or concrete rings. Variations include the provision of smaller diameter internal thermoplastic pipeworks, which are either added and raised simultaneously within the larger diameter rings or installed in entirety on completion.
- Telescopic or jointed pipe structures
  These are thermoplastic pipe lining systems, typically 300 mm to 600 mm diameter. Proprietary telescopic systems consist of 3 m pipes extendable on slip joints to a total length of 4–5 m. Additional sections are attached using couplings.
- Welded structures
  These are not so commonly used, but typically consist of 6 m lengths of 300 mm steel pipework welded together as the landfill is raised.

A3.2 Construction quality assurance and monitoring objectives

All structures built within a landfill to be used for monitoring purposes should be based on the following minimum construction quality assurance (CQA) and design requirements.

- The objectives of the monitoring point should be stated clearly in advance of construction, and its design tailored to meet these objectives.
- CQA procedures should be adopted to document the design, construction and maintenance of the monitoring point.
- The possibility of failure of a number of built monitoring points should be considered.

It may be appropriate to allow for the construction of additional monitoring points to cover this possibility. A feasibility assessment for retro-fitting monitoring structures should be provided.

- The completion details for headworks should accommodate the needs of monitoring personnel.

It is common for built monitoring structures to have multiple uses (e.g. leachate and gas extraction). In designing headworks, due consideration should be given for safe access for monitoring personnel, including allowance for the use of any designated monitoring equipment.

A3.3 Construction design features

Key design features include the following.

- Foundations
  i.e. foundation design and structural support needed to support weight and avoid puncturing the landfill lining system.
- Structure
  i.e. materials and features required to maintain verticality and prevent collapse or damage.
- Means of leachate entry
  i.e. selection of appropriate location and type of openings to meet the monitoring objectives.
- Headworks design
  i.e. allowing safe access for monitoring, and facilities to carry out the monitoring specified in the objectives.

An illustration of good practice for the design of stacked and telescopic structures is provided in Figure A3.1 with comment in the following sections.

A3.4 Foundations

Foundations are needed to adequately support the weight (including settlement pressure) of any built structure, to maintain verticality and to avoid damage to underlying materials. Two circumstances arise.

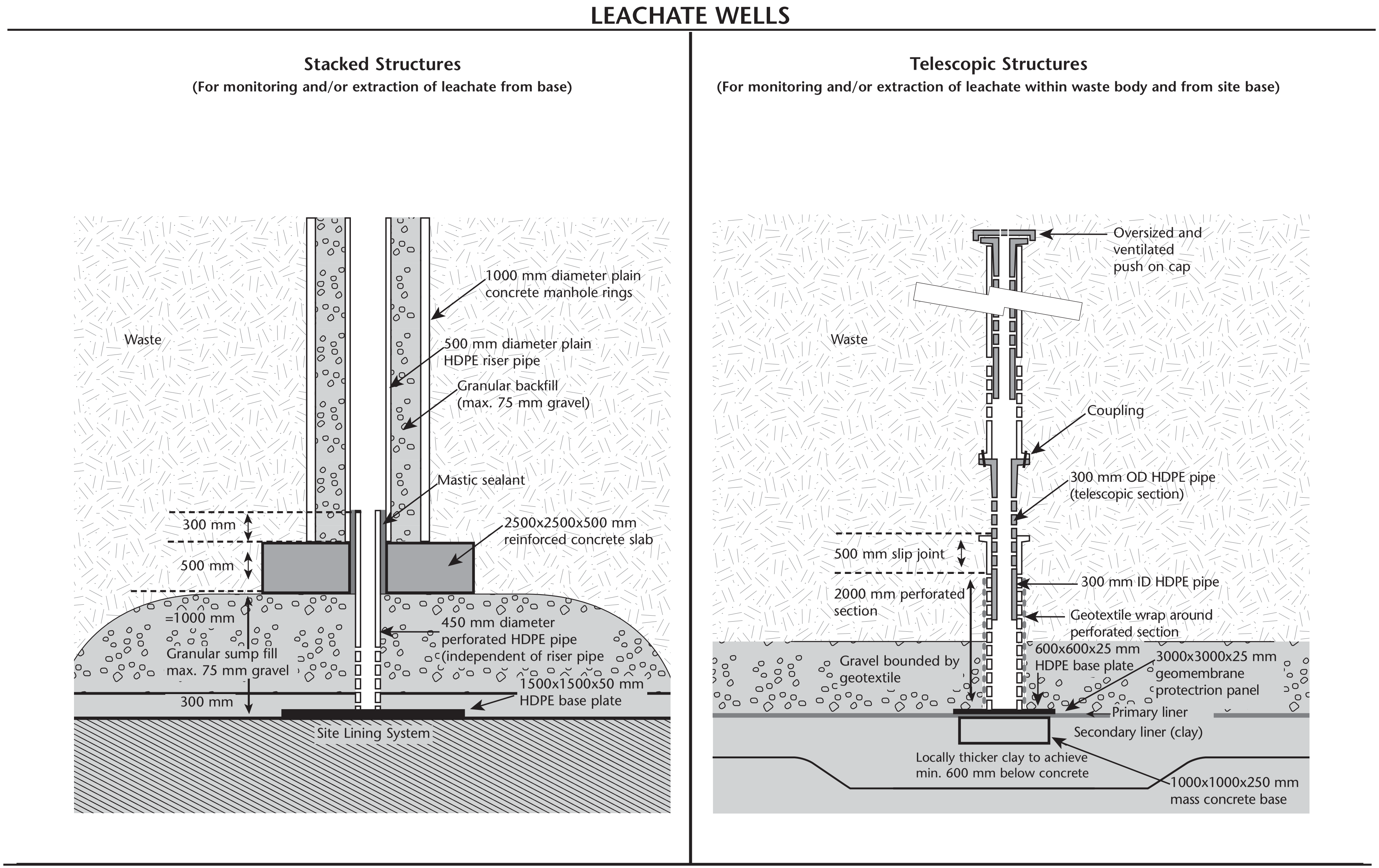
- Structures sited directly on the site base.
  A level, load-bearing foundation is required.
- Structures sited at higher levels within waste.
  Less stringent engineering measures may be acceptable, depending on the depth of waste below the structure and the ultimate height of the structure.

In all cases, engineering calculations should be provided to confirm the load-bearing capability of the structure and its long-term stability.

One type of basal foundation is illustrated for a stacked leachate well in Figure A3.1. This shows a reinforced concrete foundation slab set above a 1 m granular base, which acts to spread the load of the main stacked section over a wider area and allows monitoring of leachate at the base of the site. This could be part of, or separate to, a basal drainage layer. The basal section of the leachate well incorporates a basal slip-jointed section to allow vertical movement of the structure and to minimise the total weight resting on the basal liner.

A more conventional concrete slab foundation is shown in the Figure A3.1 for a telescopic liner. The use of telescopic pipework can significantly reduce the downward force on a foundation.

Figure A3.1 Examples designs for built leachate wells



All details and dimensions are for example purpose only. Actual details should be designed and certified by a competent person.

A3.5 Structure

A3.5.1 Maintaining verticality during construction

Maintaining verticality in built structures is one of the more difficult practical problems associated with all types of built leachate-monitoring structures. Particular problems arise when pipes have to be extended to large depths (e.g. greater than 20°m) or where pipework emerges through temporary side walls or terraces.

The chances of pipework remaining vertical can be increased by:

- using a secure coupling method to ensure successive sections of pipework are fixed vertically and will not slip laterally;
- using a means to measure and maintain verticality of newly installed sections;
- installing within a protective outer liner to prevent disturbance by machinery;

After installation, verticality is maintained by design features that minimise shear and settlement, as described in the following section.

A3.5.2 Preventing shear and settlement damage

To reduce the potential for damage through settlement and lateral movements of waste, structures ideally need to be protected externally in two ways:

- Protection from the downward force of waste settlement.
  Achieved by the use of a smooth outer surface (collar couplings should be avoided), and by the use of a slip medium, generally a loosely compacted granular material immediately surrounding the stacked or telescopic pipework.
- Protection from lateral movements.
  Achieved by the use of a well-compacted granular material or other strong material surrounding the slip medium.

Constructing these two concentric layers in granular materials is generally impractical on most landfill sites. Many operators overcome this difficulty by using a sacrificial outer liner (e.g. concrete ring) with a granular material used to infill the annular space between this and the main riser pipe (Figure A3.1).

A3.5.3 Lining materials

Lining materials need to be able to cope with significant lateral stress caused by waste movement, the chemistry of the leachate and, sometimes, high temperatures. (Biodegrading domestic wastes can produce temperatures in excess of 30°C. Fires in landfill sites do occasionally occur.) These issues should be the prime consideration in selecting materials.

Lining materials in use include:

- Concrete rings
  Concrete must be designed to take account of leachate quality (some leachate may be of low pH and high in sulphate and chloride, all of which are aggressive to cement), of weight of overlying rings in the finished structure, and of the need for holes/porous sections (which are structurally weaker) to allow leachate ingress.
- Plastics
  Polypropylene, high and medium density polyethylene (HDPE and MDPE) and poly-vinyl chloride (PVC) have all been used with success. Pipe should be flush jointed or telescopic, of a grade suitable to withstand collapse pressure, lateral movement and weight of overlying sections in the finished structure. The likely temperature range should also be considered.
- Steel
  Usually meets strength requirements, but consideration needs to be given to possible corrosion problems, depending on the leachate quality.

A3.6 Means of leachate entry

A3.6.1 Size and type of granular surround materials

Granular material in landfill sites, particular drainage media, needs to be sized to minimise biofouling. In practice, larger gravel sizes have been found to be preferable for this purpose. Typical sizes in use include:

- 18–32 mm diameter;
- 16–40 mm diameter;
- 40 mm diameter.

Non-calcareous materials are often specified for granular layers, because of the possibility of dissolution of calcite in acidic leachate, followed by long-term precipitation in pores or pipe openings in the drainage system.

A3.6.2 Size and distribution of openings

The size and position of openings or machined slots in external and internal linings should be determined in relation to the objectives of the monitoring point.

- For built structures to be utilised for gas extraction. *Openings may be required throughout the majority of the length to maximise gas collection.*
- For built structures to be utilised for leachate dewatering. *Openings are probably required at the base (particularly if a drainage layer is present) and may be required higher in the waste.*
- For built structures intended to record the level of leachate at the base of the site. *Openings may only be necessary in the lower part of the structure.*

The size of openings should be less than the size of surrounding granular material, but not so small as to be easily blocked by biofouling or solid materials. Opening sizes vary according to the practical experience of different operators. Some reported sizes and spacings for concrete rings are:

- 0.5 cm diameter holes, four to six holes per circumference, spaced 10 cm to 35 cm vertically.
- 3 cm diameter holes, spaced every 25 cm around the circumference and 50 cm vertically.

Internal linings can include holed pipework or machine-slotted pipework, which typically range in size from 1 mm to 5 mm slot size. Some operators prefer to use drilled holes similar to those in external concrete rings to minimise clogging or biofouling.

A3.7 Headworks design considerations

Structures built through landfill sites often have multiple uses, which can lead to conflicting requirements. These dictate the complexity of the headworks design, such as:

- If used for gas extraction, it is important to provide an air-tight seal to avoid drawing oxygen from the atmosphere into the system when under suction.
- To control leachate levels, a pump may need to be temporarily or permanently installed.
- For gas monitoring, gas taps are needed.
- For measuring leachate levels with conventional dip meters an access port is needed. Measurements may need to be taken when both gas suction is off (i.e. an isolating valve needs to be accessible) and the leachate pump is not operating.
- For measuring leachate levels, a procedure is needed to establish and record measurement datum each time a new section is installed; see Appendix 2 (Section A2.3).

Appendix 4:

Borehole drilling methods

A4.1 Introduction

Borehole drilling methods are reviewed within the following Environment Agency Research and Development Document:

Environment Agency (2000). Groundwater and contaminated land project: technical aspects of site characterisation. R&D Technical Report HOCO 373. Environment Agency, Bristol.

The above document is presented in four volumes, of which Volume 2 includes a series of technical sheets on drilling methods.

Other details are drawn from a variety of sources, including the Site Investigation Steering Group (1993) and Blakey *et al*. (1997).

A4.2 Design issues

A4.2.1 Drilling close to or into the base of a landfill

When drilling to the base of any landfill site a decision needs to be taken whether or not it is safe to drill to the base of waste to provide a good leachate monitoring point. This is clearly not a sensible option if the elevation of the base is not known exactly and consists of, for example, an artificial liner of limited thickness.

In sites that are underlain by a significant thickness of natural low permeability material it may be possible to drill a short distance into this layer with the agreement of the Environment Agency. This needs to be assessed on a site-specific basis in relation to risk. Where risks are unacceptable or insufficiently defined, drilling through the base should be avoided.

To avoid puncture, boreholes should not normally be drilled into waste any closer than 3 m above the site base unless precise survey information is available and borehole drilling depths can be controlled carefully and certified by independent supervision. In all cases ground elevations and position should be confirmed before and after drilling. The competent person responsible for specification of the drilling contract should ensure that the liabilities and contingency measures to be adopted in the event of puncturing the site base are clearly established in advance of drilling works.

If the basal lining (natural or engineered) of a site is accidentally punctured during drilling this should be reported immediately to the Environment Agency and contingency measures implemented to seal the base of the hole to minimise leachate leakage. Additional assessment monitoring and remediation measures may need to be initiated as a result of such incidents.

A4.2.2 Precautions to avoid borehole collapse during drilling in waste

The specification for construction of a leachate monitoring point should include the depth to the base of installed lining within the drilled borehole. The contractor should be made aware of this specification in advance of tendering for the work so that appropriate drilling techniques can be used to ensure that the depth specified is achievable and can be certified by measurement by the person responsible for supervision of the contract.

When drilling in waste, particularly below leachate level, the side walls of the drilled hole may become unstable and collapse. In these instances, either temporary casing (or possibly drilling fluid) may be needed to support the side walls during drilling to allow lining to be installed into a clean open hole on completion. While it may be possible to install a lining below leachate level without the need for temporary casing, the possibility of collapse should be considered, particularly if there is no history of drilling for the site. Where collapse occurs in unlined boreholes, it may be necessary to over-deepen the borehole to achieve the specified lining depths. Where there is doubt as to the likely success of open hole drilling methods, back-up procedures should be specified clearly to provide formation support in the event that lining depths are not achieved.

Drilling methodologies capable of utilising temporary casing include:

- cable tool percussion ('shell and auger');
- rotary hollow stem augers;
- specialist rotary drilling systems (e.g. 'Odex' or 'SimCas'; see below).

Alternatively, the same objective can be achieved by utilising two drilling rigs. For example, a continuous flight or single flight rotary auger can be used to drill through the waste and to clear obstructions, followed by a cable tool rig to clean out and provide temporary casing to support the side walls during installation of the monitoring point lining.

A4.2.3 Selecting depth and diameter of boreholes in waste

Before specifying a drilling methodology for waste, a clear specification of the depth and diameter of the completed monitoring installation is required.

For monitoring purposes, smaller diameter installations (typically between 100 mm and 300 mm) are preferred. If an annular gravel pack and surface seal are to be installed around a lining, the borehole needs to be drilled at a diameter ideally 100 mm or greater than the outside diameter of the lining material. For example, to install a 150 mm diameter lining with a gravel pack usually requires a hole diameter of 250 mm or greater. Where a gravel pack is not needed (e.g. for installations within hollow stem augers) a drilled hole slightly wider than the final lining is adequate, though this assumes that the formation will readily collapse around the final lining on withdrawal of the augers.

Some considerations in selecting a borehole and lining diameter follow.

- Larger diameter installations (over 300 mm in diameter) are not ideal as monitoring points for obtaining appropriate leachate quality samples because of the accumulation of large volumes of standing water, which may require purging before samples can be taken. They can be good monitoring points for sampling if they are pumped regularly for other reasons (e.g. for leachate level control), but in this case they would not necessarily make good leachate-level monitoring points.
- To construct boreholes capable of accommodating large diameter linings, particularly at greater depths, requires the use of very large drilling or piling rigs. Such equipment can be costly and problematical to employ on landfills. Drilling at any diameter below 25-30 m depth in waste is particularly difficult.
- Installations smaller than 100 mm diameter can be utilised for monitoring in waste, though these are probably only suitable in relatively shallow sites (probably no greater than 10 m depth) where they are less likely to be damaged by waste movement. Linings of 100 mm diameter or larger usually have greater strength to resist lateral forces exerted by settlement and lateral movements of waste.
- If monitoring points are also to be used for dewatering or for gas extraction they need to be of sufficient diameter to accommodate pumps (dewatering pumps typically require a minimum hole diameter of 100 mm). The optimum lining diameter for leachate monitoring and control purposes is probably 125–150 mm.

A4.2.4 Selecting depth and diameter of boreholes in natural ground

It should not be assumed that boreholes should simply be drilled to a depth governed by the depth of waste in the adjacent landfill or any other rule of thumb. The depth of drilling should be specified in the light of an understanding of the hydrogeological conditions and physical characteristics of the underlying strata. Every site setting is unique. A competent professional should undertake specification of drilling depths for groundwater-monitoring boreholes.

The depth of drilling should take account of factors accumulated and assessed from prior site investigation, which include the following.

- Knowledge of the depth and lateral extent of the groundwater system to be monitored. If this lies below perched or other groundwater systems, steps need to be taken to ensure a seal is maintained between the systems, both during drilling and following installation of the monitoring point.
- Knowledge of the likely depth and seasonal variation in the water table in unconfined groundwater systems. Normally, drilling should continue below the lowest level of seasonal water table variation, to a depth sufficient to allow adequate purging and sampling.
- Knowledge of the most likely depth of contamination arising from the landfill site. This

will vary, depending on factors such as where exactly contamination enters the groundwater system, how far down-gradient of the site the monitoring point is located and the hydraulic characteristics of the groundwater system. For example, in a flood plain a component of groundwater movement will be vertically upwards, the result of discharges to surface water, so that monitoring points can probably be designed to relatively shallow depths. Conversely, a landfill on a hill top may require deeper monitoring points because of the tendency for groundwater to move vertically downwards.

- Knowledge of the vertical distribution of contamination. This may require the provision of multi-level, nested or clustered boreholes.

A4.3 Drilling methods

A4.3.1 Health and safety

Waste materials are highly variable and potentially hazardous. Guidance issued by the Institute of Civil Engineers Site Investigation Steering Group (1993) for safe drilling in wastes should be followed. Most landfills are designated as high- or medium-risk drilling environments (category 'red' or 'yellow'); contracts with drilling companies should make proper allowance for the necessary procedures and equipment needed to complete works safely.

Drilling of monitoring boreholes adjacent to landfill sites can be equally hazardous as a result of gas or leachate migration. Special precautions may need to be taken to ensure the safety of drilling personnel.

A4.3.2 Drilling in waste

The most commonly used conventional drilling methods are:

- continuous flight augers;
- single flight augers;
- hollow stem augers;
- cable percussion (shell and auger);
- large diameter single-tube barrel.

The danger of bringing contamination in the flushing medium in contact with personnel at ground surface means that the use of conventional rotary drilling rigs in waste is not recommended (Site Investigation Steering Group, 1993). The use of air as a flushing medium in waste is particularly hazardous and should be avoided, unless the dispersion of air can be fully controlled at the well head.

Some drilling programmes have been completed successfully using more than one type of drilling rig. For example, it is possible to drill through waste using a continuous or single flight auger at 300 mm diameter. A percussion rig can then be used to clean out and support the hole using 250 mm diameter tools and a temporary casing. A 150 mm diameter lining can then be installed. This type of method has been used successfully for installations up to 30 m deep.

A4.3.3 Drilling natural ground

The choice of drilling method and equipment employed should be made on a site-specific basis while considering the following:

- depth and diameter of drilling required and likely depth of first water strike;
- ability to penetrate the formations anticipated;
- degree of contamination anticipated;
- ability to obtain samples and identify different formations;
- ability to identify groundwater inflows;
- extent of disturbance to ground materials during drilling;
- impact of drilling technique on groundwater quality;
- ability to undertake in-situ testing and to install monitoring equipment.

The most commonly used drilling methods are:

- conventional rotary drilling;
- cable percussion (shell and auger);
- augers (hollow stem, continuous flight or single flight).

A summary of advantages and disadvantages of conventional drilling methods is presented in Table A4.1 and a brief description of each and their suitability for monitoring well installation is given in the following sections.

Table A4.1 Advantages and disadvantages of drilling methods for monitoring borehole installations.

Drilling method	Advantages	Disadvantages
Cable tool	• inexpensive • easily cleaned • easy to identify lithological changes and water strikes • bulk and undisturbed ('U100') samples possible •minimum use of drilling fluids • use of temporary casing allows accurate installation of lining and annular fill	• slow • cannot penetrate hard rock • can smear sides of borehole
Rotary auger	• rapid • inexpensive • easily cleaned • hollow stem augers allow continuous sampling in unconsolidated materials • lining can be installed directly into hollow stem augers • no drilling fluids needed	• cannot penetrate hard rock • hollow stem augers cannot penetrate where cobbles or boulders are present • sampling depth and water strikes difficult to identify using solid stem augers • solid stem augers cannot be used in loose ground (hole collapses) • unable to install annular fill and seals in collapsing ground
Other rotary methods	• can be inexpensive • fast in consolidated materials • can be adapted to drill all formation types continuous samples can be cored in consolidated rock and clay	• can be expensive • fluids need to be added (e.g. air, foam, water, mud) • possible introduction of contaminants (including oil from air compressor) with circulating fluid • recovery of samples can be slow when drilling at great depths • can smear sides of borehole • synchronous casing methods in unconsolidated formations only allow installation of narrow-diameter lining

A4.3.4 Cable tool percussion boring

The percussion, cable tool or 'shell and auger' method, as it is commonly referred, is simple, versatile and relatively inexpensive. This method, as the name implies, involves the lifting and dropping of different tools to break, penetrate and remove the soil and/or rock formations encountered.

A typical site investigation rig consists of a winch, which is normally powered by a diesel engine, and an A-frame or derrick of about 6 m in height. Larger rigs designed for deeper drilling or large-diameter drilling (e.g. for pile installation) are also available. In soft formations, a temporary casing has to be driven down as the drilling proceeds to support the sides of the borehole. To achieve progress it is sometimes necessary to add water to the borehole during boring.

Temporary steel casing is usually inserted to ensure that the borehole remains stable during boring operations. This also serves to reduce cross-contamination from groundwater at different horizons.

Site investigation rigs are suitable for drilling in unconsolidated materials, including waste. In very loose materials, such as wet sand and gravel formations, drilling progress can be very slow. Obstructions such as large boulders, metallic objects, tyres and even an accumulation of filled plastic bags, which cannot be removed by chiselling, can lead to abandonment of the borehole. In these cases either a further hole has to be attempted in another location or an alternative drilling method used. In deeper holes the temporary steel casing can become jammed in the borehole, which requires the slow process of hydraulic jacking to remove it.

Larger percussion rigs are able to penetrate consolidated materials and drill at larger diameters.

A4.3.5 Solid stem continuous flight rotary auger drilling

This drilling rig comprises a drill mast normally 3–6 m high and a hydraulically powered rotating continuous flight auger. The drilling rods are helical, and are effectively screwed into the ground. The technique does not require a flushing medium such as water or air. Auger sections are usually connected by key-and-pin mechanisms and do not, therefore, require lubricants. Inclined boreholes can be drilled, subject to the nature of the formation.

Following completion of the drilling operation, the auger has to be withdrawn from the hole before lining materials can be installed. This can sometimes lead to borehole instability, particularly within saturated ground. In general, continuous flight augers are of limited use when drilling in very soft, fine-grained soils, in 'clean' granular soils and in almost all soils below the groundwater level.

Augers are commonly used in waste because of their ability to progress rapidly through ground that cable tool rigs would either take a long time to drill or become obstructed. However, shredded articles, and particularly wire, may become entangled around the augers and in some circumstances may be left bridging the borehole. This can lead to difficulties with lining installations.

It is important to note that it is nearly impossible to drill through a contaminated soil zone with a solid-stem continuous flight auger without transporting contaminants downwards.

A4.3.6 Hollow stem continuous flight rotary auger drilling

This system of drilling is very similar to the technique described above, but with the key difference that all down-hole tools are constructed around a hollow tube through which sampling, testing and placement of borehole instrumentation can be achieved. The technique does not require water- or air-flushing media, and nor do joints need to be greased. Most conventional hollow stem augers have an internal diameter of less than 125 mm, which allows lining diameters no greater than 100 mm to be installed. The drilling rods are considerably heavier than conventional rotary tools and consequently the depth of drilling is more limited.

A4.3.7 Other rotary drilling methods

Rotary drilling provides a technique that uses a variety of rock-cutting tools mounted at the end of a drill pipe of smaller dimension. The drill pipe is rotated mechanically. Cuttings can be brought to the surface by the tool itself or, more commonly, by means of a circulating fluid. This drilling technique is suitable for use in stable ground to depths in excess of 50 m, and is often the only viable drilling method when penetrating hard formations.

Generally, the circulating fluid is delivered through the drill pipe before it passes through the drill bit and then upward through the annular space between the borehole wall and the drill rod. The types of flushing media commonly employed include air, water, foam, mud, bentonite, polyacrylamide, guar and xanthan. Air and water are used most commonly for contaminated land investigations. The use of air as a flushing media when drilling in waste is not recommended by the Site Investigation Steering Group (1993), for safety reasons.

All drilling fluids will to some degree invade the formation and therefore could contaminate and interact with the surrounding formation. When air is used as the medium, the potential for chemical interaction with groundwater or leachate must be considered carefully. Large quantities of air may be introduced into the borehole (20–40 cubic metres per minute), and experience shows that air entrapment in groundwater may occur several hundreds of metres from the borehole being drilled. Furthermore, compressor oil often becomes entrained within the air stream, which can lead to temporary hydrocarbon contamination within the borehole.

With both mud and air rotary drilling, lubricants must be used on the drill pipe to make it easy to thread together and take apart during drilling. Standard lubricants should not be used because they contain petroleum hydrocarbons and heavy metals. A Teflon-based lubricant is available for use, and food-grade lubricants used on food processing machinery can also be used without presenting the potential for contaminating the borehole. At the termination of drilling each borehole, the fluid must be recovered.

Conventional rotary drilling methods are generally quicker than other methods, but require larger drilling rigs, which may not be able to gain access to all areas of a site.

A4.3.8 Other methods

There are numerous other methods used to install monitoring boreholes, particular at shallow depths. These methods must be considered both in terms of their ease of operation and their applicability to meeting information objectives. Where novel methods are used, prior consultation with the Environment Agency should take place to assess their effectiveness against the objectives of the drilling programme.

A4.4 Sources of contamination

A4.4.1 Addition of water during drilling

It is sometimes necessary and unavoidable for water to be added, either as a circulating fluid for rotary drilling or to loosen up unconsolidated materials in percussion drilling. Where water is added it must come from a source of known quality. Where critical, a sample and analysis of the added water should be provided as a reference against water samples recovered from the borehole during drilling or from monitoring installations.

A4.4.2 Decontamination of equipment

All equipment used for drilling into waste should be thoroughly cleaned at the start and on completion of works. As a basic minimum, all equipment should be washed down using a steam cleaner. Other decontamination procedures may be necessary if contact with specific hazardous substances occurs or is anticipated.

If boreholes are being drilled into uncontaminated strata, decontamination between each borehole may be necessary. This may simply consist of rinsing, pressure washing or steam-cleaning parts of the equipment used down-hole. If the rig has been used within contaminated ground, the complete recirculation system of the drill rig must be cleaned thoroughly and decontaminated before moving to the next borehole location. In some instances, quality control (QC) measures should be introduced to certify the cleanliness of the equipment. These should be reviewed in advance with the Environment Agency.

A4.4.3 Disposal of drilling materials and fluids

Borehole drilling and development can produce large quantities of water that requires disposal. Prior to disposal, silt should be removed from the water by use of a series of simple settling tanks. If chemically contaminated, advice should be sought from the Environment Agency for safe disposal prior to commencement of works.

Drill cuttings and settled solids may also be contaminated, in which case arrangements may need to be made for disposal at an appropriately licensed facility.

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Appendix 5:

Borehole completion details

A5.1 Introduction

No guidance documents in the UK provide specific details relevant to the design and installation of monitoring boreholes. Outline details for piezometer and long-screened ('standpipe') installations are described in BS5930 and other geotechnical references. Detailed guidance relevant to water-well drilling is available from texts such as Driscol (1986) and Brandon (1986). UK research on aspects of monitoring borehole design is summarised in Blakey et al. (1997; Appendix C4) and referenced in relevant sections below. More detailed manuals are available from the USA, including Aller *et al*. (1989), which specifically deals with the design and installation of monitoring boreholes.

The following appendix draws some general information from these and other sources, though for much greater detail the original documents are best consulted.

A5.2 Design considerations

A5.2.1 Use of unlined boreholes for monitoring

Boreholes drilled into competent[1] strata may, in some instances, be completed without the need for lining. Any boreholes completed as open holes require the upper section of the borehole to be sealed from ground surface by the installation of steel casing of at least 1 m length, grouted in place.

The depth of such boreholes should, however, be limited in accordance with general guidance given in this document, which requires that long-screened or open boreholes should not normally be greater than 10m deep and only used where groundwater flow is primarily horizontal.

A5.2.2 Diameter of completed installation

The internal diameter of a completed installation should be sufficient to accommodate designated monitoring equipment for sampling and water level measurements.

Most boreholes constructed for monitoring purposes are typically completed with linings that range in diameter between 19 mm and 200 mm, though some multi-level installations incorporate individual sampling lines as small as 6 mm in diameter.

For general groundwater monitoring purposes, it is recommended that the completed lining diameter should normally be between 50 mm and 200 mm. Larger diameter installations are not ideal for obtaining appropriate groundwater or leachate samples, unless they are pumped regularly or are sampled using depth samplers. Smaller diameter installations may not be ideal for combined sampling and water level measurements, and in low-yielding formations may not be capable of yielding sufficient sample volume for laboratory analysis.

Smaller diameter (less than 50 mm diameter) installations should not be dismissed, particularly since these are increasingly being developed, both for research and commercially, to enable better vertical characterisation of groundwater. However, where these are used, technical justification should be provided, including specification of monitoring objectives and the monitoring equipment to be employed.

1 That is, strata of sufficient strength to stand unsupported.

A5.2.3 Influence of well construction materials and sampling equipment on water quality of samples

The following text is paraphrased from Blakey *et al*. (1997; Appendix C4):

- Any construction material or sampling equipment that comes into contact with the water sample being collected can affect the integrity of the sample by leaching compounds into solution, by the adsorption (and subsequent desorption) of compounds from the solution, by gas diffusion through the material and also by solute transfer.
- Most studies (e.g. Baxter, 1982; Barker *et al*., 1987) have concentrated on the adsorption and subsequent desorption of volatile solvents from plastic pipework, and not the inorganic constituents of groundwater.
- The general advice when sampling for organic compounds is to use either polyethylene (PE), polypropylene or PTFE ('Teflon') tubing, which all have a hard surface, in preference to soft rubbers and plasticiser-containing plastics, which have a greater tendency to adsorb and leach volatile compounds.
- Standardisation of borehole construction and sampling techniques at any one site is desirable.

A5.3 Lining materials and screens

A5.3.1 Selection of lining material in waste

Materials used to line monitoring boreholes in waste need primarily to cope with potentially high temperatures and significant lateral stress caused by waste movement. These issues tend to override any other design concerns, such as the absorptive and/or desorptive properties of the lining material.

Suitable lining materials include HDPE and MDPE and uPVC. Other materials, such as steel and polypropylene, have also been used successfully.

A5.3.2 Selection of lining material in natural ground

For groundwater monitoring, suitable borehole linings include stainless steel, HDPE and MDPE, and uPVC. For general monitoring purposes, uPVC and PE are practical and economical. Stainless steel or more inert plastics, such as tetrafluoroethylene (teflon or TFE) may sometimes be preferable for specific contamination studies.

Lining with flush-threaded pipe joints, which leave a smooth bore on both the inside and outside of the joined pipes, is preferable to the use of any other coupling methods. Flush threads provide smooth internal and external surfaces, which enable annular filters and seals to be installed more readily and also simplify the use of sampling equipment.

The use of solvent-based glues for attaching joints or any other use in a borehole should be avoided.

A5.3.3 Selection of borehole screens

A properly designed borehole screen serves the purpose of allowing water to flow into the borehole while minimising the amount of sediment inflow, particularly when used in conjunction with a gravel pack. Many screens can be supplied in a variety of slot sizes and may also incorporate filter wraps to reduce the size of openings. In water-well design, it is possible to relate slot size to the formation being screened to ensure that silt is removed from the formation during development of the well, to produce a clear inflow of water. Monitoring boreholes around landfills may be located in low permeability and fine-grained formations that contain proportionately greater amounts of silt and clay particles than commonly found in aquifer systems used for water abstraction. This can lead to difficulties in completely removing sediment from all samples.

Screen aperture

Screen apertures should be selected to minimise fine particles that enter the borehole and to optimise flow into the borehole at a velocity that will not cause undue turbulence.

For monitoring boreholes in very fine formations (e.g. predominantly silts or clays), it is very difficult to achieve either of these objectives. If the formation grain sizes are at or below fine sand (0.2 mm) the use of small slots (e.g. 0.25 m or 0.5 m) will do nothing to stop particle entry, but may actually increase entrance velocities and encourage entrainment. If a very small slot size is achieved (e.g. by use of a geotextile wrap), there is a risk of clogging. In these situations, the use of a filter pack (e.g. 0.5–2 mm grain size) with as wide an annulus as possible around the screen should be encouraged, rather than reducing the slot size to a point at which clogging may occur. Particular care with well development is necessary in these constructions (see Appendix 6).

For monitoring wells in sandy or coarser formations, the slot size and screen may be based on water well design principles (e.g. Driscoll, 1986; Aller *et al*., 1989).

For monitoring boreholes in waste, the selection of a screen slot size is often governed by the selection of lining material. Some plastics (e.g. HDPE) can only be cut with relatively coarse slots (typically 3 mm), while PVC can be machine-cut to 0.25 mm or smaller. Slot sizes are not so critical as in natural ground, except where the waste is composed of a significant proportion of unconsolidated material. In these cases a gravel pack or a geotextile wrap around the screen can be beneficial.

Screen length

Screen lengths should normally be no greater than 6 m and ideally shorter than this. Where it is necessary to screen strata for intervals in excess of 10 m, separate monitoring points should be provided at different vertical intervals. Where natural water-level variations are likely to exceed 10 m, the screened interval may need to be extended.

A5.4 Annular backfill

A5.4.1 Filter material

The role of a filter material is to support the formation around the screen and, in suitable strata, to provide improved hydraulic characteristics to minimise turbulent flow into a well during pumping. The filter material is typically sand or gravel. It needs to be larger than the effective slot size of the screen, but should not be excessively coarse or it will serve no filtering purpose. For example, the use of 10 mm gravel around screens provides very little filtration potential.

A gravel pack is not an essential design feature for leachate-monitoring points, but does have benefits in cushioning the lining from damage and providing a filter between the waste and the screen. Where used, the gravel pack should be larger than the slot size of the lining. For example, a HDPE screen with 3 mm slots could be packed with a 5 mm or 6 mm single-size gravel.

A5.4.2 Design issues for filter materials

Considerations for filter packs include the following:

- use a washed, rounded chemically inert sand or gravel (e.g. quartz sand);
- extend the filter pack to between 0.5 m and 2 m above the screened interval to allow for settlement;
- for installations greater than 15 m to 20 m deep, particularly below water, use a tremie pipe (e.g. 25 mm to 50 mm in diameter) to emplace sand to the depth required and avoid bridging on the side walls of the borehole;
- water may be needed to wash filter material, particularly sand, into the borehole. Use only clean water and as little as possible;
- a written record of materials added and depths to the top of each layer should be maintained and recorded with the borehole log;
- a competent person should be on site to supervise and certify the installation.

For more technical details on selection and installation of filter materials, see Aller *et al*. (1989).

A5.4.3 Annular seals and grouting

The purpose of annular seals is to isolate the screened section(s) of a monitoring borehole and to prevent contaminants entering the borehole from surface.

Typically, bentonite clay in the form of dehydrated pellets, powder or granules is placed above the filter sand for a depth of at least 1 m. In some shallow boreholes it may be economic to completely seal to ground surface with bentonite. In deeper boreholes a grout sealant is commonly used. Coated (baked) bentonite pellets can be used to delay the time of hydration of bentonite, and are particularly useful where tremie pipes are used in deeper or multiple installations.

The use of sealants in monitoring boreholes introduces a potential source of contamination, by ‘bleeding’ from the grout or bentonite into the sampling zone. Bentonite can introduce elevated sodium concentrations and fine suspended solids into groundwater. Samples from grout-contaminated wells are characterised by high pH values (usually over 10) and elevated magnesium and sulphate (derived from Portland cement). Once contaminated, it can take many years for a grout- or bentonite-contaminated borehole to lose all traces of contamination.

To reduce this risk, it is recommended that a layer of fine sand be placed above a gravel pack, which should itself extend above the top of screen (after allowing for settlement). Where sand is already used as a screen filter, it may simply be better to extend the height of the sand by a further 0.5 m.

Where cement-based grout is used, bentonite pellets should be added first for at least a depth of 1 m (and preferably for 2–3 m) above the filter material, as a barrier to vertical movement of grout during installation. It is important that the bentonite be hydrated and sealed before adding any grout.

A5.5 Multi-level monitoring installations

Completion of more than one sampling interval within the same borehole provides a number of challenges for the contractor and competent professional responsible for their design and installation. As interest develops in improving the vertical characterisation of contaminant plumes, it is likely that these types of installations will increase in usage. These types of installations should never be installed without competent supervision.

A5.5.1 Nested installations

The number of nested piezometers than can be placed in one borehole is limited by the borehole size and the size of the tubing (and any couplings) used. Installation, in theory, is similar to that described above for a single piezometer, apart from the need to set separate piezometers into the borehole. There are many practical problems in emplacing more than one structure in a borehole, which should never be attempted without competent supervision. It is recommended that no more than two nested installations be placed in a single borehole. Specific problems are:

- Reducing annulus
  As more pipes are added to a borehole the available annulus space reduces. This limits the ability to emplace the filter and sealing materials accurately, and probably excludes the use of a tremie pipe (see below).
- Settlement
  The base of each piezometer in a nested sequence needs to be embedded in filter sand above a sealed layer. Care needs to be taken to avoid each successively higher pipe settling through the underlying sealing layer.
- Excessive pipework
  Where multiple pipes are placed in a borehole in which the temporary casing has to be removed during installation, the risk of jamming or damaging the pipes during removal of the temporary casing is heightened.

A5.5.2 Multi-level installations

Multi-level or multiple-port samplers comprise a modular or continuous single lining string with access ports at specified intervals that allow a hydraulic connection to the adjacent aquifer or sampling zone. There are a number of proprietary systems available for commercial usage. All have common design features.

Ports with sample tubes

These types of devices utilise separate access tubes, which are attached to ports within a single casing string. The number of ports is determined by how many access tubes can be accommodated within the casing string. Ports are sampled via the access tubes, either by using conventional, but narrow-diameter, sampling tools or by the use of dedicated gas lift samplers and pressure transducers installed at the ports at the time of construction.

Variants on this system include the following:

- Continuous multi-channel tubing
  This is a continuous piece of lining that contains pre-formed chambers, which removes the need for separate sample tubes.
- 'Sock' samplers
  The tubes and ports are pre-formed within a continuous porous 'sock' prior to installation. The sock is filled with bentonite or other sealant after installation.

Ports with drained access devices

These types of devices differ from the above in that ports are fixed within the casing string without tubing access to surface. Each port incorporates a specially designed coupling, which locks onto a sampling device lowered into the borehole from the surface. Once the sampling device is registered against a specific port, samples are collected by opening the port and gravity-draining water into the sampling device. Level measurements are obtained using transducers located at each port.

A5.5.3 Sealing and backfilling multilevel installations

Bedrock installations – use of packers

Seals between ports on multi-level installations in unweathered and massive bedrock can be formed using packers. Packers are designed to expand into the borehole after installation – either by hydraulic or mechanical inflation from the surface, or by natural expansion of material within the packer itself. Some, but not all, packers can be deflated to enable their removal from the boreholes. The use of packers in weathered, highly fractured or poorly competent formations alone is unlikely to provide an effective seal against the borehole side wall and should be avoided.

Backfill materials can be used above packers to improve sealing.

Other installations – backfill

The use of multi-level systems in unconsolidated, fractured or weathered strata requires backfill materials to be placed into the annular space of the borehole. Accurate emplacement of materials is essential and should not be undertaken without competent supervision. In deeper boreholes (e.g. over 20 m deep), particularly where materials are placed below the water table, a tremie pipe should be used to ensure materials are placed to the correct depth. The use of fluid sealants (e.g. grout, bentonite mud, synthetic compounds) is not recommended for use where relatively short-screened intervals are sealed between sample ports, because of the inability to control the placement and expansion of material to the accuracy required.

Use of tremie pipes for backfilling

In using tremie pipes some simple precautions need to be taken:

- Size of tremie pipe
  A tremie pipe is typically formed from 1 to 3 m lengths of flush-threaded plastic pipe. The diameter of the pipe should be sufficient to cope with materials being used — typically they are 25 to 50 mm in diameter; 50 mm diameter pipes are preferable. A large funnel should be available to pour materials into the pipe from the surface. The tremie pipe should be set no nearer than 1 m above the base of the borehole annulus at any time to allow materials to settle freely through the bottom of the pipe into the borehole without clogging up the base of the tremie pipe.
- Filter material
  The filter material used to surround the ports of the multi-level installation should be greater than the slot size of the port, but otherwise as small as possible. For ports with 100 m or 250 m mesh openings, sand of between 0.5 and 1 mm in size is adequate. This should be quartz sand.
- Placement of filter material
  Sand poured into a tremie pipe needs clean water to be added to avoid blocking the pipe — particularly above water level. A steady but slow flow of water into the tremie pipe works well. The volume of material added should be recorded at all times to compare with depth measurements in the borehole. A plumb line should be used constantly to confirm depths. Time should be allowed for the sand to settle in the borehole after pouring and before adding further material.
- Sealing material
  Where tremie pipes are used it is essential to use a sealing material that will not stick to the side walls of the tremie during installation. Coated bentonite pellets are ideal for this use.
- Placement of sealing material
  Coated bentonite pellets can be added using the same tremie pipe employed for the addition of filter material. Water is not normally needed as pellets are typically granular and will fall freely under their own weight. The volume of material added should be recorded at all times to compare with depth measurements in the borehole. A plumb line should be used constantly to confirm depths. Time should be allowed for the pellets to settle in the borehole after pouring and before adding further material.

A5.6 Headworks

Headworks should be provided on all completed monitoring points to provide safe access for monitoring personnel, unobstructed access for monitoring equipment and to avoid damage from vandalism. The design of headworks also depends on any other uses for the borehole (e.g. gas or leachate extraction).

Headworks can be completed flush with, or protruding above, ground level. Whichever type of completion is selected, the completed structure should be sealed into the borehole annulus to prevent surface leakage of water into the borehole. The surrounding area at ground surface should ideally be completed with a concrete pad to shed water away from the borehole and to facilitate sampling.

Protruding headworks are easier to locate and less likely to be effected by surface drainage. Where flush-fitting headworks need to be used (e.g. at sites subject to severe vandalism, or to avoid damage from plant and machinery), borehole logs should incorporate clear descriptions of how to locate these points, particularly in vegetated areas.

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Appendix 6:

Borehole cleaning and development

A6.1 Introduction

Following installation, most boreholes require development to remove fluids added during drilling, to clean out silt and clay collected in the borehole and to correct damage caused by the drilling process. The primary objective of borehole development is to recreate as far as possible the natural conditions that surround the borehole, so samples that give an appropriate representation of water quality in the surrounding formation can be collected readily.

Borehole development (and cleaning for maintenance purposes) is often an overlooked aspect of monitoring-borehole construction, primarily because of the time and cost involved in achieving full development. A balance has to be achieved between the objective of fully developing or cleaning out a borehole and the objective of attaining an appropriate sample of groundwater (or leachate).

The text in the following section is largely paraphrased from Section 7 of Aller *et al*. (1989), which provides a comprehensive review of monitoring-borehole development.

A6.2 Factors that affect borehole development

Three primary factors influence the process of borehole development:

- Type of geological strata
  In hard consolidated rocks, such as granites and limestones, few fines are released from the rock matrix so that borehole development can be achieved relatively easily. However, fine materials may form part of the rock matrix, or be present in fractures or in weathered sections of the rock.

  In consolidated formations (such as mudstones and siltstones) and fine grained rocks (such as chalk), clay and silt particles may be readily freed from the formation into the borehole.

  In unconsolidated formations, such as sands, gravels, silts and clays, the structure of the formation immediately around the borehole may have altered during drilling and fine-grained particles can be released readily from the formation in varying proportions.

- Design and completion of the borehole
  In clean, well-sorted sands and gravels, monitoring boreholes can be completed relatively easily using an appropriately sized screen with no filter pack.

  In fine-grained unconsolidated formations, monitoring boreholes are normally completed using a screen and sand filter. Development of these, particularly at depth, can be problematical and very slow. Difficulties are compounded where unconsolidated material is stratified and the screened section straddles coarse and fine-grained materials.

  Filters packs should be at last 50 mm thick — i.e. a borehole should be at least 100 mm larger than the installed lining.

- Drilling technique
  Air rotary rigs leave fine particles on borehole walls and within fissures adjacent to the borehole. Development procedures are aimed at removing these fines.

  Where casing has been driven or augers used, the interface between the casing and the surrounding formation becomes smeared with fine particulates, which must be removed during development.

  If drilling fluids, such as mud, are used, the accumulated 'mudcake' must be removed during development. Other fluids or additives, which are added during drilling, also need to be removed as efficiently as possible by the development process.

A6.3 Methods for borehole development

A6.3.1 Unsuitable methods

The use of air-lift or hydraulic (water or air) jetting techniques should be discouraged within boreholes where these methods have not been used during drilling.

The introduction of air into a monitoring borehole, particularly after installation of the lining, can lead to entrapment of the air in the formation, localised chemical alteration of groundwater and, perhaps most importantly, the destruction of the structure of the formation or filter pack that surrounds the borehole screen.

Air used directly from commercial compressors often contains a thin mist of oil. This can be removed from the air stream by the addition of specialist filters or by the use of 'oil free' compressors.

Water-jetting techniques similarly result in uncontrolled damage to the filter pack or formation. An argument for the use of water jetting could be made in consolidated rocks, where the jetting process may help to loosen fines in fractures and on the side walls of the borehole.

A6.3.2 Suitable methods

The most suitable methods for borehole development are:

- bailing;
- surge block or inertial pump surging;
- pumping, overpumping and/or backwashing.

Used singly or in combination, the above methods provide a balance between the need to remove fine particles rapidly and the need to avoid the introduction of unnecessary contaminants into the borehole.

A6.3.3 Bailing

Applications
Primarily for use in relatively clean, permeable formations.

Tools
Weighted bailers with a bottom-filling valve attached to cable. These can be operated by hand, but a hydraulic winch (typically used with a small drilling rig) may be better employed. The bailer should be only slightly smaller in size than the borehole.

Procedure
Surge the bailer within the borehole. The most effective operation is where the bail line is allowed to fall rapidly, but is then retrieved quickly. This mobilises fine-grained particles from the surrounding formation and in the borehole and lifts these into suspension or forms a slurry, which can then be removed from the borehole by the bailer. Successive bails remove water and solids from the borehole and induce an inflow of particulates through the screen. The procedure should continue until the water is free from suspended particulate matter.

Problems
The method is not effective in fine sand, silts or clays, or in poorly designed boreholes in which too vigorous a surging action can simply result in an increasing volume of fine material drawn into the borehole. The procedure may take a long time.

A6.3.4 Surge block

Applications
Applications are to destroy bridging of material and to create the sustained agitation needed to develop a borehole. The surge block is primarily for use in relatively clean, permeable formations.

Tools
1. Driller surge block used in conjunction with bailer or pump;
2. Large diameter inertial pump (driven mechanically rather than by hand).

Procedure
The surge block or inertial pump is moved vertically within the borehole, with its position moved along the whole length of the screen. The surging action mobilises fine-grained particles from the surrounding formation and in the borehole and lifts these into suspension or forms a slurry. Where an inertial pump is used, fine-grained material is pumped continuously from the borehole. Where a surge block is used, this must occasionally be removed from the borehole and a pump or bailer then employed to remove water and particulates, before introducing the surge block again. The procedure should continue until the water is free from suspended particulate matter.

If the borehole is properly designed, increased success with development should be achieved by proceeding along the following steps:

1. initially operate the surge block with short gentle strokes above the screen intake;
2. remove particulates regularly (or use an inertial pump);
3. gradually increase the surging rate at each depth until the particulate concentration reduces;
4. incrementally increase the depth of surging towards the bottom of the well.

Problems
The method is not effective in fine sand, silts or clays, or in poorly designed boreholes in which too vigorous a surging action can simply result in increasing the volume of fine material drawn into the borehole.

A6.3.5 Pumping, overpumping and/or backwashing

Applications
This is probably the easiest and most commonly employed technique for well development in any situation.

Tools
1. Submersible or similar pump with hose, cable, power source and control equipment; or
2. Centrifugal suction pump (where suction is possible – i.e. maximum pumping depth of approximately 8°m) and ancillary hose, power source and control equipment; or
3. Controlled twin-tube air or fluid lift pump, compressor, rig and ancillary equipment.

Procedure
Pumping simply involves operating the pump at a yield which is less than or equivalent to the yield of the borehole (i.e. dewatering of the borehole is avoided). This induces groundwater inflow through the borehole screen. Particulates in the flow of water are removed through the pump to the surface.

Overpumping is where the pump is operated at a capacity greater than the yield of the borehole, thereby inducing rapid inflow velocities through the screen, which in turn increase the rate of inflow of particulates. Proper well design is needed to avoid damaging the filter pack in this situation.

Backwashing can only be used where a backflow prevention valve is not installed in the pump. The pump is alternately started and stopped, which creates a surging action in the borehole and induces a greater inflow of particulates through the screen into the well, which can be then be removed by a sustained period of pumping.

Problems
Some risk of damage to the pump, particularly by submersibles, is involved in this process. Narrow-diameter submersible pumps are less able to deal with solids than larger diameter pumps. Overpumping may result in excessive inflow of solids, particularly in silty formations, which could bury the pump.

Use of single high-pressure air hoses is discouraged, as these usually result in uncontrolled discharges of grit from the borehole, and may damage the screen and filter pack (if installed). Limited use of an air hose can sometimes be effective in breaking up encrusted silt and clay on the base of a borehole when pumping or surging initially fails.

A6.4 Development in low-permeability formations

None of the above methods are completely satisfactory in low-permeability formations. One method proposed by Barcelona et al. (1985) for low-permeability consolidated strata (quoted in Aller *et al*. 1989) is as follows:

"Clean water should be circulated down the well casing, out through the well intake and gravel pack, and up the open borehole prior to placement of the grout or seal in the annulus. Relatively high water velocities can be maintained, and the mudcake from the borehole wall will be broken down effectively and removed. Flow rates should be controlled to avoid floating the gravel pack out of the borehole. Because of the relatively low hydraulic conductivity of geologic materials outside the well, a negligible amount of water will penetrate the formation being monitored. However, immediately following the procedure, the well sealant should be installed and the well pumped to remove as much of the water used in the development process as possible."

Other practical advice on development of wells in low-permeability formations is provided by Gass (1986).

References

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Driscol F.G. (1986). *Groundwater and wells.* Johnson Division, St Paul.

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Appendix 7:

Borehole inspection and maintenence

A7.1 Introduction

Most groundwater-monitoring boreholes require periodic maintenance. The most common problem is associated with silt accumulation in the base of a borehole, which can completely block screened intervals. Boreholes may also become blocked through pinching of the lining or by foreign objects.

Depths can be checked by comparison with details in borehole logs. If borehole logs do not exist, it may be necessary to carry out a caliper, geophysical or camera survey to help identify construction details.

Any boreholes that cannot be rehabilitated should be replaced. Abandoned boreholes should be sealed and capped in accordance with Environment Agency guidance (Environment Agency 1998). In general, abandoned boreholes should be sealed with cement-based grout or bentonite and capped in a manner that prevents any confusion with active monitoring points. The site-monitoring plan, drawings and monitoring point register should be amended to document the abandonment clearly.

The text in the following section is drawn from a number of sources, including Appendix B of Blakey *et al*. (1997) and the authors' experience. A significant part of the text is summarised from Section 8 of Aller *et al*. (1989).

A7.2 Factors that cause borehole deterioration

A7.2.1 Poor borehole design

Boreholes constructed with inappropriately sized well screens and filters are likely to cause long-term maintenance problems. Other problems may arise from the use of filter materials that are chemically incompatible with the groundwater or leachate or by the use of poor-quality borehole linings, which may collapse because of hydrostatic pressures.

A7.2.2 Poor installation technique

If records of the installation process are not available, and particularly if a competent person was not present on site to take responsibility for quality assurance (QA), questions can reasonably be raised on the integrity of the borehole construction. Borehole screens may be positioned inappropriately, filter material may be placed inaccurately, bentonite or cement seals may be prepared poorly and placed badly, and may even bridge the screened interval, where it may contaminate water samples. Surface water may enter poorly sealed boreholes through the annular space.

A7.2.3 Poor development

The aims of developing a borehole after construction is to remove materials and effects that arose from the drilling process (see Appendix 6), as well as to remove fines from the filter pack, borehole and formation. Lack of development can compromise water quality and, in some cases, can lead to clogging of the borehole with drilling muds.

A7.2.4 Borehole stability

Unstable boreholes can arise from the use of thin-walled linings that are unable to resist hydrostatic pressures or waste movement, and from improper screen placement combined with excessive pumping, which results in screen collapse.

A7.2.5 Incrustation

Incrustations on well screens or within filter material arise as three types:

- Chemical
  Typically caused by carbonate, hydroxide or sulphate precipitation on or within the screen intake.
- Physical
  Typically caused by sediments that plug the intake or surrounding filter or strata.
- Biological
  Typically caused by bacteria that grow in the filter, surrounding formation or within the borehole. Bacterial growth is dependent on the quantity of nutrients present, which may be contained within the formation water or may have been introduced by the drilling process. The type of bacteria is dependent on the absence or presence of oxygen. Bacterial growth is very common in leachate wells – often resulting in 'foaming' on the leachate surface and slime coatings on the side of boreholes – particularly in boreholes that are pumped regularly.

Incrustation problems are commonly caused by a combination of the above processes.

A7.3 Checks on borehole performance

Periodic checks on the performance of a monitoring borehole can be introduced routinely into monitoring programmes and should be documented carefully. Performance data should be reviewed periodically to ensure samples and water level measurements are not influenced unduly by deterioration of the borehole. Specific checks on performance include:

- Borehole depth measurement
  Depth measurements should be recorded at least annually and, if possible, every time a sample is taken.Depth measurements should be compared with the original depth recorded on borehole logs and with the depth of the screen interval in the borehole. If the screened section of the borehole is blocked (e.g. with sediment), the validity of data from the borehole may be called into question.
- Water level variations
  Maximum and minimum water levels should be reviewed (annually or biannually) with comparison to the level of the top of the screen intake.

  if the water level in the borehole falls below the top of the screen intake, samples taken from the borehole can alter compared to samples collected when the water level lies above the screen intake. For boreholes where this is a regular occurrence (e.g. those used for combined gas and groundwater monitoring), the variation in chemistry caused by this effect becomes part of the natural variability recorded during the initial characterisation monitoring programme and ongoing baseline. For boreholes where this happens rarely, a change in water level below the screen intake may help explain anomalous data.
- Comparative water level data
  Water level measurements from all boreholes should be compared routinely against those of other boreholes in the same groundwater system.

  Water levels, expressed in metres above Ordnance Datum (mAOD) should be plotted in time-series format against those of other boreholes in the same groundwater system, or those of other boreholes in the same hydraulic landfill cell. Marked departures in trends between boreholes (which have been validated by re-measurement) may result from poor design of the borehole or some deterioration in the borehole structure.

  Care should be taken in comparing data from boreholes in the same landfill cell, particularly in well-compacted and deep landfills. Perched water levels are commonly developed, which may result in completely different water level variations that cannot be used for this purpose.
- Reduction in borehole yield
  Drawdown levels during pumping of boreholes should be recorded routinely and reviewed periodically.

  Where boreholes are pumped, particularly throughout a prolonged period of purging, the water level should be recorded before and after pumping. Comparison of the maximum drawdown achieved for a particular pumping rate and how this changes with time provides an indicator of whether or not the yield of the borehole is declining. If the drawdown in water level increases for the same pumping rate, it is possible that some blockage is occurring around the well screen or within the adjacent formation.

  Where drawdown data have not been recorded routinely during sampling, hydraulic conductivity tests *could be used as a more formal alternative for comparing the hydraulic efficiency of a borehole.*

In all cases, care must be taken when interpreting data from boreholes in which the water level lies within the screened interval. A change in water level may result in completely different yield characteristics because of vertical variations in the natural permeability of the adjacent strata.

- Increased sediment loading of samples
  A descriptive note of sediment loading in a sample should be maintained as part of routine record keeping during sampling.

  In poorly designed or undeveloped monitoring boreholes, sediment input to the borehole may increase with time. If sediment loading is persistent or noticeably worsens with time, this may influence the quality of the water samples and/or lead to sediment accumulation in the borehole (which will be revealed by depth measurements).

A7.4 Investigative techniques

A7.4.1 Introduction

In situations where a borehole design is unknown or an obstruction or constriction has been identified, down-hole investigations may be undertaken to try and provide a clearer picture of the borehole structure or blockage. Some geophysical methods may also provide information that can be used to interpret conditions in the strata around the borehole or in the annulus.

A summary of geophysical logs, their application and requirements are shown in Table A7.1 which, along with the following summary of methods, is extracted from Blakey *et al*. (1997). Not all techniques are appropriate to all boreholes and specialist advice must be taken before any one method is used. In general, a combination of logs is necessary to allow reliable interpretation of results. Interpretation of data, particularly geophysical data, can be ambiguous and should not be attempted without specialist knowledge of the limitations and applicability of the technique.

Some of the logs only operate in water, while others can be used only in uncased boreholes. The requirements are given in Table A7.1.

Most of the tools have a diameter of 50 mm or less. The upper diameter limit for geophysical logging varies according to the tool being used. The formation logs, resistivity, spontaneous potential and natural gamma start to lose definition at diameters above about 300 mm, while temperature and heat pulse flow meter logs may be distorted by convective flow in large diameter boreholes.

The most frequently used down-hole logging techniques are described below.

A7.4.2 Physical logs

- Closed circuit television or other cameras
  A closed circuit television (CCTV) inspection of a lined borehole is probably the most effective means of identifying screen position or damage, such as clogged screens or blockage. Cameras need to be selected carefully in relation to the diameter of the boreholes being investigated. In turbid waters, picture resolution may be poor.
- Caliper log
  This tool has three spring-loaded arms that measure the diameter of the borehole. It can indicate probable fracture zones in unlined boreholes and may be used to confirm the diameter of an unlined borehole. The spring-loaded arms may catch and damage borehole screens and should be used for screen identification only after exhausting all other methods.

A7.4.3 Formation logs suitable for use in lined boreholes

- Natural gamma log
  The natural gamma log is a measure of the natural gamma radiation emitted from the formation. It is usually assumed that the natural gamma radiation is caused by the decay of potassium-40 and therefore a high gamma count is interpreted as a high potassium-bearing formation, such as clay or shale. Limestone normally has a low gamma count and sandstone an intermediate count.

  This is the most useful of the lithological logs, as it can be used in both the saturated and unsaturated zones. It is most commonly carried out prior to the installation of a monitoring-borehole lining. Since gamma radiation passes through the casing, a useful log can be obtained within a temporary steel casing or within a lined monitoring borehole.

  Gamma logs react to cement grout or bentonite behind a borehole lining and, depending on the contrast against the natural formation, may provide an indication of the integrity of borehole construction.

Table A7.1 Comparison of down-hole logging techniques

Log	Borehole	Casing	Borehole construction	Lithology	Fractures	Fluid movement	Fluid quality
Resistivity	Required	Uncased or plastic screen	–	Y	–	–	Y
Spontaneous potential	Required	Uncased or plastic screen	–	Y	–	–	Y
Natural gamma	Not required	Cased or uncased	Y	Y	–	–	–
Gamma–gamma	Not required	Cased or uncased	–	Y	–	–	–
Neutron	Not required	Cased or uncased	–	Y	–	–	–
Sonic	Required	Uncased	Y[1]	–	Y	–	–
Caliper	Not required	Cased or uncased	Y	–	Y	–	-
Temperature	Required	Cased or uncased	–	–	–	Y	–
Conductivity	Required	Cased or uncased	–	–	–	–	Y
Flowmeter	Required	Cased or uncased	–	–	–	Y	–
Television	Not required Must be clean	Cased or uncased	Y	–	Y		–

Notes:
1. Can be used in cased hole to check cement grout.

A7.4.4 Other formation logs for use in open boreholes

The following logs are used normally for site investigation purposes within unlined boreholes and have no specific application in lined monitoring boreholes:

- Gamma-gamma (density)
  The gamma–gamma or density log is the result of lowering a collimated gamma source into the borehole. The gamma radiation is directed into the formation and is attenuated according to the formation properties. It is most attenuated by high atomic weight elements, so a non-porous rock with high calcium, magnesium and iron concentrations has more effect than a highly porous rock with lighter elements (and pore spaces, which contain hydrogen in the form of water). It is a difficult log to run as it requires a smooth borehole wall to ensure that the gamma radiation is directed into the formation and not into the borehole.
- Neutron (porosity)
  The neutron log is similar in its operation to the density log. In this case it is a source of neutron radiation that is lowered into the borehole and the reaction between neutrons and hydrogen atoms recorded. The number of hydrogen atoms is, in most cases, proportional to the porosity of the formation and hence the resultant log can be interpreted in terms of porosity. Like the density log, this log is most effective in a uniform, small-diameter borehole. In theory, the neutron log can be run in a steel-cased borehole, but since it is affected by diameter changes behind the casing, interpretation can be ambiguous. Plastic casing contains a high proportion of hydrogen atoms and has a marked effect on the log.
- Resistivity log
  Resistivity logs cannot be used in cased boreholes or above the water table in the saturated zone. Plastic casing is non-conducting so electrical current is not able to pass into the formation, while a steel screen causes a short circuit between the electrodes.

  The resistivity log provides a measure of the resistivity of the formation. Various methods of measurement are available, such as single point, 16 and 64 inch normal, guard and laterolog, the difference being the distribution and spacing of the electrodes. The measurement made is mainly of the resistivity of the formation porewater. In fresh-water aquifers, high resistivity indicates that the formation has low porosity, such as limestone or crystalline rocks. Low resistivity indicates high-porosity formations, such as unconsolidated clay, sand or gravel. However, highly conductive water, such as found in cases of saline intrusion and leachate contamination, may give a similar reported effect. Experienced personnel are required for good interpretation of logs taken where conditions are difficult.
- Spontaneous potential logs
  Spontaneous potential logs cannot be used in cased boreholes or above the water table in the saturated zone. Plastic casing is non-conducting and electrical current is not able to pass into the formation, while a steel screen causes a short circuit between the electrodes.

  The potential log gives a measurement of the natural electrical potential developed when the salinity of the borehole water differs from that of the porewater in the formation. Its main use is in boreholes drilled with a saline mud (a practice normally discouraged in landfill investigations). However, it might detect zones of leachate within an aquifer that contains mostly fresh water.
- Sonic
  This tool propagates sound waves into the formation and records their characteristics in terms of fracturing and hence permeability. If used successfully, the permeable horizons in the borehole can be delineated; these show the main flow horizons in the aquifer.

A7.4.5 Fluid logs

Fluid logs can be readily run in lined or unlined boreholes to investigate vertical variation in water properties, which in turn may reveal information on movement of water into and out of the borehole. These are particularly useful in boreholes with very long screens or where groundwater flow is stratified or fissure flow is dominant.

- Temperature
  This is a log of the borehole fluid temperature. Where no vertical flow occurs in an aquifer, the groundwater temperature steadily increases with depth at the rate of about 2 C per 100 m. Departures from this gradient in a borehole can mean that a vertical fluid flow is occurring in the borehole; distinct steps in the temperature profile usually indicate inflow levels. The temperature regime in the vicinity of landfills is modified by heat generated by the decomposition process within the landfill itself, and temperature anomalies in the borehole log can indicate that the water is polluted by the landfill.

- Conductivity
  The electrical conductivity of the borehole fluid is proportional to the dissolved solids and hence groundwater quality. A conductivity log therefore indicates polluted zones within the borehole, but the interpretation needs to take account of any vertical flow that may be taking place within the borehole.
- Flowmeter
  A spinner flowmeter is not normally sufficiently sensitive to measure naturally occurring vertical flows in the borehole. A more sensitive type, such as the heat pulse flowmeter, is more suitable. This can measure flow rates down to 1 mm/s and will operate in a 50 mm diameter borehole. Convective flow may develop in boreholes with diameters larger than about 300 mm, which interferes with heat pulse flowmeter measurements.

A7.5 Maintenance and rehabilitation of boreholes

A7.5.1 Sediment removal

The most common maintenance problems are the accumulation of sediment at the bottom of the borehole or the need to recover foreign objects (rocks, insects, vegetation, etc.) dropped into the borehole.

Options for removing sediment from a borehole are limited and include the following:

- Boreholes less than 8 m deep (within suction-lift depth)
  Use a centrifugal pump and place the intake in the sediment at the base of the borehole, which should 'vacuum' lift the sediment. Water is needed to fluidise the sediment and may need to be added.
- Boreholes up to 60 m deep
  Use an inertial pump and surge this into the sediment at the base of the well. Once fluidised, sediment can sometimes be lifted through the pump to the surface. If sediment blocks the hole above water level, water may need to be added from the surface to fluidise it.
- Boreholes at any depth
  Use a bailer, which when used with a winch (e.g. on a small drilling rig), can be effective.

Use of single high-pressure air hoses is discouraged, as these usually result in uncontrolled discharges of grit from the borehole, and may damage the screen and filter pack. Limited use of an air hose can sometimes be effective in breaking-up encrusted silt and clay on the base of a borehole if pumping or surging initially fails.

Controlled twin-tube air or fluid-lift pumps can be used to pump sediment.

A7.5.2 Chemical treatment

Chemical treatment (often combined with mechanical techniques) has been used traditionally to restore well yields in production boreholes. These techniques are not commonly used for monitoring boreholes, since the addition of chemicals can cause severe changes in the borehole environment and may be long lasting or even permanent. These changes may adversely effect some or all future water-quality samples. If chemical agents are introduced, analysis of the borehole water immediately before and after treatment should be undertaken to provide a measure of the impact of the treatment.

Three categories of chemicals are used:

- Acids
  Primarily used to dissolve incrustations.
- Biocides
  Primarily used to kill bacteria.
- Surfactants
  Primarily used to disperse clay by lowering the surface tension of the water.

A7.5.3 Mechanical rehabilitation

Mechanical rehabilitation methods to improve well yield are the same methods as used for well development (see Appendix 6). The uncontrolled use of high-pressure air is discouraged.

Any type of rehabilitation for incrustation can be supplemented by the use of a wire brush or mechanical scraper alongside bailing or pumping to remove loose particles on the side walls of the screen or borehole. Blockages can sometimes be dealt with using drain rods.

A7.5.4 External borehole maintenance

Routine inspection and maintenance of the exposed section of the borehole and protective headworks should include the following:

- Surface seal/concrete pad
  Any cracks or damage to the surface seal surrounding the borehole and headworks should be repaired to prevent surface water entry to the borehole surrounds. In cases of extreme damage, the entire seal should be broken out and replaced.

- Protective headworks
  Protective headworks should be maintained so that they are kept free of rust, allow ready access by monitoring personnel and protect the borehole from vandalism and ingress of water and foreign objects. Locks should be maintained in operational condition.
- Borehole lining cover
  A cover should be maintained separately on top of the borehole lining to prevent foreign objects accidentally falling into the borehole.

  Where sampling devices or tubes extend beyond the top of a borehole lining, these should be checked for blockages and purpose-designed lining caps should be provided to prevent foreign objects accidentally falling into the borehole.
- Labelling
  External and internal labelling should be maintained in good condition and should correspond exactly with the monitoring point register. Particular care is required in the maintenance of labelling on multiple monitoring points.

References

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Appendix 8:

Example monitoring record forms

A8.1 Introduction

A number of example forms are provided in this appendix for recording monitoring data:

- Table A8.1 Environmental observations;
- Table A8.2 Water movements;
- Table A8.3 Equipment calibration;
- Table A8.4 Water levels;
- Table A8.5 Borehole purging and field measurements;
- Table A8.6 Sample collection;
- Table A8.7 Chain of custody.

A8.2 Environmental observation record form

An example form is provided as Table A8.1. This form could be adapted as part of a general site diary that covers environmental observations. Descriptions of information and examples applicable to each heading are given below.

Heading information

Field	Description (with explanatory text)	Examples
Sheet _ of _	Sequential sheet number for individual monitoring point.	*1 of 3*
Site Name	Name of landfill site. *It is preferable to use the name stated on the permit unless some other name is commonly used.*	*Mountain Top Landfill Site*
Site Operator	The named permit holder and/or landfill operator.	*ABC Landfill Co.*
Environment Agency Permit Number	Permit or Licence Reference Number.	*WCC 123456*
Date From	Start of recording period.	*1 January 2000*
Date To	End of recording period.	*31 January 2000*

Data requirements

Field	Description (with explanatory text)	Examples
Date	Date of observation.	*5 January 2000*
Type of Observation	Category of observation.	*RO* *Run-off to stream* *Veg* *Vegetation die-back* *Lch* *Leachate seepages*
Location of Observation	Description of observation location. *Use local names, or grid reference as appropriate. Could be used in conjunction with plan of site with observational points indexed by number.*	*Northern edge of cell 1* *Northern site ditch (Grid Reference: SP 12345 67890)* *Land off-site adjacent to western site boundary*
Details	Brief description of observation.	*Leachate seepages at surface* *Suspended solids entering ditch following heavy rainfall* *Gaps in crop growth adjacent to site boundary – gas damage?*
Action Taken	Brief note of follow-up action taken (if any).	*Referred to Technical Manager* *Known problem – ongoing monitoring in hand* *Interceptor ditch constructed on (date)*
Recorded By	Name of person recording observation.	*A. Smith*
Notes	Any other general notes relevant to observations.	*Exceptional heavy rainfall between 1 and 5 January* *Transferred main landfill input from Area A to Area B during January*

Quality assurance

Field	Description (with explanatory text)	Examples
Name	Name of person responsible for supervising or managing work.	*Survey: Person responsible for taking field measurements* *QC Manager: Person responsible for QC checks of data* *Manager: Person responsible for monitoring programmes*
Date	Date when each task, including paperwork, is completed.	*3/3/00*
Inits	Initials of responsible person.	*ABC*

Data processing trail

Field	Description (with explanatory text)	Examples
Schedule Completed	Date confirming schedule has been checked against Monitoring Plan Specification and signed off as completed. *Include initials of person responsible for planning survey work.*	*10/3/00, ABK*
Data Validated	Date when data have been double-checked and validated. *Include initials of person responsible for validation.*	*15/3/00, PDW*
Computer Updated	Date when data have been entered into computer system (where used). *Include initials of person responsible for data entry.*	*15/3/00, PDW*

Table A8.1 Example field sheet for Environmental Observation.

Environmental Observation Record Form				Sheet ___ of ___	
Site Name:			Environment Agency Permit Number:	Date From:	
Site Operator:				Date to:	
Date	Type of Observation	Location of Observation (include Grid Reference if a specific point of observation)	Details	Action Taken	Recorded by

Notes:	Quality Assurance				Data Processing Trail		
		Name	Date	Inits		Date	Inits
	Survey:				Schedule Completed:		
	QC Manager:				Data Validated:		
	Manager:				Computer Updated::		

A8.3 Water movements record form

An example form is provided as Table A8.2. This form is a summary of information over a specified period and draws information from a number of different sources at a landfill. Any removal or addition of water should be included in the record.

The form does not include all information necessary to analyse the water balance for a specific part of a site, but is intended to include all relevant water measurements that can be recorded usefully and from which a water balance could be constructed. Other data such as waste type, waste volume, waste density, waste absorption, cell geometry, restoration cover, infiltration, etc., are necessary to evaluate a water balance fully.

Heading information

Field	Description (with explanatory text)	Examples
Sheet _of _	Sequential page numbers for each register.	*1 of 3*
Site Name	Name of landfill site. *It is preferable to use the name stated on the permit unless some other name is commonly used.*	*Mountain Top Landfill Site*
Site Operator	The named permit holder and/or landfill operator.	*ABC Landfill Co.*
Environment Agency Permit Number	Permit or Licence Reference Number.	*WCC 123456*
Total Rainfall During Period (mm)	Total rainfall in mm recorded from site records or from Met Office data.	*25*
Period of Summary	Start and end date for summarised data. *An annual summary should be prepared as a minimum.*	*1 to 31 January 2002* *1 January to 31 March 2003* *1 January to 31 December 2003*
Date Prepared	Date summary sheet prepared.	*31 January 2004*

Data requirements

Field	Description (with explanatory text)	Examples
Site Area Name	Site Area or Landfill Cell Name *Separate details should be provided for each hydraulically separate landfill cell in which water other than rainfall has been artificially removed or applied.*	Cell 1
Percent Capped	Estimate of the average percentage of site area that was covered with a low-permeability capping layer during recording period.	0%, 100%, 25%
Effective Rainfall	Rainfall in mm falling onto site area after accounting for evapotranspiration losses. Leave blank if not known.	10
Liquid Waste	Total volume of liquid waste disposed into site area (m^3).	250
Leachate Transfers In	Total volume of liquid removed from other parts of the site and disposed into this site area (m^3).	540
Transfer Source	Area from which transfer originated.	Cell 2
Other Inputs	Total volume of liquids disposed from other external sources –(m^3). *For example, clean water (e.g. added to enhance biodegradation).*	90
Discharges Off-site	Total volume of liquid removed and disposed off-site –(m^3). *For example to sewer or via tanker to treatment works.*	360
Leachate Transfers Out	Total volume of liquid removed and transferred for disposal to other parts of site (m^3). *If disposed to more than one other area, itemise each separately.*	480
Transfer Destination	Area to which transfer was made.	Cell 3
Other Outputs	Total volume of liquids removed by any other means (m^3).	13
Leachate Level Change	Average recorded change in leachate level over period based on monitoring results –(m).	+0.4, –0.2, 0.0
Comments	Any notable points.	*Sharp rise in leachate levels probably caused by recent overfilling of older wastes. Leachate volume estimates are based on pump usage time – significant uncertainty*
Totals	Sum of each unshaded column. *Total leachate transfers recorded as inputs and outputs should be equal.*	–

Quality assurance

Field	Description (with explanatory text)	
Name	Name of person responsible for supervising or managing work.	*Record Checked: Person responsible for collating data* *QC Manager: Person responsible for QC checks of data* *Manager: Person responsible for monitoring programmes*
Date	Date when each task, including paperwork, is completed.	*3/3/03*
Inits	Initials of responsible person.	*ABC*

Data processing trail

Field	Description (with explanatory text)	Examples
Schedule Completed	Date confirming when schedule has been checked against Monitoring Plan Specification and signed off as completed. *Include initials of person responsible for planning survey work.*	*10/3/04, ABK*
Data Validated	Date when data have been double-checked and validated. *Include initials of person responsible for validation.*	*15/3/04, PDW*
Computer Updated	Date when data have been entered into computer system (where used). *Include initials of person responsible for data entry.*	*15/3/04, PDW*

Table A8.2 Example field sheet for recording water movements

Water Movements Record Form		Sheet ___ of ___
Site Name:	Environment Agency Permit Number:	Period of Summary: (From:/To) Date Prepared:
Site Operator:	Total Rainfall During Period (mm):	Summary Prepared by:

		Liquid Inputs During period					Liquid Outputs During period				Storage Change	
Site Area Name	Percent Capped	Effective Rainfall	Liquid Waste	Leachate Transfers In	Transfer Source	Other Inputs	Discharges off-site	Leachate Transfers Out	Transfer Destination	Other Outputs	Leachate Level Change	Comments
	%	mm	m^3	m^3		m^3	m^3	m^3		m^3	m	
TOTALS:												

Notes	Quality Assurance				Data Processing Trail		
		Name	Date	Inits		Date	Inits
	Record Checked:				Schedule Completed:		
	QC Manager:				Data Validated:		
	Manager:				Archive Records Updated::		

A8.4 Equipment calibration forms

An example form is provided as Table A8.3. This form covers field instrumentation in common usage, but may need to be modified to cover other instrumentation.

Heading information

Field	Description (with explanatory text)	Examples
Sheet __ of __:	Sequential page numbers for each survey.	*1 of 3*
Site Name	Name of landfill site. *It is preferable to use the name stated on the permit unless some other name is commonly used.*	*Mountain Top Landfill Site*
Site Operator	The named permit holder and/or landfill operator.	*ABC Landfill Co.*
Environment Agency Permit Number	Permit or Licence Reference Number.	*WCC 123456*
Survey Reference	Survey Title.	*Quarterly Survey – May 2001* *Six-Monthly Survey – June 2001*
Survey Personnel	Name(s) of survey personnel. *Include company name if work undertaken by external contractor.*	*AB Smith (AA Monitoring Co)*

Water level dip meters

Field	Description (with explanatory text)	Examples
Date	Date of calibration check	*26 June 2001*
Field Instrument – Model/Serial Number	Model and serial number of dip meter.	*ABC Co Supreme Dipmeter, AB1234567*
Field Instrument – Total Length	Total length of dip meter (m).	*60.000*
Field Instrument – Dip Meter Measurement Against Standard	Length of standard tape length measured with dip meter (m).	*60.005*
Standard – Describe	Description of standard tape used.	*ABC Tools certified metal tape*
Standard – Tape Length	Length of tape used to check against dipper (m).	*100.000*
Difference	Difference in length between two tapes (Dip Meter	*0.005*
Initials	Measurement – Standard Tape Length) (m). Initials of person carrying out measurement.	*PBC*

Water quality instruments used in survey

Field	Description (with explanatory text)	Examples
Inst No	Reference Number used in calibration table to identify instrument.	*1, 2, 3*
Type	Type of instrument.	*Temp, pH, EC, DO, Eh*
Units of Measurement	Units used for calibration.	*deg C, pH units, µS/cm, % saturation, mV*
Model	Model name for instrument.	*OK Equipment Co, AB-300*
Serial No	Serial number of instrument.	*AKW-347819*
Comments	Any relevant comments.	*New probe recently purchased*

Calibration records

Field	Description (with explanatory text)	Examples
Inst No	Reference Number used in calibration table to identify instrument.	*1, 2, 3*
Date	Date of calibration.	*23/7/01*
Time	Time of calibration.	*09:05*
Calibration Standard 1 (& 2)	Standards for calibration.	*See below*
Ref Std 1 (& 2)	Measurement value of standard solution in appropriate units. *For pH meters these are the buffer standards.*	*EC Meters 1000µS/cm* *pH Meters 4.01, 7.01, 10.01* *DO Meters Zero% oxygen*
Reading Before Cal	Reading by instrument immediately before calibration. *Indicates drift from previous reference for instruments calibrated more than once during survey – for example pH meters.*	*6.97 (against standard of 7.01)*
Cal (√)	Tick after calibrating to standard.	√
Inits	Initials of person carrying out calibration.	*PBC*

Quality assurance

Field	Description (with explanatory text)	Examples
Name	Name of person responsible for supervising or managing work.	*Survey: Person responsible for taking field measurements* *QC Manager: Person responsible for QC checks of data* *Manager: Person responsible for monitoring programmes*
Date	Date when each task, including paperwork, is completed.	*3/3/00*
Inits	Initials of responsible person.	*ABC*

Table A8.3 Example field sheet for recording equipment calibration

Equipment Calibration Record Form		Sheet ___ of ___
Site Name:	Environment Agency Permit Number:	Survey Reference:
Site Operator:		Survey Personnel:

Water Level Dip Meters

Date	Field Instrument			Standard		Difference	Initials
	Model / Serial Number	Total Length	Dip Meter Measurement Against Standard	Describe	Tape Length		
		m	m		m	m	

Comments:

Note: If difference is greater than 1cm over 30m then dip meter should be replaced.

Water Quality Instruments Used in Survey

Inst No	Type	Units of Measurement	Model	Serial No	Comments
1					
2					
3					
4					
5					
6					

Calibration Records

Inst No	Date	Time	Calibration Standard 1			Calibration Standard 2			Initials
			Ref Std 1	Reading Before Cal	Cal (√)	Ref Std 2	Reading Before Cal	Cal (√)	

Comments:

Notes::	Quality Assurance::			
		Name	*Date*	*Inits*
	Survey:			
	QC Manager:			
	Manager:			

A8.5 Water level record form

An example form is provided as Table A8.4. This form could be used or modified for use for recording groundwater levels, leachate levels or surface water levels when these are being measured without sampling. Descriptions of information and examples applicable to each heading are given below.

Heading information

Field	Description (with explanatory text)	Examples
Sheet __ of __:	Sequential page numbers for each survey.	*1 of 3*
Site Name	Name of landfill site. *It is preferable to use the name stated on the permit unless some other name is commonly used.*	*Mountain Top Landfill Site*
Site Operator	The named permit holder and/or landfill operator.	*ABC Landfill Co.*
Environment Agency Permit Number	Permit or Licence Reference Number.	*WCC 123456*
Survey	Survey Title.	*Monthly Survey – May 2001* *Quarterly Survey – June 2001*
Survey Personnel	Name(s) of survey personnel. *Include company name if work undertaken by external contractor.*	*AB Smith (AA Monitoring Co)*

Data requirements

All monitoring points scheduled for monitoring should be included on this form. An explanatory comment should be provided where no data are obtained. This facilitates comparison against schedules set out in the Site Monitoring Plan.

Data requirements

Field	Description (with explanatory text)	Examples
Date	Date of measurement.	*3/7/2001*
Time	Time of measurement (not always necessary).	*14:50*
Mon Point	Monitoring point reference number.	*GW1, L1*
Datum Description	Simple description of datum point used for water level measurements.	*Top of external casing* *Top of internal lining* *Yellow mark on bridge deck*
Datum Elevation	Surveyed elevation of datum point. *Expressed as metres above Ordnance Datum.*	*95.42*
Datum Status	Code indicating reliability of datum elevation.	*S Surveyed* *E Estimated* *U Unknown*
Depth to Water	Depth to water level. *Recorded as metres below datum point (mbd). If dry, record as 'dry'.*	*3.56*
Depth to Base	Depth to base of monitoring point. *Recorded as metres below datum point (mbd). The depth should be measured if the monitoring point is dry or if the datum point has changed. Otherwise it should be recorded at least annually.*	*3.56*
Comments	Record any relevant information that may influence water levels measurements.	*Base silted-up since last survey* *Datum raised since last survey – new concrete rings added* *Headworks damaged – in need of repair* *Flooding around headworks*
QC	Data checked by QC supervisor for obvious errors in field data.	*Highlight records that are anomalous* *Tick records that are consistent with historic data*
Notes	Other additional information. *For example, unusual weather, access or safety problems requiring attention.*	*Torrential rain overnight* *Damaged headworks*

Quality assurance

Field	Description (with explanatory text)	Examples
Name	Name of person responsible for supervising or managing work.	*Survey: Person responsible for taking field measurements QC Manager: Person responsible for QC checks of data* *Manager: Person responsible for monitoring programmes*
Date	Date when each task, including paperwork, is completed.	*3/3/01*
Inits	Initials of responsible person.	*ABC*

Data processing trail

Field	Description (with explanatory text)	Examples
Schedule Completed.	Date confirming when schedule has been checked against Monitoring Plan Specification and signed off as Completed. *Include initials of person responsible for planning survey work*.	*10/3/01, ABK*
Data Validated	Date when data have been double-checked and validated. *Include initials of person responsible for validation.*	*15/3/01, PDW*
Computer Updated	Date when data have been entered into computer system (where used). *Include initials of person responsible for data entry.*	*15/3/01, PDW*

Table A8.4 Example field sheet for recording water levels only

Water Level Record Form		Sheet ___ of ___
Site Name:	Environment Agency Permit Number:	Survey Reference:
Site Operator:		Survey Personnel:

Date	Time	Mon Point	Datum Description	Datum Elevation	Datum Status	Depth to Water[1]	Depth to Base[2]	Comments	QC
				mAOD	S/E/U	mbd	mbd		

Notes:	**Quality Assurance**				**Data Processing Trail**		
		Name	*Date*	*Inits*		*Date*	*Inits*
	Survey:				Schedule Completed:		
	QC Manager:				Data Validated:		
	Manager:				Computer Updated:		

1. If monitoring point is dry, record as 'dry'.
2. Depth to base should always be measured if monitoring point is dry.

A8.6 Borehole purging record

An example form is provided as Table A8.5. This form could be used to record purging from any vertical structure. Once purging strategies have been established for monitoring points, this form can be condensed to record the information appropriate for the strategies used. It may then be combined with the sample collection form (Table A8.6).

Heading information

Field	Description (with explanatory text)	Examples
Sheet __ of __:	Sequential page numbers for each survey.	*1 of 3*
Site Name	Name of landfill site. *It is preferable to use the name stated on the permit unless some other name is commonly used.*	*Mountain Top Landfill Site*
Site Operator	The named permit holder and/or landfill operator.	*ABC Landfill Co.*
Environment Agency Permit Number	Permit or Licence Reference Number.	*WCC 123456*
Weather Conditions	Weather conditions on day of survey.	*Overcast and cloudy and cool following following week of heavy rainfall*
Survey Reference	Survey title.	*Quarterly Survey – June 2001* *Six-Monthly Survey – September 2001*
Survey Personnel	Name(s) of survey personnel. *Include company name if work undertaken by external contractor.*	*AB Smith (AA Monitoring Co)*
Monitoring Point	Monitoring point reference number.	*GW1, L1*

Strategy and equipment used

Field	Description (with explanatory text)	Examples
Purge Strategy	Purging method adopted.	*SWQ Pump until WQ determinands stabilise* *3 _ BV Pump 3 _ well volumes* *D&R Dewater hole and allow water level to recover* *LFT Low flow timed purge (rate and time based on prior testing)* *LFP Low flow purging using dedicated pump* *DS Depth sample – no purging* *SS Surface sample – no purging*
Purge Equipment	Type of equipment used for purging.	*Bailer* *Inertial pump* *Submersible* *Bladder pump*
Dedicated Pump?	Y – yes if installed at least 24 hours in advance of purging; N – no otherwise.	Y
Flow Measurement	Method for recording flow and/or purge volume.	*Bucket with stopwatch* *Flow meter*

Monitoring point measurements and well volume estimate

All monitoring points scheduled for monitoring should be included on this form. An explanatory comment should be provided where no data are obtained. This facilitates comparison against schedules set out in the Site Monitoring Plan.

Monitoring point measurements and well volume estimate

Field	Description (with explanatory text)	Examples
Date of Measurement	Date of purging.	*3/7/2001*
Liner ID	Internal diameter of borehole lining in mm.	*50*
Datum Point	Brief description of datum point used for water level measurements.	*Steel cap* *Top of internal liner*
Depth to Water	Depth to water level. *Recorded as metres below datum point (mbd).* *If dry, record as 'dry'.*	3.56 *Dry*
Depth to Base	Depth to base of monitoring point. *Recorded as metres below datum point (mbd).* *The depth should always be measured if the monitoring point is dry.*	5.67
Depth of Water	Depth of water above base of borehole lining. Difference in value between 'Depth to Base' and 'Depth to Water'.	2.11
Well Volume	Volume in litres. *Calculated from equation V = 1000.p. _ (D/2000)2 _ h (where p = 3.142, D = diameter of borehole lining in mm and h is saturated depth in m).*	*For a 50 mm diameter well with a saturated depth of 2.11 m:* *V = 1000 _ 3.142 _ (50/2000)2 _ 2.11 = 4.1 litres*
3 _ well volume	3 times well volume in litres. *Only needed if purge strategy is to remove 3x well volumes.*	*4.1 _ 3 = 12.3 litres*

Purging record

Field	Description (with explanatory text)	Examples
Start Time of Purging	Time pumping commenced (only needed for timed purge).	*14:50*
End Time of Purging	Time pumping ceased (only needed for timed purge).	*14:58*
Purge Duration	Difference between end time and start time expressed in minutes (only needed for timed purge).	*14:58 − 14:50 = 8 min*
Purging Rate	Average rate of purging if measured. *Only needed for timed purge. Alternatively, it can be estimated by dividing 'Volume Purged'/'Purge Duration'.*	*2 l/min* *15/8 = 1.9 l/min*
Volume Purged	Actual volume of water removed during purging, in litres *Either measured, or calculated from 'Pumping Rate' _ 'Purge Duration'.*	*15*
No of well volumes	Actual number of well volumes removed. *Calculated by dividing 'Volume Purged/'Well Volume'.*	*15/12.3 = 1.2*
Depth to Water after Purge	Depth to water level recorded as metres below datum point (mbd) on completion of purging.	*5.3*
Pumped Dry?	Y – yes; N – no. *Yes if dry or if level has fallen below base of screened interval.*	*Y*

Water quality measurements (if applicable)

If stability of determinands is monitored during purging, then sufficient measurements need to be taken at different times to demonstrate that stability has occurred. At least three separate measurements should be provided to show readings at timed intervals.

Field	Description (with explanatory text)	Examples
Use Flow through Cell?	Y – yes if used; N – no otherwise.	*Y*
min	Time in minutes since purging started. *At least three separate readings should be recorded on this form. Not all intermediate readings need be shown.*	*2*
Vol	Vol of water removed at time of measurement (litres).	*0.5*
nVol	Number of well volumes removed.	*1, 2, 3, etc.*
Temp (deg C)	Temperature in degrees centigrade.	*12.5*
pH	pH in pH units.	*7.21*
EC (µS/cm)	Electrical conductivity in µS/cm.	*630*
DO (mg/l or %)	Dissolved oxygen expressed as mg/l or % saturation.	*2.35 mg/l* *28%*

Quality assurance

Field	Description (with explanatory text)	Examples
Name	Name of person responsible for supervising or managing work.	*Survey: Person responsible for* taking *field measurements* *QC Manager:Person responsible for QC checks of data* *Manager: Person responsible for monitoring programmes*
Date	Date when each task, including paperwork, is completed.	*3/3/01*
Inits	Initials of responsible person.	*ABC*

Data processing trail

Field	Description (with explanatory text)	Examples
Schedule Completed	Date confirming when schedule has been checked against Monitoring Plan Specification and signed off as completed. *Include initials of person responsible for planning survey work.*	*10/3/01, ABK*
Data Validated	Date when data have been double-checked and validated. *Include initials of person responsible for validation.*	*15/3/01, PDW*
Computer Updated	Date when data have been entered into computer system (where used). *Include initials of person responsible for data entry.*	*15/3/01, PDW*

Table A8.5 Example field sheet for recording borehole-purging process

Borehole Purging Record Form		Sheet ___ of ___
Site Name:	Environment Agency Permit Number:	Survey Reference:
Site Operator:	Weather Conditions	Survey Personnel:

	Monitoring Point					
Strategy and equipment used						
Purge strategy (Use code)						
Purge equipment (State type)						
Dedicated pump? (Y/N)						
Flow measurement (Method)						
Monitoring point measurements and well volume estimate						
Date of measurement						
Liner ID: (mm)						
Datum point						
Depth to water: (mbd)						
Depth to base: (mbd)						
Depth of water: (metres)						
Well volume: (litres)						
3 x well volume (litres)						
Purging record						
Start time of purging h: min						
End time of purging (h: min)						
Purge duration (min)						
Purging rate (l/min)						
Volume purged litres						
No of well volumes n						
Depth to water after purge (mbd)						
Pumped dry? (Y/N)						

Water quality measurements (if applicable)

	min	Vol	nVol						
Use flow through cell? (Y/N)									
Temp (deg C)									
pH									
EC (S/cm)									
DO (mg/l or %)									

Sample taken? (Y/N)						

See seperate sheet for sample collection data

Quality Assurance				Data Processing Trail		
	Name	*Date*	*Inits*		*Date*	*Inits*
Survey:				Schedule Completed:		
QC Manager:				Data Validated:		
Manager:				Computer Updated:		

A8.7 Sample collection form

An example form is provided as Table A8.6. This form could be used for recording information for sample collection of groundwater, leachate or surface waters.

Heading information

Field	Description **(with explanatory text)**	Examples
Sheet __ of __:	Sequential page numbers for each survey.	*1 of 3*
Site Name	Name of landfill site. *It is preferable to use the name stated on the permit unless some other name is commonly used.*	*Mountain Top Landfill Site*
Site Operator	The named permit holder and/or landfill operator.	*ABC Landfill Co.*
Environment Agency Permit Number	Permit or Licence Reference Number.	*WCC 123456*
Weather Conditions	Weather conditions on day of survey.	*Overcast and cloudy and cool following week of heavy rainfall*
Survey Reference	Survey title.	*Quarterly Survey – June 2001* *Six-Monthly Survey – September 2001*
Survey Personnel	Name(s) of survey personnel. *Include company name if work undertaken by external contractor*	*AB Smith (AA Monitoring Co)*
Monitoring Point or Sample Reference	Monitoring point reference number, or QC sample reference. *This is the sample ID that will be used on the laboratory analysis request form. QC sample IDs should not be apparent as such to the lab.*	*GW1, L1, GWA, etc.*

Strategy and equipment used

Field	Description **(with explanatory text)**	Examples
Sample Medium	Medium of sample collected.	*L Leachate* *G Groundwater* *S Surface water* *Ld Duplicate leachate* *GWfb Groundwater field blank*
Sample Type	Type of sample taken.	*C Composite (mixed sample)* *S Spot sample (taken at a specific depth without mixing)* *U Uncertain*
Sample Equipment	Type of equipment used for sampling.	*Bailer* *Inertial pump* *Submersible* *Bladder pump*
Dedicated Pump	Y – yes if installed at least 24 hours in advance of purging; N – no otherwise.	*Y*
Purge Record	Y – yes if written purge record on separate sheet; N – no otherwise.	*Y*

Sample collection information

All monitoring points scheduled for monitoring should be included on this form. An explanatory comment should be provided where no data are obtained. This facilitates comparison against schedules set out in the Site Monitoring Plan.

Field	Description **(with explanatory text)**	Examples
Date of sample	Date sample collected	*1/1/01*
Time of Sample	Time of sampling or period of sampling. *Not always required.*	*14:55* *14:50 to 15:10*
Time since Purge	Time since purging was completed.	*2 min* *35 min*
Depth to Water	Depth to water level. *Recorded as metres below datum point (mbd) at time of sampling.*	*5.3*
Pumping Rate	Pumping rate used for sampling (litres per minute).	*0.5 l/min*
Odour	Record any distinguishing smell.	*Sulphidal, hydrocarbons – tarry*
Colour/ appearance	*Record any distinguishing water coloration (not sediment colour) or state if clear.*	*Red (iron-stained), clear*
Sediment	Record presence of sediment.	*Fine silt particles* *Sand and silt – 50% of unfiltered samples*
Comments	Any general comments.	–

Sample containers and field treatment

Form allows up to five sample containers with optional filtration or preservation methods.

Sample containers and field treatment

Field	Description **(with explanatory text)**	Examples
Ref	Ref for type of sample container.	*1, 2, 3*
Type	Type of container.	*PET PET (plastic) bottle* *PE Polyethylene (plastic) bottle* *GC Glass – clear* *GB Glass – brown*
Vol	Capacity of container in litres.	*0.25, 1, 2.5*
Filt	Filter used for field filtration.	*None* *'Purewater Co' 0.45 µm*
Prsv	State preservative if preservative added to container.	
Lab Ref Number or Samples Taken	Record Lab No for each container (if used) or Tick box under each monitoring point for each sample container filled.	*L35709* √

QC sample information

Use this section to record the applicability of QC samples.

Field	Description **(with explanatory text)**	Examples
Tick if QC Sample	Tick box if this is a QC sample.	√
QC Sample Type	Specify QC sample type *For QC samples only.*	*Duplicate* *Ammonia standard* *GW field blank*
Main Samples Referred to	State which main samples are covered by this QC sample. *For QC samples only.*	L1 *All SW samples*
QC Samples Referring to Main Sample	State which QC samples apply to this main sample. *For main samples only.*	*L1d* *GWfb*

Water quality measures

If determinands were monitored (for stability) during purging, records will be the same as those taken at the end of purging. Otherwise separate measurements are needed on this form.

Field	Description **(with explanatory text)**	Examples
Use Flow Through Cell	Y – yes if used; N – no otherwise.	*Y*
Temp (deg C)	Temperature in degrees centigrade.	*12.5*
pH	pH in pH units.	*7.21*
EC (µS/cm)	Electrical conductivity in µS/cm.	*630*
DO (mg/l or %)	Dissolved oxygen expressed as mg/l or % saturation.	*2.35mg/l* *28%*
Eh (mV)	Redox potential recorded as millivolts.	*−55*

Quality assuarance

Field	Description **(with explanatory text)**	Examples
Name	Name of person responsible for supervising or managing work.	*Survey: Person responsible for taking field measurements* *QC Manager: Person responsible for QC checks of data* *Manager: Person responsible for monitoring programmes*
Date	Date when each task, including paperwork, is completed.	*3/3/01*
Inits	Initials of responsible person.	*ABC*

Data processing trail

Field	Description **(with explanatory text)**	Examples
Schedule Completed	Date confirming when schedule has been checked against Monitoring Plan Specification and signed off as completed. *Include initials of person responsible for planning survey work.*	*10/3/01, ABK*
Data Validated	Date when data have been double-checked and validated. *Include initials of person responsible for validation.*	*15/3/01, PDW*
Computer Updated	Date when data have been entered into computer system (where used). *Include initials of person responsible for data entry.*	*15/3/01, PDW*

Table A8.6 Example field sheet for recording collection of water samples

Sample Collection Form		**Sheet ___ of ___**
Site Name:	Environment Agency Permit Number:	Survey Reference:
Site Operator:	Weather Conditions:	Survey Personnel:

	Monitoring Point or Sample Reference No					

Strategy and equipment used

Sample type	G/L/S/O						
Sample objective	(Use code)						
Sample equipment	(State type)						
Dedicated pump?	(Y/N)						
Purge record?	(Y/N)						

Sample collection information

Date of sample							
Time of sample	h:min						
Time since purge	min						
Depth to water:	(mbd)						
Pumping rate	(l/min)						
Odour							
Colour/appearance							
Sediment							
Comments							

Sample containers and field treatment

Ref	Type	Vol	Filt	Prsv	Lab Ref No or Samples Taken (Tick box)					
1										
2										
3										
4										
5										

QC Sample information

Tick if QC sample						
QC sample type						
Main samples referred to						
QC samples referring to main sample						

Water quality measurements (if applicable)

Use flow through cell?	(Y/N)						
Temp	(deg C)						
pH							
EC	(S/cm)						
DO	(mg/l or %)						
Eh	mV						

Quality Assurance				**Data Processing Trail**		
	Name	*Date*	*Inits*		*Date*	*Inits*
Survey:				Schedule Completed:		
QC Manager:				Data Validated:		
Manager:				Computer Updated:		

A8.8 Laboratory analysis request form

A form is required to indicate sample identities and analysis requirements to the laboratory. This should be supplied by the laboratory and should include space for information (e.g. added preservative), comments (e.g. likely concentration) and special requests (e.g. a requirement for immediate sub-sampling and preservation) relating to each sample.

A8.9 Chain of custody document

An example form is provided as Table A8.7. These forms record the movement of samples from the point of sample to the laboratory and are essential where legal issues are involved.

Heading information

Field	Description **(with explanatory text)**	Examples
Sheet __ of __:	Sequential page numbers for each sample batch.	*1 of 3*
Site Name	Name of landfill site. *It is preferable to use the name stated on the permit unless some other name is commonly used.*	*Mountain Top Landfill Site*
Site Operator	The named permit holder and/or landfill operator.	*ABC Landfill Co.*
Survey Reference	Survey Title.	*Quarterly Survey – June 2001* *Six-Monthly Survey – September 2001*
Organisation Ref	Organisation Reference Code. *Use a project code or other identifiable code relevant to the organisation responsible for the samples.* *Leave blank otherwise.*	*L1530/47*
Laboratory Ref	Laboratory Reference code. *Use a project code or other identifiable code relevant to the laboratory receiving the samples. Leave blank otherwise.*	*HA/4508*
Sampling Date(s)	Date or period of sampling. *Date or dates over which sampling was carried out.*	*5/4/2003* *5/4 to 7/42003*

Person and organisation responsible for samples

Field	Description **(with explanatory text)**	Examples
Person Responsible	Name.	*JG Smith*
Position.	Position of person responsible for samples.	*Environmental Scientist*
Signature	Signature of person responsible for samples.	–
Organisation	Name of organisation responsible for samples.	*A1 Sampling Co Ltd*
Address	Address of organisation responsible for samples.	*3 Market Street* *Moniton, Landfillshire* *MT43 6AS*
Tel No	Telephone number.	*0107 1234567*
Fax No	Fax number.	*0107 1234568*
email	email address.	*Sample.team@A1Sample.co.uk*

Sample identification

Field	Description **(with explanatory text)**	Examples
Sample Container Ref	Ref Number for each individual sample container. *Use lab ref number if provided with sample containers. Numbers should be unique and correspond with those used on Sample Form (see Table A8.6).*	*L12507*
Mon Point Ref	Monitoring point reference number. *Links each sample container to a monitoring point.*	*GW1, L1, GWA*
Date Sampled	Date sample collected.	*1/1/03*
Time Sampled	Time of sampling or period of sampling.	*14:55* *14:50 to 15:10*
Sample Type	Type of sample collected.	*L Leachate* *G Groundwater* *S Surface water*
Container Type	Type of container.	*PET PET (plastic) bottle* *PE Polyethylene (plastic) bottle* *GC Glass – clear* *GB Glass – brown*
Container Size	Capacity of container in litres.	*0.25, 1, 2.5*
No and Type of Packages	Describe packages.	*3 _ cool boxes* *1 _ milk crate*
Describe Seals or Markings	Describe sealing used for security.	*Wrapped with brown packaging tape*

Chain of custody and copy forms

This part of the form should record the passage of samples from the person and/or organisation who takes the samples to their receipt at the laboratory. The number of companies and/or individuals involved will vary, and could simply involve direct transfer from the sampler to the laboratory without separate packaging or the use of a courier. Details on the form should be modified accordingly. For legal samples, it is vital that a continuous traceable chain is recorded formally.

Field	Description **(with explanatory text)**	Examples
From (Organisation)	Organisation responsible for relinquishing samples.	*A1 Sampling Co Ltd*
Relinquished By	Name and signature of person handing over samples.	*AB Smith*
Form Copy No	Copy Ref of Signed form. *Code used to identify copy of form signed. This copy should be retained by the person and/or organisation relinquishing the sample.*	*2, 3*
Date	Date samples were transferred.	*3/3/03*
Time	Time samples were transferred	*16:35*
To (Organisation)	Organisation responsible for receipt of samples. *Name of company – e.g. a courier. For legal reasons transfers of samples internally within companies should also be recorded on this form.*	*EverFast Couriers plc*
Received By	Name and signature of person receiving samples.	*XY Jones*

Table A8.7 Example chain of custody form

Chain of Custody Record		Sheet ___ of ___
Site Name:	Site Operator:	Survey Reference:
Organisation Ref (e.g. Project Number):	Laboratory Reference:	Sampling Date(s):

Person and Organisation Responsible for Samples

Person Responsible:	Position:	Signature:
Organisation:		Tel No:
Address:		Fax No: email:

Sample Indentification

Sample Container Ref	Mon Point Ref	Date Sampled	Time Sampled	Sample Type	Container Type	Container Size (litres)	Comments

No and type of packages prepared for transfer:	Describe any seals or markings applied to packaging or samples:

Chain of Custody and Copy Forms

From (Organisation)	Relinquished by (Print name with signature)	Form Copy Number	Date	Time	To (Organisation)	Received by (Print name with signature)
		2				
		3				
		4				
		5				

1. *The* **laboratory should return the Top Sheet of the form complete with all signatures** *to the organisation responsible for the samples as soon as samples are received at the laboratory.*
2. **Copy 1** *of this form should be enclosed with samples in a sealed envelope prior to despatch to the laboratory.*
3. *The organisation relinquishing the samples should retain the form copy number indicated above.*

Appendix 9:

Example monitoring protocols

A9.1 Introduction

Two protocols are produced in this Appendix as examples:

- protocol for obtaining a sample from a borehole;
- protocol for decontamination of equipment.

The sampling protocol is partly adapted from Blakey et al. (1997), but has been revised and restructured.

Other protocols and information relating to issues such as surface water and biological samples can be derived from the National Sampling Procedures Manual (Environment Agency, 1998), or from monitoring methods described by the Standing Committee of Analysts (1996).

A9.2 Structure of monitoring protocols

A9.2.1 Generic protocol structure

A monitoring protocol should take account of all the practical tasks necessary to plan, implement and complete a procedure in a consistent and reproducible manner. The structure presented below identifies the key tasks in a protocol and provides a brief outline of issues to be considered under each task heading.

- Planning
  Client instructions; monitoring objectives; site and sample location plan; sample location details; access arrangements and routes; special procedures required for handling contaminated water; sample specification and laboratory co-ordination; personnel and time needed; general Health and Safety arrangements; notifications.
- Equipment
  Miscellaneous items; personal protective equipment; field measurement equipment; sampling equipment; sample containers, transfer vessels and crates; cleaning equipment; contaminated water storage and disposal equipment.
- Field documentation
  Job information documents; monitoring procedure documents; transport, sample submission and chain of custody documents.
- Pre-use checks and/or decontamination of equipment
  Functionality of equipment; clean and decontaminate equipment; pre-site checks.
- Monitoring procedure (e.g. taking a water sample from a borehole)
  Physical measurements; equipment assembly and installation; site calibration of equipment; borehole purging; field instrument measurements; general sample collection procedure; specialist samples (volatiles); QC samples.
- Completion and decontamination
  Equipment recovery, cleaning and decontamination; secure monitoring location; disposal of contaminated purge water.
- Sample labels, packaging, chain of custody and delivery
  Labelling and packaging of samples, documentation and chain of custody; delivery arrangements.
- Additional notes
  Additional instructions for special circumstances.

A9.3 Example protocol for sampling groundwater or leachate from a monitoring borehole by pumping

A9.3.1 Planning

Management/client instructions — **Check**

1	Client/site details with contact telephone number	
2	Project reference number/details	
3	Available budgets	

Monitoring objectives

1	Agree monitoring objectives with management/client (in writing)	
2	Define the need for specialist procedures for sampling and analysis in the light of objectives	
3	Redraft monitoring protocol to meet monitoring objectives (if necessary)	

Site and sample location plan

1	Site map showing borehole locations with reference numbers	

Sample location details

1	Obtain and summarise all information relating to the monitoring points necessary for sampling (e.g. for boreholes) Borehole depth, diameter, screened interval, approx. water level, headworks details, details of any dedicated pumping system	
2	Collate and summarise any other relevant information from previous surveys where relevant, e.g. purging and sampling rates/drawdown response to pumping/time taken to purge and sample	

Access arrangements and routes

1	Check with client the access routes and ground conditions for field vehicles/personnel	
2	Confirm any site-specific Health and Safety instructions (in writing)	
3	Agree any other conditions of entry to the site or off-site monitoring points.	

Special procedures required for handling contaminated water

1	Determine method of disposal for purge water Where doubt exists in relation to disposal of potentially contaminated waters, advice should be sought from the Environment Agency	
2	Obtain consents for disposal of purge water (if required)	
3	Prepare health and safety procedures for monitoring personnel for handling contaminated purge waters	
4	Prepare instructions for monitoring personnel for disposal of contaminated purge water	

Sample specification and laboratory co-ordination

1	Discuss the sample analytical requirements with the analyst, e.g. determinands, sample type and condition, sample containers, sample storage, reception arrangements. Other sample requirements (e.g. filtration, preservation, bottle headspace should also be confirmed).	
2	Define quality control procedures and samples to be taken	
3	Define arrangements for handling and analysis of contaminated samples	
4	Obtain quotation (where necessary)	
5	Confirm all arrangements in writing, including delivery and/or collection of prepared sample containers	

Personnel and time needed

1	Define number of monitoring personnel and experience / competence needed	
2	Define number of days required to obtain all samples	
3	Confirm budgets	

A9.3.1 Planning (cont)

General Health and Safety arrangements

1	Prepare a Site Operating Procedure (SOP) based on your organisations Health and Safety policy statement The SOP should take account of the employer's responsibility with respect to the Control of Substances Hazardous to Health (COSHH) Regulations 1988. Each SOP should be assigned a specific hazard/risk code, which can be used to identify appropriate Personal Protective Equipment (PPE) for the task	

Notifications

1	Notify all interested parties of arrangements for sampling., e.g. client, site manager, Environment Agency, landowners, etc.	

A9.3.2 Equipment

Miscellaneous items

1	Vehicle (specify if 4WD or specialist transport needed)	
2	Keys for monitoring points and site and other points of access.	
3	Tool kit For monitoring equipment and to help with access to borehole headworks	
4	Spare fuel, oil and batteries for equipment	

Personal protective equipment

1	Basic PPE equipment, e.g. overalls, safety boots, hard hat, high visibility jacket, ear defenders, goggles, disposable gloves, protective gloves	
2	Other PPE equipment (specified by Health and Safety assessment), e.g. face masks and filters, etc.	
3	Wet weather or cold weather clothing, e.g. overtrousers, kagoule, thermals, thermal gloves, etc.	
4.	Communications equipment, e.g. mobile phone and/or site radio (check site-specific safety aspects for use) If working alone, make arrangements for confirmed communication with third party	

Field measurement equipment

1	Groundwater level dipper Check length is sufficient for all monitoring points	
2	Weighted plumb line Check length is sufficient for all monitoring points	
3	Tape measure	
4	Temperature meter and probe	
5	pH meter, including probe and calibration solutions	
6	Conductivity meter, including probe and calibration solutions	
7	Dissolved oxygen (DO) meter, including probe and calibration solutions	
8	Eh meter, including probe and calibration solutions	
9	Flow through cell Including tubing and coupling attachments	
10	Beaker(s) for field measurements (where flow through cell not available)	
11	Deionised or distilled water in rinse bottle	

Sampling equipment

1	Pumping and sampling equipment, e.g. Bailers, reel and lifting cable Inertial pumping equipment, including valves, tubing, extension tubing, actuator, tools Submersible pumping equipment, including generator, control box, hose and reel Bladder pumping equipment, including air supply, control box, hose and reel Suction pump equipment, including suction hose, discharge hose and tools Peristaltic pumping equipment, including silicon sample tubing	
2.	Flow- or volume-measuring equipment, e.g. Graduated bucket or drum Bucket and stopwatch (for flows up to approx. 30 l/min) Cumulative flow meter (for steady pumped discharges)	

Sample containers, transfer vessels and crates

1	Crates for carrying equipment to and from monitoring points	
2	Sample bottles (supplied by lab)	
3	Quality control samples and containers, e.g. field standards and blanks (NB At least one duplicate sample should be obtained for every 10 samples taken)	
4	Filtration and preservation equipment, e.g. disposable cartridge filters, preservative solutions (where supplied by lab outside of supplied bottles)	
5	Transfer sample vessels, e.g. beakers, funnels	
6	Packaging crates, e.g. cool boxes containing pre-frozen freezer packs	

Cleaning equipment

1	Sample area cleaning equipment, e.g. plastic sheet, paper towels	
2	5 litre container of clean water For rinsing equipment, probes, etc.	
3	Equipment decontamination solutions and vessels	

Contaminated water storage and disposal equipment

(NB if purge water has to be disposed elsewhere for treatment, separate arrangements should be made in advance of site work for storage of water prior to disposal.)

1	Temporary pumping storage reservoir, e.g. 200 litre plastic bins	
2	Purge water discharge equipment, e.g. siphon tubing with inertial foot valve and/or suction pump and hose	

A9.3.3 Field Documentation

Job information documents

1	Site plan showing monitoring locations	
2	Monitoring point register	
3	Copy of monitoring protocols	

Monitoring procedure documents

1	Field notebook	
2	Equipment calibration form(s), e.g. for field instruments pH, EC, DO, Eh	
3	Purging record form	
4	Sampling record form	

Transport, sample submission and chain of custody documents

1	Laboratory submission forms, e.g. Laboratory labels (if separate from bottles) Laboratory manifest and/or analysis request forms	
2	Chain of custody forms (if needed)	
3	Courier manifest (if needed)	

A9.3.4 Pre-use checks and/or decontamination of equipment

Functionality of equipment

1	Check all equipment is operational, e.g. check batteries, probes, meters, etc., are in working order	
2	Check calibrate equipment, e.g. dip meters, pH, temperature, conductivity, Eh and DO probes Ensure that calibration and standard solutions are in date for use during the sampling exercise	

Clean and decontaminate equipment

1	Clean all equipment, e.g. all equipment used to contact samples should be cleaned	
2.	Decontaminate equipment, e.g any equipment used for previous sampling should be decontaminated (see separate procedure)	
3.	Familiarise monitoring personnel with site cleaning and decontamination procedures Where special procedures are required, monitoring personnel should be informed fully at this stage	

Pre-site checks

1	Complete sample identification information onto sample bottle labels Check details on pre-printed labels supplied by laboratory (particularly where these are linked to computerised reception arrangements at the laboratory); labels should be placed on the container itself rather than the lid	
2	Define calibration frequency for each instrument, e.g. EC – a.m./midday/p.m. pH – at each monitoring point DO – at each monitoring point etc.	
3	Check all equipment into vehicle	

A9.3.5 Monitoring procedure (e.g. taking a water sample from a borehole)

Physical measurements

1	Unlock and/or remove protective cover Where dedicated sampling equipment is installed in a borehole, this should not be disturbed until after completion of physical measurements to avoid displacement of the standing water level	
2	Observe and record damage to condition of surface seals, headworks and lining	
3	Measure and record organic vapour reading (if required) Use a photo-ionisation detector or organic vapour detector	
4	Measure and record specific gas concentrations (if required), e.g. methane, carbon dioxide, hydrogen sulphide Use a flammable gas or specific gas detector	
5	Measure and record depth and thickness of any floating product layer (if required) Use an oil–water interface probe.	
6	Describe and record height of datum point used for measurements above ground level Use tape measure or dipper	
7	Measure and record borehole dimensions and water level relative to datum e.g. lining diameter (d), depth to water (dip), depth to base of borehole (depth) Using a groundwater level dipper for water levels; use plumb line for depth measurements If borehole dimensions vary significantly from borehole records, particularly if the screened section of the borehole is blocked, take advice before sampling. Highlight this information on standard field forms	
8	Calculate and record borehole water volume: Length of water column in borehole (L) = depth — dip 1 _ borehole volume = $\pi d^2.L/4$ (using consistent units).	
9	Calculate and record purge volume (if required), e.g. 3 _ borehole volume	

Equipment assembly and installation

1	Layout and assemble all purging, field measurement and sampling equipment Use clean plastic sheet wherever practical or necessary Separate sampling, field measurement and purging equipment	
2	Layout all sample bottles and decontaminated sampling equipment in an area free from possible sources of contamination and separate from other equipment	
3	Ensure sample bottle labels are correct and firmly attached	
4	Layout and separate all specialist sampling equipment and containers Where volatiles are being sampled, cleanliness and separation of all sampling equipment from volatile sources such as petrol fumes is vital; quality control samples should be distributed as necessary for this purpose	
5	Layout discharge point for purge water, e.g. area of ground or ditch set aside for clean discharges unrestored landfill area set aside for leachate discharges storage containers to receive contaminated purge water NOTE: Any discharges to surface should be directed at a sufficient distance from the borehole to prevent water returning to the borehole head works	
6	Install or adjust purging and/or sampling equipment to appropriate depth in borehole, e.g. *for dedicated equipment already set at a fixed intake level: do not disturb* *for other dedicated equipment: lift or lower gently to pumping depth* *for non-dedicated equipment: lower to pumping depth* Depending on equipment used, secure or mark pumping position (e.g. by locking the cable drum or by using a catch-plate) Record intake position of pump in borehole	
7	Connect pumping equipment to power and control sources, e.g. generator or actuator or compressor and any control units	

Site calibration of equipment

1	Re-calibrate all equipment on site as required, e.g. EC, pH, DO, Eh – at each monitoring point or 2–3 times per day; record on calibration record form	

Borehole purging

1	Connect discharge hose from borehole pump outlet to discharge point or storage containers	
2	Set up discharge flow measurement arrangements, e.g. connect discharge to flow meter prepare personnel with bucket and/or stop watch	
3	Connect discharge to flow-through cell (if used to monitor stability of water quality during purging) Flow-through cell should be set-up with field instruments already connected	
4	Start pumping and adjust pumping rate, e.g. match to predetermined purge rates match to borehole yield run pump at max. capacity	
5	Measure and record as necessary, e.g. discharge volume and flow rate field measurements (Temp, pH, EC, DO, etc.) water level	
6	Continue pumping and recording measurements until purging criteria met Reduce pumping rate or cease pumping at end of purge	
7	Measure and record water level on completion of purge (where siltation is likely to occur, also record depth to base of borehole)	

Field instrument measurements

1	Measure and record field measurements immediately before or at the time of sampling, e.g. temperature, pH, EC, DO DO and Eh measurements should be carried out in a flow-through cell only pH, temperature and EC may be recorded in a beaker	

General sample collection procedure

1	Measure and record water level before sampling Ensure water level is not below any criteria specified by sampling objectives; Note, in particular, where the level of water is lower than the screen intake level in the borehole	
2	Reduce pumping rate to 1 litre/min or less	
3	Take samples that do not require field filtration or preservation Fill the sample bottles direct from the discharge tubing wherever possible. Rinse the bottles with sample water and fill to the top, leaving no air space. Check sample label, adding any necessary additional information	
4	Take samples that require preservation without field filtration Fill as above, *but do not rinse* bottles and only fill to level in bottle as instructed by laboratory	
5	Take samples that require field filtration without preservation Use filtration device according to instructions and fill directly from filter or filtration device into sample bottle. Rinse the bottle with filtered sample water and fill to the top, leaving no air space. Check sample label, adding any necessary additional information Filtration for metal determinands is normally through a 0.45 µm membrane filters (after discarding the first aliquot of filtered sample).	
6	Take samples that require field filtration and preservation Filter and fill as above, *but do not rinse* bottles and only fill to level in bottle as instructed by laboratory	

Specialist samples –(volatiles)

1	Reduce pumping rate to 0.5 litre/min or less	
2	Take sample, ensuring no aeration at discharge point from pump, e.g. base-fitting valve discharge from bailer (not poured) siphon discharge from inertial pump low-flow discharge from submersible pump direct discharge from bladder pump	
3	Fill glass vial or other sample container to the brim and screw on the cap with PTFE-lined septum; check sample, adding any necessary additional information There should be no headspace within the vial	
4	Immediately store the vials upside-down in a cool-box to minimise the loss of volatiles	

Quality control samples

1	Collect sample duplicate (as required) Collect full set of duplicate samples following sample procedures set out above; one in 10 samples is the recommended ratio for duplicate samples	
2	Collect field standard and field blank samples (as required) These samples are rinsed through the sampling equipment into containers identical to the main samples, immediately after sampling; check sample labels, adding any necessary additional information	
3	Any trip standards and blanks should remain unopened unless specified otherwise; check sample labels, adding any necessary additional information Trip standards and blanks are samples prepared in the laboratory, transported to the field and returned to the laboratory. They are generally never opened, although some require field preservation. They provide a control for the field standards and blanks	

A9.3.6 Completion and decontamination

Equipment recovery, cleaning and decontamination

1	Withdraw non-dedicated equipment from borehole, taking care not to damage equipment or borehole	
2	Disassemble the equipment on the plastic sheet, rinse with clean, deionised or distilled water, as appropriate, and pack the equipment away	
3	Rinse all non-disposable sampling accessories (e.g. bailers) with organic-free and/or deionised water before packing them away	
4	Remove all storage and transfer equipment from site	

Secure monitoring location

1	Replace protective covers on monitoring points and secure	

Disposal of contaminated purge water

1	Dispose contaminated purge water, e.g. *Disposal off-site*: ensure all containers are made safe for transport and disposal and/or make arrangements with disposal company to collect *Disposal to alternative site location*: transport or pump to on-site disposal area (e.g. open landfill area, leachate sump) *Returned to adjacent irrigation point/leachate borehole*: Siphon or pump water to disposal point	
2	Dispose of heavily contaminated or disposable equipment	

A9.3.7 Sample labels, packaging, chain of custody and delivery

Labelling and packaging of samples

1	Clean the outer surface of all sample containers with paper towels (dye free) using deionised or organic-free water, as necessary	
2	Check that all sample bottles are labelled correctly and securely	
3	Seal each sample container as appropriate, e.g. by wrapping tape around lid. (e.g. Teflon tape on volatile samples; use PVC tape on all other samples)	
4	Protect containers from breakage as appropriate, e.g. place polynet over glass containers and/or wrap in bubble pack and securely tape bubble pack	
5	Place all samples in storage and transport containers, e.g. cool boxes that contain freezer packs (where preservation requires) crates or cartons	

Documentation and chain of custody

1	Record all samples taken on sample collection forms	
2	Complete laboratory analysis request forms and place one copy inside sample transport containers	
3	Prepare chain-of-custody documentation (if required) and seal one copy inside sample transport containers	
4	Seal all transport containers with tape	
5	Sign and date custody seals (if required) and secure over openings of all transport containers	

Delivery arrangements

1	Prepare courier manifest	
2	Hand over sample to courier or transport directly to laboratory All samples should be delivered to a laboratory within a stated time period from sampling (ideally on the same day as sampling) Delivery time will be dependent on the range of analysis requested, in accordance with sample holding times determined by preservation, storage and transport arrangements Chain-of-custody documents should be completed each time samples are transferred to another person or company	
3	Deliver to laboratory Delivery of samples should be receipted by laboratory; Chain-of-custody document should be completed where necessary	

A9.3.8 Additional notes

Additional instructions for special circumstances

1	Equipment used for sampling 'contaminated' water should be marked appropriately and must be stored and maintained separately from equipment used for 'clean' water samples	
2	Where dedicated sampling equipment for each borehole is not available, and previous monitoring data demonstrate that a range of levels of contamination will be encountered during a sampling exercise, attempt to commence the sampling exercise with the least-contaminated borehole, finishing with the most heavily contaminated borehole.	
3	For large-diameter observation boreholes, a dual pump array for purging and sampling may be required	
4	Conditions in the borehole (e.g. presence of silt or other heavy particulates) may affect the temporal variations in the data, or be responsible for systematic trends; where changes in borehole conditions are encountered, monitoring personnel must discuss observations with their supervisor prior to sampling	

A9.4 Example protocol for decontamination of equipment

The following protocol is based on the American Society for Testing Material (ASTM 1997) standard D5088.

A9.4.1 Planning Decontamination objectives

1	Determine which equipment needs to be decontaminated and to what extent, e.g. determine sample requirements (e.g. inorganic, organic or both) identify all equipment that will contact the water sample identify other non-contacting equipment for cleaning	

A9.4.2 Equipment

Reagents

1	Detergent – non-phosphate detergent solution, e.g. Alquinox, Liquinox, Decon 90	
2	Acid rinse (inorganic desorbing agent), e.g. 10% nitric or hydrochloric acid solution made from reagent-grade nitric or hydrochloric acid and deionised water	
3	Solvent rinse (organic desorbing agent), e.g. isopropanol, acetone or methanol (pesticide grade).	
4	Control rinse water, e.g. should be from a water supply of known chemical composition	
5	Deionised water, e.g. organic-free reagent grade	

A9.4.3 Cleaning of equipment in contact with water sample

Minimum procedure

1	Wash equipment in detergent solution	
2	Rinse with control rinse water	

Inorganic analyses — rigorous procedure

1	Wash equipment in detergent solution using a brush made of inert material to remove any particles or surface film Where a brush is inadequate or cannot be used, detergent solution should be circulated through the equipment (e.g. through sample tubing or pumps)
2	Rinse or flush equipment thoroughly with control water
3	Rinse or flush with inorganic desorbing agent
4	Rinse or flush with control water

Organic analyses — rigorous procedure

1	Wash equipment in detergent solution using a brush made of inert material to remove any particles or surface film Where a brush is inadequate or cannot be used, detergent solution should be circulated through the equipment (e.g. through sample tubing or pumps)	
2	Rinse or flush equipment thoroughly with control water	
3	Rinse or flush with inorganic desorbing agent (not necessary if samples will not be used for inorganic chemical analyses)	
4	Rinse or flush with control water	
5	Rinse or flush with organic desorbing agent	
6	Rise or flush with deionised water	
7	Allow equipment to air-dry before next use	
8	Wrap equipment for transport with inert material until used for sampling, e.g. aluminium foil or plastic wrap	

A9.4.4 Cleaning of other non-sample contact equipment

General procedure

1	Clean equipment with portable power washer or steam-cleaning machine or (for smaller items) Hand wash with brush using detergent solution	
2	Rinse with control rinse water	

A9.4.5 Record keeping

General procedure

1	Record date, time and decontamination procedure used for each item of sample equipment	
2	Record individuals involved in procedure	
3	Record details of type and name of reagents used, including rinse water	

REFERENCES

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Appendix 10:

Sampling equipment

A10.1 Introduction

The content of the following Appendix is drawn from a number of sources, but acknowledgement is particularly given to Blakey et al. (1997), from which some of the following sections are reproduced or paraphrased.

A10.2 Level measurement equipment

A10.2.1 Water level and depth measurement devices for use in boreholes

Water levels in boreholes can be measured by a variety of devices, of which the most commonly used are electric tapes. Other methods, such as pressure transducers or float devices, are sometimes used for remote or continuous monitoring by connecting to a data logger or chart recorder.

Electric tapes

Used for recording water and leachate level in vertical structures. An electrical circuit is formed when the contacts on the probe are submerged in water.

In highly conductive waters (e.g. leachates) the contact may remain formed for a long time and can even be set off by moisture in the structure, giving inaccurate results. This can sometimes be overcome by the use of a sensitivity switch and by shrouding the probe.

In low-conductivity waters (e.g. some groundwaters), the conductivity of the water may be insufficient to form the contact. This can also be overcome by the use of a sensitivity switch.

Tapes can stretch – particularly in hot environments. They should be periodically calibrated against a tape not used for dipping purposes. Where lengths are inaccurate by more than 1 cm in 30 m (0.03%), the tape should be replaced.

Tapes can break by catching on snags. When repairs are made in which a short length (e.g. 1 m) is cut off, it is easy to misread measurements. To avoid confusion, it is recommended that any cuts are made at lengths of at least 5 metres and preferably at 10 metres.

Plumb lines

Depth to the base of a monitoring point is best measured with a weighted plumb line. In practice, this measurement is commonly made using electric water level tapes (and some manufacturers have developed probes that electronically signal when the base is reached). Most water level tapes are not pressure rated to be submerged below the water level without the possibility of leakage breaching the probe seals. They are rarely sufficiently weighted to be able to reliably confirm the base level of deeper monitoring points, which can compromise the accuracy of the measurement.

Any electric tape or plumb line used for depth measurement should be:

- capable of recording levels to an accuracy of 1 cm in 30 m (0.03%);
- calibrated at least annually against a tape of constant length
  plastic-coated electric tapes can stretch, particularly where affected by higher temperature leachates or exposed to high ambient temperatures for prolonged periods.

  Any tape unable to meet the specified measurement accuracy (i.e. to within 0.03%) should be replaced.

Floats

Floats are not commonly used, except in water level recorders.

Transducers

Pressure transducers record pressure in a fluid at a point of measurement. Combined with data loggers, they are ideal for remote locations or where continuous records need to be obtained. Data can be downloaded from data loggers direct to the computer.

Accuracy and reliability of transducers is variable, and it is important to install a transducer of appropriate specification for the range of depths to be measured. They should be calibrated frequently against measurements using dip meters and should be capable of measuring to an accuracy similar to that of a dip tape (i.e. 0.03%).

A10.3 Borehole sampling equipment

A10.3.1 Introduction

Flow rates for purging boreholes should be high enough to be time efficient without causing significant drawdown of the water level or disturbance of the sample. Flow rates used during sampling should be low to prevent agitation and/or aeration of the sample during transfer. Barcelona *et al*. (1984) recommend flow rates not greater than 100 ml/min for sampling volatile chemical constituents. As with all sampling equipment, selection must be site specific and consideration must be given to the determinands sampled.

Many sampling methods and types of sampling device are capable of obtaining leachate and groundwater samples from boreholes; all have their advantages and disadvantages. On some occasions it may be necessary to use separate devices for purging and sampling (e.g. a pump for removal of purge water followed by a bailer used for sampling). The following section provides information on the most common methods and devices currently in use, under the general headings:

- Bailers and depth samplers;
- Suction pumps;
- Inertial pumps;
- Electric submersible pumps;
- Gas-displacement and bladder pumps.

A10.3.2 Bailers and depth samplers

Bailers and depth samplers can be obtained for use in monitoring points over a wide range of diameters, and can be constructed from a wide range of plastics or stainless steel. These devices provide a simple means of obtaining a 'grab' sample, either from the top of the water column (bailers) or from a specific depth in the water column (depth samplers). Both methods involve manually (or mechanically) lowering the sampling device into the borehole on a rope or wire and then withdrawing the device full of water to the ground surface.

Bailers can also be used as a means of purging boreholes, though this involves a great deal of physical effort and is less efficient than pumping methods.

Advantages and disadvantages are summarised in Table A10.1. For a more comprehensive discussion on bailers, see for example Nielsen and Yeates (1985) and MacPherson and Pankow (1988).

Bailers

Bailer are lowered to the water table where they are allowed to fill before being pulled back to the surface for sample recovery. Bailers are usually constructed from PVC, polypropylene, PTFE (Teflon) or stainless steel.

The bailer may be of varying levels of sophistication:

- bucket type (open top, sealed base);
- bottom check-valve only (Figure A10.1). A ball and seat arrangement remains open during the sampler's descent, but closes under the weight of liquid in the sampler during removal;
- Double check valve bailer (point source bailer – Figure A10.1). Theoretically, both the upper and lower check valves close once the bailer stops descending through the water column, to collect a point-specific sample. Double check-valve bailers allow depth sampling within the borehole.

Discrete depth samplers — manually activated

The simplest type of depth samplers are triggered via a weighted messenger clipped to the support line, which allows a sample to be grabbed from a predetermined point in the borehole. The bottom seal is often fitted with a valve and sampling tube to minimise aeration of the sample.

The advantages of the this type of bailer are:

- ability to sample at a preselected level in the borehole;
- inexpensive.

Figure A10.1 Bailers and depth samplers

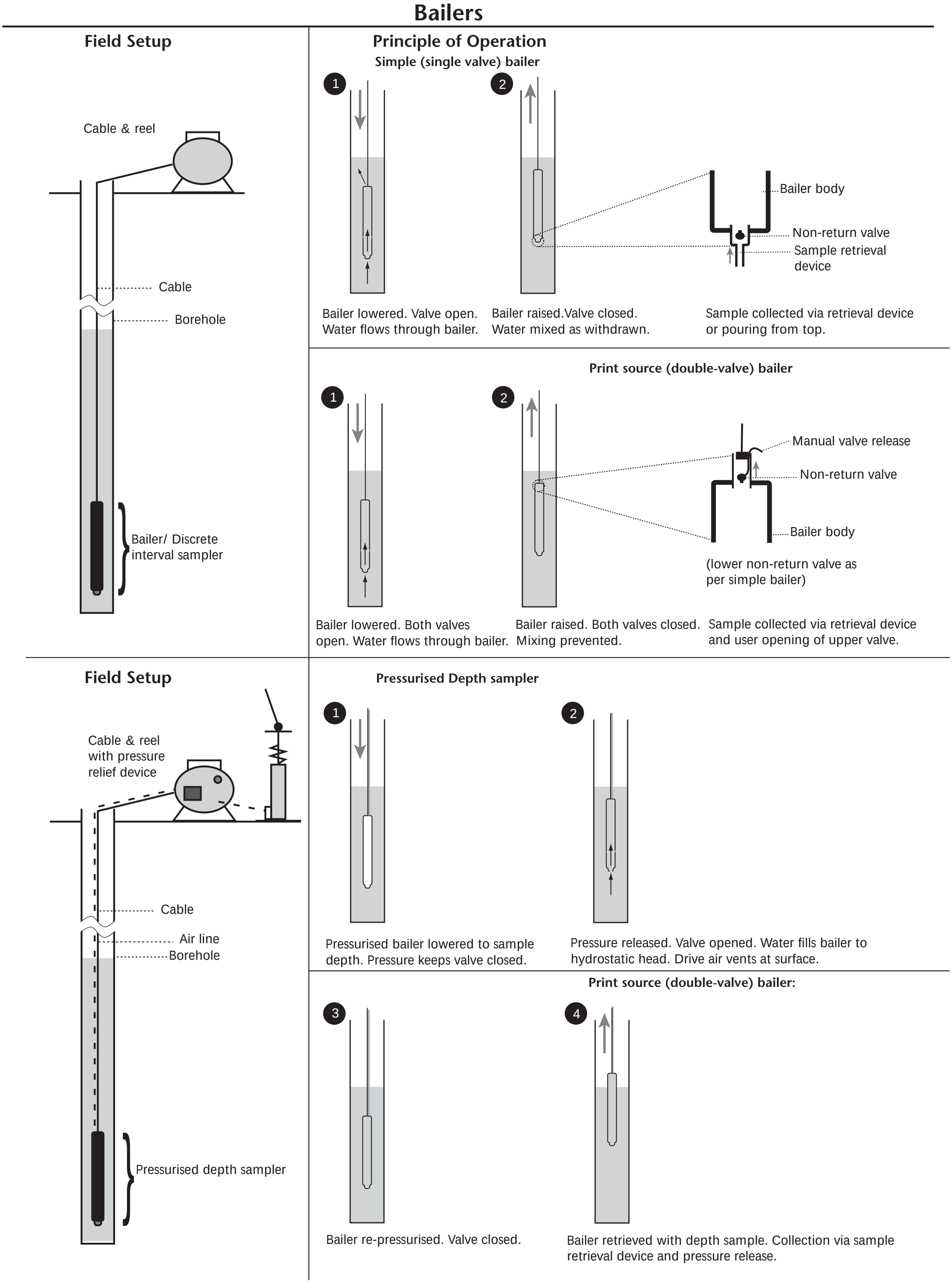


Table A10.1 Common types of borehole sampling equipment

Equipment type	Description	Advantages	Disadvantages
Depth samplers			
Bailers	Cylinder of appropriate diameter on rope or wire Ideally filling through bottom check-valve Can be PVC, PTFE, stainless steel, or other material	Low cost Dedicated or disposable options Easy to operate Readily portable	Can only sample top of water column Low abstraction rate makes purging slow Causes agitation if operated too vigorously Bailing cable a source of cross-contamination
Discrete depth samplers	Container with closure at each end – either a valve or a trigger mechanism Lowered to required depth, sample, then withdraw	Low cost – can be dedicated Fairly easy to operate Readily portable Can take depth profile of water column by sequential sampling	Low abstraction rate makes purging slow Causes agitation if operated too vigorously Closures can fail, particularly when suspended solids present
Pumps			
Electric submersible	Electrically powered positive displacement pumps, down to 50 mm diameter	50 mm diameter pumps can operate to approx. 75 m depth Larger diameter pumps will operate deeper Easy to operate Can be used for purging Can be used for low-flow purging[1]	Need vehicular access for equipment (heavy) Cause pressure changes and agitation Reduced capability in presence of suspended solids and higher temperatures
Inertial	Length of tubing with foot valve Oscillation causes water column to rise up tube Can be powered by hand or mechanically	Low cost dedicated system Can operate to approx. 60 m depth[2] Lightweight and portable mechanical unit available Simple field maintenance Can operate in silty conditions Can be used for purging[2]	Can entrain suspended solids Causes agitation of sample
Suction (including peristaltic)	Surface mounted pumps operating by suction exerted on water column	Pump is at surface – dedicated tubing can be left in hole Inertial pumps can be used as priming mechanism to avoid cross-contamination	Can only operate to 7.6 m depth or less Suction degasses sample Causes pressure changes and agitation May require priming, causing cross-contamination
Gas lift	Compressed air or gas provides positive pressure in sampler, driving sample to surface	Can operate to any depth	Gas comes into contact with sample, which may be degassed or subject to pressure changes Compressor and/or tank must be taken to site
Bladder	Compressed air or gas enters bladder in sampler, forcing sample to surface Down to 50 mm diameter	Can operate to any depth Little sample disturbance Can be used for low-flow purging	Relatively expensive Low abstraction rate makes purging difficult

1. Use of low flow rates can cause suspended solids to fall back down discharge line, resulting in blockage of the pump.
2. If operated mechanically.

The disadvantages are:

- water passing through the tube as it travels downward may not be completely flushed out by the time it reaches the desired sampling level;
- the device may not seal completely in water that contains suspended particles (though this problem is less frequent than it is with bottom check-valve bailers).

Discrete depth samplers – mechanically activated

Essentially, these are the same as the manually activated systems with the exception that activation is either pneumatic (Figure A10.1) or electrical. However, depth samplers such as these do provide a more representative sample than bailers, while still being inexpensive, reliable and easy to maintain and operate. They are ideal for groundwater sampling for the analysis of general chemical parameters. Sequential sampling from the water surface to the bottom of the borehole is possible, which enables a profile of the water column to be measured.

A10.3.3 Suction pumps

Suction-lift mechanisms are surface-mounted pumps, which are electrically, diesel or petrol powered. The practical limit of suction lift of approximately 7.6 m (at sea level, reducing with altitude), means this method of sampling is only practical for shallow water levels. The most commonly employed suction-lift pumps are the surface centrifugal pump and the peristaltic pump.

Advantages and disadvantages are summarised in Table A10.1.

Surface centrifugal pumps

The pump must first be primed by filling the impeller housing (self-priming). Water in the rotating impeller is discharged by a centrifugal force, which creates a partial vacuum, lifting water out of the borehole (Figure A10.2). These pumps are capable of very high delivery rates.

Suction pumps can be used readily for purging boreholes with shallow water levels, but there are several disadvantages to their use for sampling purposes:

- degassing of volatile compounds through the negative pressure caused by the vacuum;
- degassing through the action of the impeller, which imparts both a significant pressure change and a high degree of turbulence to the sample;
- potential cross-contamination from the priming water.

Peristaltic pump

These are self-priming, low-volume vacuum pumps that consist of a rotor and several ball-bearing rollers within a pump head (Figure A10.2). Flexible tubing is squeezed by the rollers as they revolve around the rotor, creating suction. One end of the tubing, typically fitted with an intake strainer or screen, is placed into the borehole, while the other is directed into a sample container. Only the tubing comes into direct contact with the sample. However, only silicone tubing has the flexibility to be used around the rollers, but this is unsuitable for sampling some constituents (primarily organics) because of its adsorbing character.

Peristaltic pumps are particularly useful where samples have to be collected from narrow access tubes.

The largest perceived disadvantage of a peristaltic pump is that it subjects water samples to negative pressures, which will affect the concentrations of dissolved gases and the pH of samples taken. Barker et al. (1987) suggest that volatilisation losses using suction-lift devices are insignificant relative to analytical and hydrogeological uncertainties.

A10.3.4 Inertial pumps

Inertial pumps are comparatively cheap and suitable for a wide range of applications; their use as dedicated samplers is increasing.

The operating principle of the pump is based on the inertia of a column of water contained within a riser tubing. The pump consists of a foot valve connected by a rigid or semi-rigid rising main that runs to ground level. The whole system is alternately lifted and lowered at a rate sufficient to drive water continuously upwards to discharge at the surface (Figure A10.3).

The pump can be operated manually at shallow depths, though it is better used with a powered mechanical drive system to achieve greater lifts (e.g. to 60 m in a 50 mm diameter borehole).

The inertial pump is suitable for well development and purging, and can operate in silty and/or sandy environments. Problems with the inertial pump arise from potential mixing of the water column in the casing caused by the up and down movements of the tubing and foot valve. However, experiments with dye have shown that mixing along the length of the casing is relatively insignificant compared to

Figure A10.2 Suction pumps

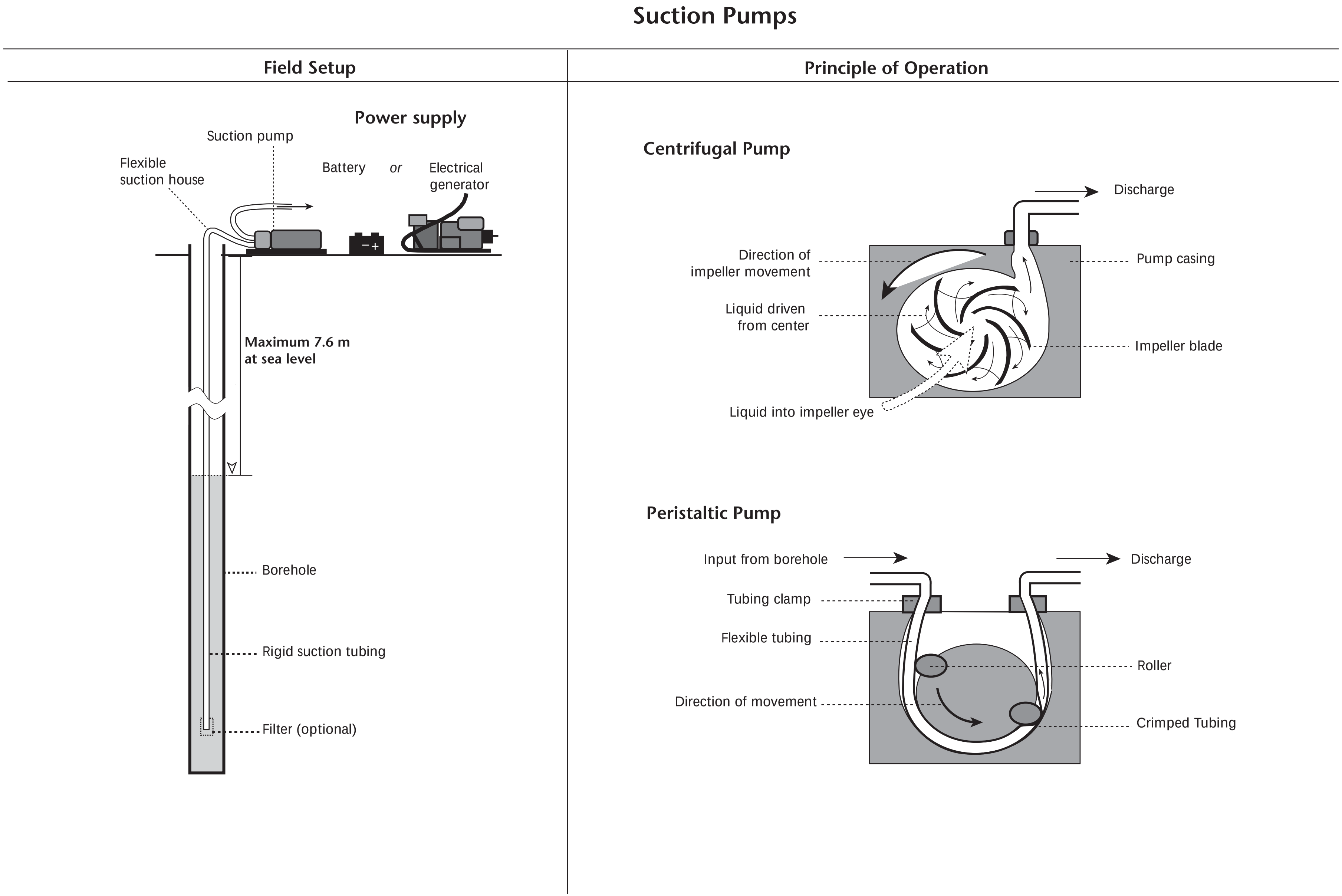
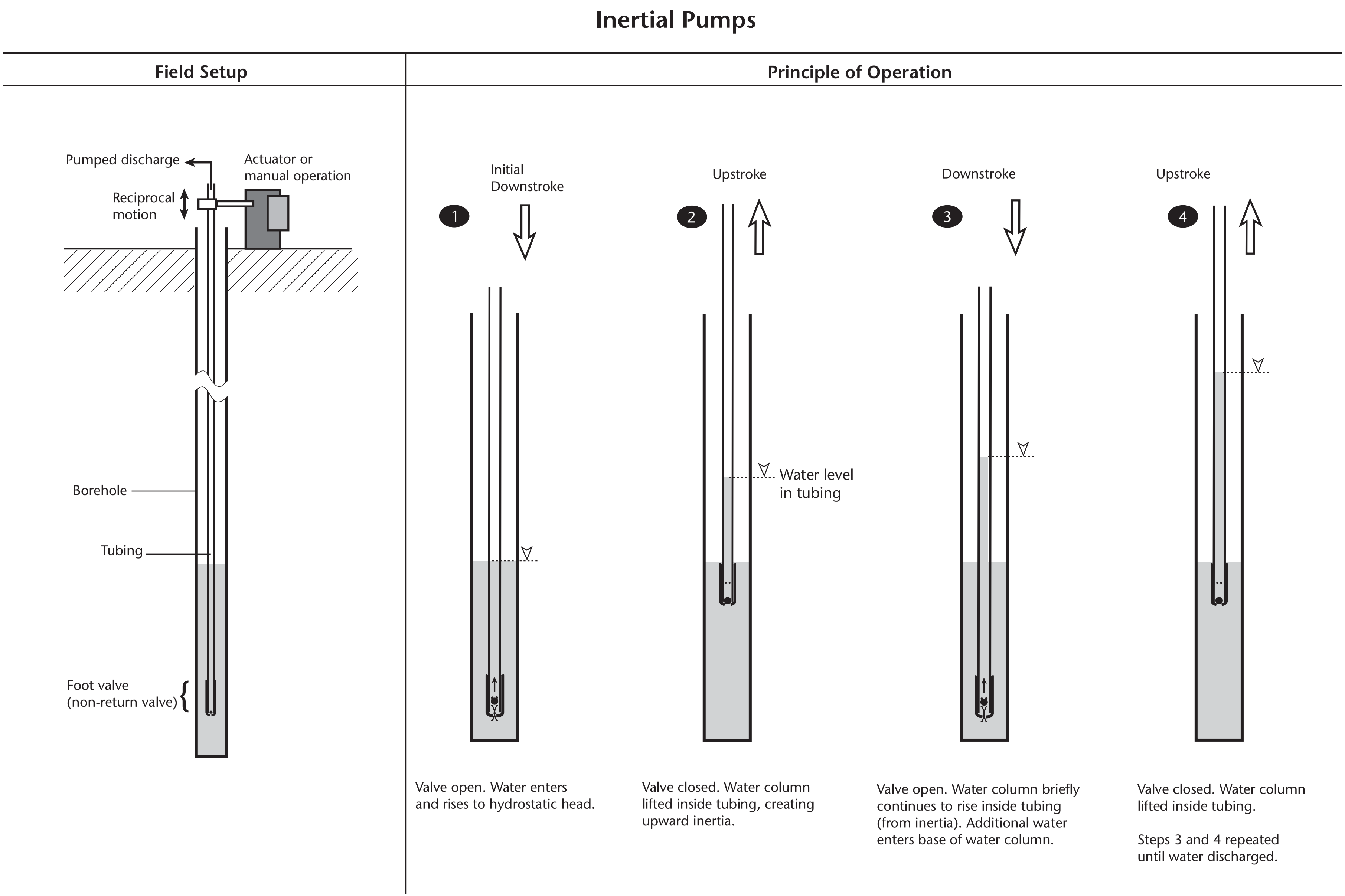


Figure A10.3 Inertial pumps



mixing across the diameter of the casing (Rannie and Nadon 1988). Other possible problems include agitation of the sampled water, and disturbance of accumulated sediment. With regard to the former, the pump has been tested for sampling volatile organics at depths of up to 8 m (Barker and Dickhout 1988), and in some instances performed better than a bladder pump. Placing the intake high in the water column, provided sufficient depth of water is available, can reduce disturbance of sediment.

One of the main advantages of the inertial pump is that its drive mechanism and pump construction materials can be selected to suit a variety of technical and budgetary requirements. Its relatively low cost compared to other pumps and the fact that stiff tubing coils can make it difficult to transfer the pump between monitoring wells, make it more suitable for use as a dedicated pump in monitoring wells for both leachate and groundwater sampling.

Advantages and disadvantages are summarised in Table A10.1.

A10.3.5 Electric submersible pumps

Electric submersible pumps operate by driving water upwards using helical rotors or gears.

Both types of pump have an electric motor below the pumping mechanism, which draws in water under slight suction, then pressurises it for discharge. In the helical rotor pump, water enters the pump through a screened intake in the middle of the pump (above the electric motor) and is pushed upwards through a rotor-stator assembly (Figure A10.4). Water is transported to the surface through a discharge line. In the gear-drive pump, the motor drives a set of two gears, which induce water through an intake screen at the top of the pump. Water is drawn through the gears and pushed in a continuous stream through a discharge port to a discharge line, which transports the water to the surface for sampling.

The inner workings of both types of pumps can be fabricated of inert or nearly inert materials. The only parts that require replacement under normal field use are the two PTFE gears in the gear-drive pump. With prolonged purging and/or sampling of water with high suspended solids, these gears may wear, resulting in diminished pump output. Water with a high suspended solids content can also cause operational problems in the helical rotor pump. High lift capabilities exist for deep-well applications (up to 600 m). From small-diameter monitoring boreholes, lifts are typically 50 m (for pumping from 50 or 75 mm diameter boreholes) to 100 m (for pumping from 100 mm diameter boreholes).

High pump rates may lead to the creation of turbulence and heat generation, especially in the helical rotor pump, which may cause alteration of sample chemistry. The potential for pressure changes (cavitation) exists at the drive mechanisms of the gear-drive pumps. Some pumps have temperature cut-out controls, which prevent their use in fluids (e.g. leachates) above the cut-off temperature.

Both types of pump are highly portable and reliable to operate, except under silty conditions.

Advantages and disadvantages are summarised in Table A10.1.

A10.3.6 Gas-displacement and bladder pumps

Gas-displacement and bladder pumps operate on the same principle, using hydrostatic pressure in the water to fill the pump chamber and compressed air to displace the water to the surface (Figure A10.4). Advantages and disadvantages are summarised in Table A10.1.

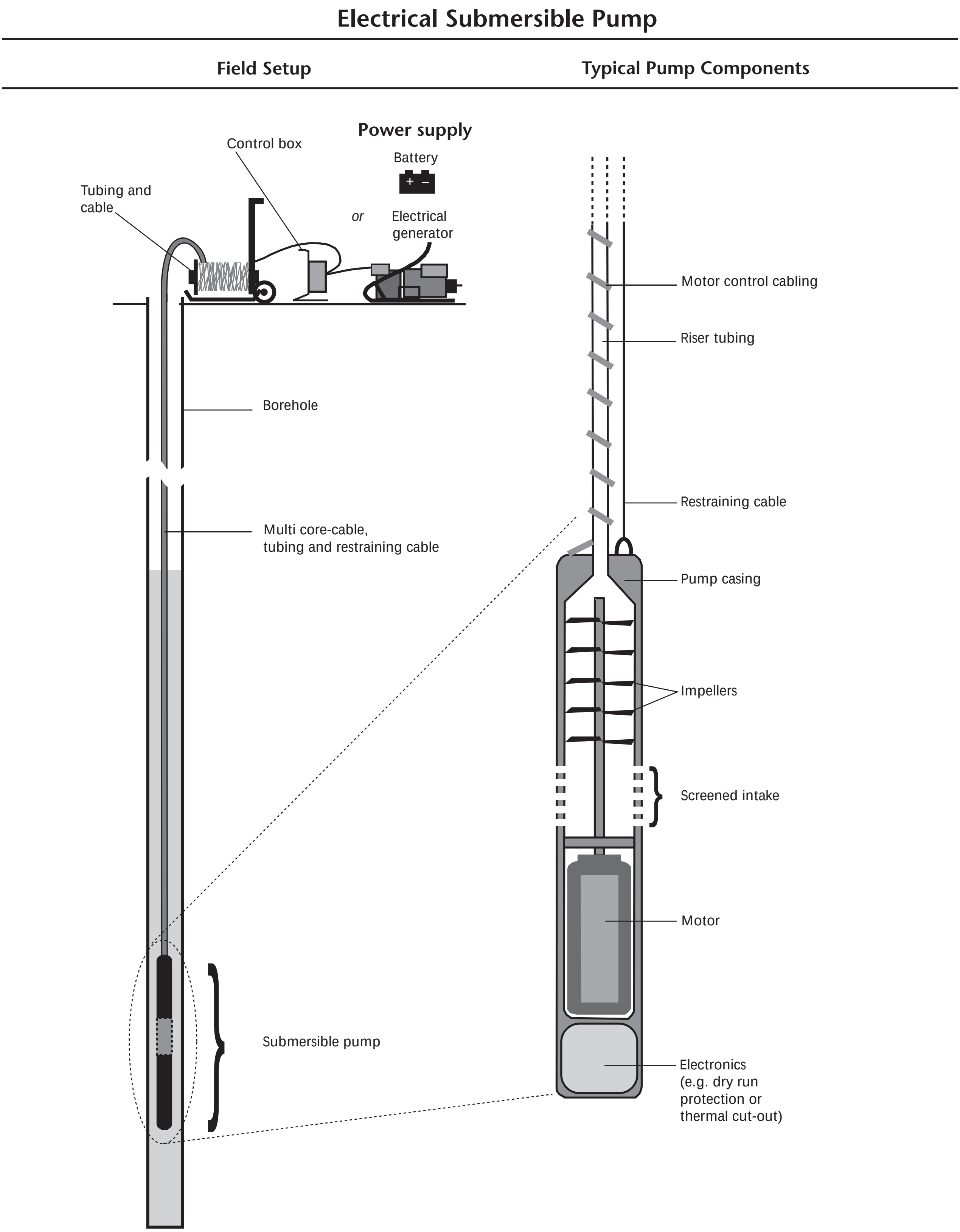
Gas-displacement pumps

A wide variety of gas-displacement pumps are available, each with a slightly different design. The simplest type of device consists of a rigid cylindrical chamber, a screened intake, a bottom water-entry check-valve, a gas-entry tube and a sample discharge tube, which are attached to the top of the cylinder. Both the gas-entry and sample-discharge lines extend into the cylindrical chamber, with the sample discharge line extending almost to the bottom (Figure A10.5).

The pump is lowered to the required sampling depth and the system fills with groundwater. A positive gas pressure is applied for a fixed period through the gas-entry tube to first close the bottom check-valve and then force groundwater up the discharge line. After a fixed period has elapsed, the pressure within the system is dissipated. Groundwater within the rising main cannot return because of the check-valve. After a pre-set period, pressure is again applied, forcing water further up the rising main, and this process continues until the sample is taken.

Flow rate from the system is optimised by adjusting the time over which pressure is applied and the interval over which the pump is allowed to refill with water. Where air pressure is applied properly, there is no contact between air and sample water and these devices can produce high-quality samples, though

Figure A10.4 | Electrical submersible pumps



usually at low yields.

Water samples can be collected by gas displacement from virtually any depth (hundreds of metres), limited only by time availability, the burst strength of the tubing, the fittings and the sampling cylinder material (Nielson and Yeates 1985).

Gas-displacement devices can be used as portable or dedicated systems. In some circumstances they may even be installed *in situ* within the borehole construction (for example, as a single buried installation or as a sampling device attached to a port on a multiple installation).

Bladder pumps

Gas-operated bladder pumps operate on the same principle as the gas-displacement pump, using hydrostatic pressure to fill the pump chamber and compressed air to displace the water to the surface. The primary difference in the bladder pump is the use of a flexible diaphragm or 'bladder' inside the pump chamber, which isolates the water from the drive gas (Figure A10.4).

Their advantages include:

- small diameter (may fit in 50 mm diameter boreholes);
- pump can be constructed of inert materials;
- little sample disturbance (therefore good for volatile compound sampling);
- models are available for pumping from depths in excess of 100 m.

These types of pump only achieve relatively low discharge rates and are therefore utilised solely where low-flow purging methods are suitable.

A10.4 Surface water sampling equipment

Water samples are usually collected from surface watercourses using bailers or other transfer vessels before pouring the water into sample containers. Where the water is deep enough, sample containers can be filled directly within the watercourse. In some instances pumps are used.

Specialist depth samplers can be used in deeper waters to obtain a water sample at a specific depth or to collect an integrated sample representative of the full depth of water.

Specialist methods are available to collect sediment and biological samples from surface waters. Sampling methods (including sediment and biological) and their advantages and disadvantages are described in detail in Standing Committee of Analysts (1996).

A10.5 Unsaturated zone sampling equipment

A10.5.1 Introduction

Investigation of the unsaturated zone (vadose zone or zone of aeration) is an essential part of some environmental monitoring programmes, as groundwater pollutants may be detected before reaching the groundwater table or saturated zone, thus providing an 'early warning' of potential groundwater pollution. The unsaturated zone is the geological profile that extends from the ground surface to the water surface in a principal water-bearing formation. Within the unsaturated zone, pore water is held in the rock matrix by hydrostatic pressure.

Two types of device are employed to sample the 'pore' water: vacuum collection and free drainage collection.

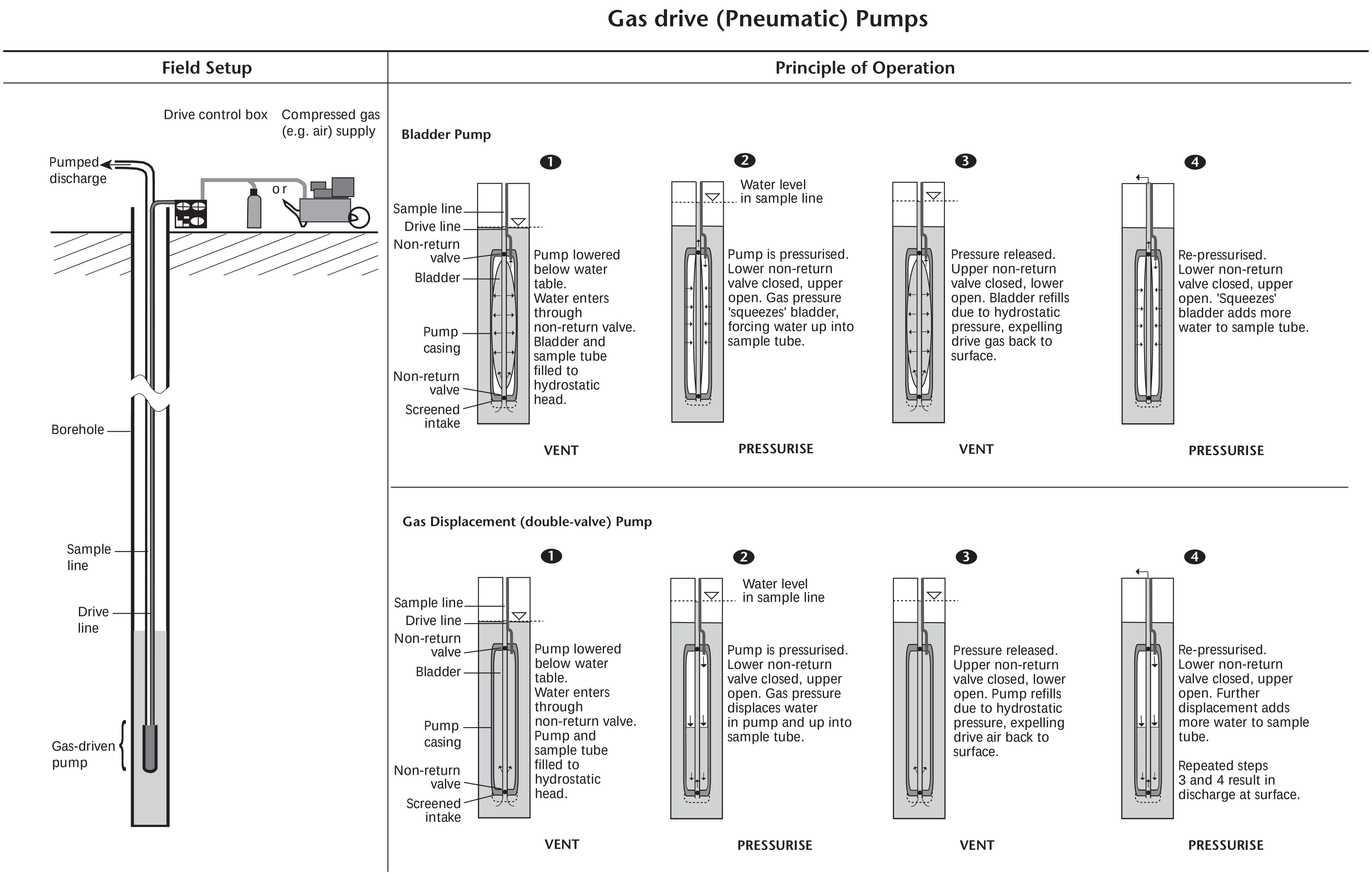
- Suction samplers
  Vacuum or suction devices (suction samplers) incorporate some type of porous material, which is placed in close contact with the soil and uses suction to collect the 'pore' water.
- Pan lysimeters
  Free drainage, or zero-tension samplers (pan lysimeters), are placed within the soil profile, where they intercept and collect water percolating through the soil under the influence of gravity.

A10.5.2 Suction samplers

Suction-cup lysimeters are very simple devices that consist of a porous cup from which run two small bore tubes. When placed in the soil, the pores in these cups become an extension of the pore space of the soil. By applying a vacuum to the interior of the cup, such that the pressure is slightly less inside the cup than in the soil solution, 'pore' water flow occurs into the cup. The sample is recovered at ground level through the application of a vacuum or positive pressure (deep installations) to the sampler.

Suction samplers may be subdivided into two categories, depending on the depth at which they are installed and therefore the method of bringing the sample to the surface. Vacuum or

Figure A10.5 Gas-displacement and bladder pumps



vacuum-pressure operated suction samplers are used when the solid depth is less than or greater than 1.8 m, respectively.

Suction-cup lysimeters are easy to install, are relatively inexpensive and can be installed without causing extensive disturbance to surrounding soil or structures. However, several problems can limit their effectiveness. Suction lysimeters are point samplers, and because of the small volume of sample obtained, the representativeness of the results is questionable. The water sampled is in 'blocks'. In structured soils, water moving through cracks may have different ionic composition than water in blocks. The suction applied may affect soil–water flow patterns. Tension meters should be installed to ensure that the proper vacuum is applied. The porous segments may become clogged, and water collected in the ' dead-space' of a lysimeter (areas from where simple water is unable to be removed) may contaminate future samples. For comprehensive discussions of the limitations of suction-cup lysimeters, see, for example, Everett *et al*. (1988) and Hornby *et al*. (1986).

Torstensson (1984) describes a modification to the basic suction-cup lysimeters that alleviates some of the problems associated with the gas-drive devices mentioned above. Practical operating depths range up to 60 m.

A10.5.3 Pan lysimeters

The pan lysimeter, which is a free-drainage type of lysimeter, was designed to study the constituents of gravitational water percolating through the unsaturated soil in situ, i.e. macropore or fracture flow in highly structured soils.

There are a number of designs for pan-type lysimeters (e.g. Hornby *et al*. 1986), which they can be constructed of any non-porous material, provided interaction between a leachate (water sample) and the pan does not jeopardise the validity of the monitoring objectives. The pan itself may be thought of as a shallow-draft funnel. Water that drains freely through the macropores collects in the soil just above the pan cavity. When the tension in the collecting water reaches zero, dripping initiates and the pan funnels the leachate into a sampling bottle. Fine sand packing or the use of a tension plate reduces capillary tension at the cavity face and promotes free-water flow into the pan.

The installation of pan lysimeters varies, but the most common methods are the trench and trench-and-tunnel techniques. The trench method can introduce a sampling bias, because if the pan lysimeter is installed close to the trench wall, the trench shelter causes the waste application equipment to avoid the actual sampling area to avoid damage to the shelter. Hence any leachate generation tends to occur away from the sampling areas. The trench-and tunnel-method was designed to overcome this problem. A pan lysimeter is installed into the side wall of a trench and connected to a remote point at the surface via a discharge line. The distance between the lysimeter and the discharge point should be at least 10 m to preclude any sampling bias above the lysimeter. When a sample is required, a vacuum is placed on the discharge line and a sample is retrieved. After the sampling lines have been installed, the lysimeter installation trench is backfilled. This method allows monitoring in the soil only to a depth of 1.5 m and has limited application for monitoring existing facilities, such as landfills (Hornby *et al*. 1986).

Pan lysimetry is a continuous sample collection system without the need for an externally applied vacuum. As only a vacuum is used to pull the sample to the surface, there is less potential for losing volatile compounds in the sample obtained. Its defined surface area may allow quantitative estimates of leachate and the method of installation enables the natural percolation of liquids through the unsaturated zone to be monitored without alteration of flow.

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Appendix 11:

Quality control sampling

A11.1 Introduction

A11.1.1 Context of Quality Control Sampling

Two types of procedure used for QC are:

- error minimisation
  achieved by standardised good practice in data collection and handling;
- error detection
  achieved by measuring and checking for errors.

Error detection itself consists of two components:

- QC sampling
  the collection of samples for the specific purpose of measuring errors (the subject of this appendix);
- Data validation
  the checking of monitoring data for errors, which includes consideration of the errors measured by QC sampling (dealt with in Appendix 13).

From the above it is clear that QC sampling is a necessary part of the overall QC effort.

A11.1.2 Quality control sampling strategy

The initial main QC sampling effort is directed at determining the overall contribution to variability made by sampling and analytical errors (as opposed to real variation in the water body). If the contribution made by errors is unacceptable in terms of the tolerable uncertainty for a particular determination, it is necessary to carry out further QC sampling to determine the main sources of the errors.

A study of the sampling, handling and analysis methods in use may direct attention to suspected sources of error, and it is then possible to select QC sampling techniques to target these.

A11.2 Types of quality control sample

Table A11.1 describes a number of types of QC sample, classified in relation to the overall sampling and analysis process. At each point in the process (see left hand column of Table A11.1) it is possible to take QC samples, and these samples provide an indication of variability introduced by all subsequent parts of the process. The later in the process a QC sample is taken, the more precisely the source of error is determined. The earlier in the process a QC sample is taken, the more sources of error are taken into account. Initially, QC samples should be taken as near the start of the process as possible, and if the errors detected are acceptable, no further action is required. If the errors detected are unacceptable, further QC samples should be taken at other points in the process to detect the sources of error.

QC samples obtained by splitting a sample (duplicates) can only detect *random errors* (which affect precision). *Systematic* errors (which cause bias) can be detected only by blanks and standards or spikes. Blanks can only detect gains in a determination (e.g. through cross-contamination or desorption), while standards and spikes can detect gains and losses (e.g. from precipitation, adsorption and degassing). Thus, the greatest amount of QC information is provided by a standard or spiked sample, and the least by a duplicate sample. Table A11.2 summarises the advantages and disadvantages of these three generic types of QC sample.

Table A11.1 | Types of quality control sample for sampling quality control

QC sample location		Duplicate QC Sample	Blank QC Samples	Standard/spiked QC Samples	Errors or variability detected
1.	Water body	Sampling duplicate (i.e. repeat entire sampling procedure)	(not possible)	(not possible)	Total of: purging/short-term natural variability, plus errors below
2.	Sampling equipment	Equipment duplicate (i.e. repeat use of sampling equipment)	Equipment field blank[1]	Equipment field standard/spike[1]	Total of: sampling equipment/some short -term natural variability (in the case of duplicate), plus errors below.
3.	Prior to treatment (e.g. filtering/ preservation)	Pre-treatment duplicate (split sample prior to treatment, then treat both samples identically)	Pre-treatment field blank	Pre-treatment field standard/spike	Total of: field treatment (filteringpreservatives), plus errors below.
4	Prior to bottling	Post-treatment duplicate	Post-treatment field blank	Post-treatment field standard/spike	Total of: ambient conditions, plus errors below
5.	Prior to transport	(not possible)	Trip blank	Trip standard/spike	Total of: handling and transport, plus errors below
6.	Sample bottles	(not possible)	Bottle blank (i.e. place deionised water in bottle and submit for analysis)	Bottle standard/spike (i.e place standard or spiked sample in bottle and submit for analysis)	Total of: bottle material and preparation, plus errors below
7.	Delivery to	Lab duplicate	Lab blank	Lab standard/spike	Total laboratory errors[1]
Type of errors detected:		**Random only**	**Random and systematic gains only**	**Random and systematic gains and losses**	

1. Only possible if equipment is removable. For dedicated sampling equipment, this QC sample becomes less important. NB: This table only relates to the sampling process. Further QC samples should be prepared in the laboratory to detect errors during the laboratory handling and analytical process.

Table A11.2 | Comparison of duplicate, blank and standard/spike samples

QC sample type	Advantages	Advantages
Duplicate	• Sampling process itself can be duplicated (sampling duplicate), providing information on errors in the entire sampling and analysis process • Relatively easily performed • Can be applied for all determinands	• Only detects random errors; systematic errors are not detected
Blank	• Easily performed • Can be applied to all determinands • Detects some random and systematic errors	• Cannot be applied to initial sampling • Only detects gains in determinand; losses are not detected
Standard/spike	• Detects all random and systematic errors from point of QC sampling	• Requires laboratory-prepared standard solution; can be more difficult to perform • Each sample usually applies to only one determinand

A11.3 Processing of quality control samples and data

A11.3.1 Quality control sample handling

QC samples should be handled in exactly the same way as normal samples. Care should be taken to achieve and record this.

Duplicate and blank samples should be labelled in such a way as to be indistinguishable from normal samples by the laboratory.

A11.3.2 Data handling

Results of all QC analyses should be interpreted and archived separately from normal results, although a record of results of duplicate analyses may also be processed with normal results.

All QC results should be referenced to their relevant monitoring results. For example, a trip sample may refer to all samples on a trip, while a sampling duplicate may refer to a single sample. In this manner, doubt arising from QC breaches will be referenced to the appropriate monitoring results.

The interpretation of QC sample results is covered in Appendix 13.

Appendix 12:

Laboratory analysis

A12.1 Preamble

This appendix provides guidance covering:

- sample handling and preparation;
- analytical techniques;
- laboratory QA and QC;
- laboratory documentation and reporting.

A12.2 Sample handling and preparation

The handling and preparation of samples, from the moment of delivery to post-analytical storage and final disposal, forms a vital part of the laboratory operation. These factors can have as much effect on data quality as the analytical techniques themselves. Furthermore, as these aspects of the operation are sometimes outside the scope of accreditation or quality schemes, it is important for laboratory users to obtain clarification on how quality is achieved in these areas.

Table A12.1 is a checklist that can be used to assess these aspects:

A12.3 Specification of analytical methods

Standard methods of analysis are available for many of the determinations required routinely by landfill monitoring. Typical specifications used by UK laboratories include:

- Standing Committee of Analysts (SCA) 'Methods for the Examination of Water and Associated Materials' (referred to as the 'Blue Book');
- American Society for Testing of Materials (ASTM);
- United States Environmental Protection Authority (USEPA).

Laboratories also commonly use variations on these standards, or methods developed in-house. This is particularly true for inorganic analysis of contaminated water samples, and for determinations of compound groups such as mineral oils and phenols. Where in-house procedures are adopted, these should be documented to the same extent as the standard methods. Where it is required to compare data from different laboratories it is preferable to use standard methods or, as a second best, include comparison with standard methods in the documentation.

Table A12.1 Checklist assessment of laboratory sample-handling aspects

Reception/registration	
Are all samples delivered during working hours unpacked and sent for analysis/preservation on day of delivery?	
Are satisfactory arrangements in place for out of hours delivery if required?	
Is the client notified of sample receipt and analysis schedule?	
Is the client allocated a single contact person for the job?	
Preservation/ storage of main sample	
Does the lab have a cool room of sufficient size for the throughput of the lab?	
Is the cool room temperature controlled at close to 4°C?	
Is the main sample stored in cool dark conditions, following sub-sampling and analysis, for an agreed acceptable period (min. 1 month)?	
Segregation	
Does the analysis request form include information on sample matrix and degree of contamination?	
Are water samples segregated from soil samples?	
Are 'clean' samples (e.g. uncontaminated groundwater or surface water) segregated from 'dirty' samples (e.g. sewage, leachate)?	
Are samples segregated by speed of analysis required?	
Preparation	
Are special requests for preparation/sub-sampling taken account of (e.g. sub-sampling from shaken or settled sample; use of special filter size)?	
Is preparation carried out immediately where required (e.g. preparation of filtered preserved sub-sample for trace metals analysis)?	
Is the sample routinely homogenised before sub-sampling?	
Where filtration is required, is the size and type of filter used appropriate for the analysis, and reported with the result?	
Is an acceptable method used for the preparation and/or sub-sampling of samples with high suspended solids content?	
Where solvent extraction is required, is the method appropriate and are quality control checks run with similar samples to enable accurate estimation of recovery rates?	
Scheduling and records	
Is sample ID transferred to sub-samples in a permanent, auditable manner?	
Are procedures scheduled well within technical time limits? (Examples of procedures with short time limits include preservation, solvent extraction, pH determination and analyses for BOD[1], nitrate, nitrite, orthophosphate and hexavalent chromium).	
For time-critical procedures, is the time recorded and reported?	
If field treatment has been carried out (e.g. filtration/ preservation) can this be included in the record?	
Disposal	
Is the period of storage after analysis sufficient?	
Are samples disposed of to an appropriate licensed facility?	

1. BOD, biochemical oxygen demand.

All methods (whether standard or in-house) require validation in the laboratory concerned, for the sample types concerned. Validation requires evaluation of the following:

- Precision;
- accuracy;
- overall uncertainty;
- limits of detection;
- applicability;
- interferences;
- traceability to national standards.

Once validated, continued performance of the method should be maintained and demonstrated through QC and proficiency testing (see next section).

The laboratory analyst should select the most appropriate method of analysis on the basis of information supplied by the client. This information should include the following.

- determination required
  (e.g. individual element, individual compound, total of a group of compounds, scan for a range of substances);
- type of sample
  (e.g. leachate; groundwater; pond water);
- likely concentration range;
- maximum acceptable minimum reporting value
  (derived from likely concentration range and, where applicable, assessment limit);
- maximum acceptable total laboratory error on a single result
  (derived from tolerable uncertainty, making allowance for errors already introduced by the sampling and handling process);
- possible hazards associated with the samples;
- required turnaround time.

For simpler determinations, a single standard method will achieve most users' requirements and there will be little discussion of appropriate technique. In other cases, a choice must be made between two or more methods, or a decision taken to modify a standard method. Examples for determinands commonly monitored at landfills include the following:

- Metals determinations.
  Metals are often analysed by ICP–AES[2] (particularly when more than five metals are to be determined, as the method allows simultaneous determination). However, the method has a high uncertainty for sodium and potassium, can be affected by interference between cations and from organics, and has limits of detection which are high in relation to drinking water limits for some trace metals (e.g. lead and cadmium). Other techniques, such as AAS[3] or ICP–MS[4], may be applicable, depending on the metals and minimum reporting limits required.

'Dissolved metals' determinations are also affected by filter type and pore size.

- Ammoniacal nitrogen
  Determination by ion-specific electrode or colorimetric method allows low-cost analysis, but with detection limits quite high in relation to the drinking water standard. The methods are also susceptible to interference. Ion chromatography offers lower limits of detection and fewer interference problems.

  Method and time of preservation also affect this determination.
- Bicarbonate
  Often calculated from a determination of alkalinity. However, in samples with significant concentrations of ammonia and/or organic acids, this will be in error. If bicarbonate concentration is required for its own sake or as a QC check, an alternative method, such as high temperature catalytic oxidation, could be used for leachate and other contaminated samples.
- Chemical oxygen demand, biochemical oxygen demand, total organic carbon
  These determinations are affected by filter type and pore size.

  Biochemical oxygen demand (BOD) suffers from poor precision and dilution effects.

  Total organic carbon (TOC) determination can involve an initial purging process that results in loss of volatile compounds. A method should be chosen that is appropriate for the sample and information required.
- Organic compounds
  Determination frequently involves solvent extraction as a first step. The solvent used and the extraction method affect the result. It is not possible to specify a 'best' extraction method, as different methods are more efficient for different analytes and matrices. Whichever method is used, a bias is introduced by the extraction process, which the laboratory must correct. It is important to check whether the corrections used apply to the type of sample being analysed.

2 Inductively Coupled Plasma–Atomic Emission Spectroscopy.
3 Atomic Absorption Spectroscopy.
4 Inductively Coupled Plasma–Mass Spectroscopy.

Environment Agency guidance on Hydrogeological Risk Assessments for Landfills and the Derivation of Groundwater *Control and Trigger Levels (2003) contains an analytical framework for screening of leachates, including recommended extraction methods and permissible bias.*

- Mineral oil
  'Mineral oil' is a term without a precise definition, and it is therefore particularly important to specify the method used and report this with the result. For example, determination by infra-red detects straight-chain hydrocarbons found in lube oil and diesel, but misses many of the compounds found in petrol. Other methods, such as the determination of specific carbon ranges by GC–FID[5], yield different results, and an appropriate method should be specified in consultation between operator, Environment Agency and laboratory.

- Phenols
  Phenols are a complex group of compounds; some tests only detect selected types of phenol.

Laboratories often make detection limits for determinations readily available to assist in decision making. Data on uncertainty (precision and accuracy) and applicability to different sample types are not so readily available, but can be equally important when considering the selection of appropriate analytical methods.

The choice of analytical method could affect field procedures. Where appropriate, sampling protocols should be modified to ensure the analytical method is as reliable as it needs to be (e.g. the need or otherwise for field filtration and preservation, or the provision of an additional volume of sample required to allow duplicate analyses).

A12.4 Laboratory quality control

When selecting an analytical laboratory, evidence of effective QC should be sought. As well as method validation (see previous section), a typical range of schemes operated by any reputable laboratory includes the following:

- Internal calibration and QC checks.
  All analytical methods undertaken should be subject to routine calibration and QC checks. These include the regular running of blanks, standards (including external standards) and spiked samples to enable estimations of accuracy and precision. Control charts should be used to provide assurance of performance. It is important that standards and spiked samples are run for relevant concentration ranges and sample types. For example, accuracy and precision may be within acceptable limits for clean water samples, but unknown (and possibly unacceptable) for leachates.

  Analytical results should be subject to audit checks prior to reporting. All calculations undertaken should be accessible to external scrutiny. Any reputable laboratory is able to produce QC and audit records on request.

- External analytical comparison checks.
  Laboratories may voluntarily participate in comparative analytical checking schemes, such as 'Aquacheck'[6] or 'LEAP'[7]. Checks cover a limited range of analyses and may not necessarily cover every analyte specified in monitoring schedules. Checks may only be undertaken on 'clean' water samples rather than more analytically difficult 'dirty' water samples, such as leachates. Laboratories should be prepared to demonstrate satisfactory performances for different types of water.

- Third party accreditation checks.
  Voluntary participation in quality assessment schemes, such as that operated by the United Kingdom Accreditation Service (UKAS), provide independent certification of standards and QC procedures operated by a laboratory, including adoption of appropriate written and chain-of-custody records. UKAS accreditation itself does not guarantee accuracy of analyses, but does require laboratories to participate in recognised external check sampling schemes.

Some laboratories subcontract work to other laboratories. In this situation it is important to establish that accountability remains with the main laboratory, and that appropriate QC measures are in place both for the analyses concerned and for the sample handling involved.

A12.5 Laboratory reporting

The 'product' of a laboratory is its reports, so the effort exerted for analytical QC should also apply to the compilation of data and reports. The laboratory should undertake routine checks for transcription errors, and preliminary validation checks on data (such as ion balance calculation) to enable the early detection of possible analytical errors.

A laboratory report should include the following information:

- sample identification;
- dates when samples were delivered, analysed and reported;
- results of determinations;

5 Gas Chromatography–Flame Ionisation Detector.
6 An interlaboratory proficiency testing scheme for water samples.
7 Laboratory Environmental Analysis Proficiency scheme.

- units of measurement;
- minimum reporting limits;
- uncertainty in laboratory measurement
  ss a minimum, analytical precision should be reported. Data on overall uncertainty (accuracy and precision) should be available on request;
- analytical method used
  this may be a simple abbreviation, but a fuller description should be available on request;
- comments or summary of sample preparation procedures
  e.g. type and pore size of filter use, digestion and/or mixing method;
- laboratory QC report
  For routine analyses this may consist simply of a check box. Full QC data should be available on request;
- analyst's comments
  e.g. problems with sample, reasons for non-reporting of analyses, ion balance outside specified range;
- Analyst's certification.

The scheduling and format of reports may be specified in a contract with a laboratory. For example, a mechanism is needed to distinguish preliminary results from final validated results, and client checking of preliminary results needs to be scheduled within a reporting scheme.

Report format may be paper based or electronic, or both. If both, it should be agreed which is the 'master' version. A number of standard reporting formats are available, particularly for electronic reporting. Many database systems adopt their own proprietary standards. Others, such as the Association of Geotechnical and Geoenvironmental Specialists (AGS) are freely available to institutional members. There is as yet no established UK standard format for environmental data. The Environment Agency is in the process of specifying a format for operator data submission compatible with their in-house WIMS (Water Information Management System) database.

Appendix 13:

Data validation

A13.1 Introduction

This appendix is concerned with the detection of errors in monitoring data. Details are given of a number of checks that should be made on monitoring data, in order to:

- provide confidence in its validity;
- direct attention to sources of error, so that corrective action can be taken.

Different types of data require different types of check, such as:

- water level or flow data
  checked for consistency mathematically and against historical records;
- inorganic chemical data
  checked using rules derived from an understanding of the chemistry of aqueous solutions.
- organic analyses
  checked using comprehensive QC sampling procedures (organic analytes are often at trace concentrations and capable of being strongly affected by sampling and handling).

This appendix consists of the following subsections:

A13.2 Monitoring data;

A13.3 Data validation;

A13.4 Validation of water level and flow data;

A13.5 Validation of water chemistry data;

A13.6 Validation of biological data;

A13.7 Automation of data validation.

A13.2 Monitoring data

Table A13.1 shows a typical range of data types that arise from a water-monitoring programme at a landfill. Some of the data (e.g. monitoring point details) remain constant over a period of time, and are best tabulated or filed separately. These data are designated as 'relational' or 'meta'– data, while other data are time dependent and entered into the core data tables or files.

Table A13.1 Example of data types that arise from water-monitoring programme

Data	'Relational' data?	Data type[1]	Internal consistency check required?[2]
Site details	Y	Text/numeric	
Monitoring point details	Y	Text/numeric	
Laboratory analyses		Numeric, censored	Y
Field quality measurements		Numeric, censored	Y
Field notes/sample history report		Text/logical	
Detection limits	Y	Numeric	
Margins of error	Y	Numeric	
Analysis method	Y	Text	
Field QC sample analysis results		Numeric, censored	Y
Lab QC results		Numeric, censored	Y
Data corrections (QC)		Numeric	
Remarks (e.g. sampler's, analyst's or data reviewer's comments)		Text	
Water/leachate level/flow data		Numeric	Y
Other data (e.g. landfill gas)		Numeric/text/logical 1	
User inputs (e.g. validation rules, threshold limits, conversion factors)	(Y)	Numeric/text/logical 1	
Records of data audits		Text/logical	

Notes
1. Data may generally be classified as numeric (including date/time data), textual or logical (Boolean, i.e. true/false). Numeric data may be censored (i.e. values above or below a limit reported as 'less than' or 'greater than' the limit).
2. See Section A13.3 'Data Validation', below.

Both relational and core data are required at the time of data validation.

It is often not possible to enter all data into a single storage system, unless the system is paper based or the electronic system is entirely in text format. Accordingly, the raw data contain information not held elsewhere. Raw data form the primary information source of any data set and should be maintained in an available form to enable data validation checks to be made at any time in the future.

A13.3 Data validation

Data should be subjected to 'internal' consistency checks and 'external' checks against other related data.

A13.3.1 Internal checks

Data should be checked for:

- simple errors (e.g. missing data, misnumbering, transcription errors);
- logical errors (e.g. data outside valid ranges);
- technical inconsistencies.

A13.3.2 External checks

The data must also be checked externally against:

- field measurements;
- simultaneous analyses from relevant nearby sampling points;
- previous analyses from the same sampling points;
- results from QC sample analyses;
- sample 'attributes' (i.e. adherence to sampling and/or handling protocols, unusual conditions).

In the following subsections, checks are described for different types of monitoring data.

A13.4 Validation of water level and flow data

A13.4.1 Internal checks

- Monitor point identification.
  Especially important with multiple or clustered monitor points or where monitoring points have been renumbered.
- Missing data.
  For example, data should be recorded on surface water bodies that are dry, or boreholes that are dry or blocked or damaged (depth to base should be included in the record).
- Transcription errors.
  A proportion (5–10%) of data should be compared against raw data, to ensure transcription errors have not been introduced during copying or validation routines.
- Data outside valid range.
  For example, levels that are below the base or above the top of a borehole or water body.
- Technical inconsistencies.
  For example, level data not correctly reduced to Ordnance Datum (e.g. because of datum-point movement), or computational errors in the calculation of flow from staff gauge readings.

A13.4.2 External checks

- Equipment calibration records.
  For example, water level dip tape accuracy (especially for repaired tapes) and flow measuring equipment calibration.
- Field notes.
  Check for any record of unusual conditions that may influence dip measurements (e.g. damaged or new headworks).
- Comparison with previous and adjacent records.
  Where data diverge from a known trend, or from a correlation with other similar data records, an explanation should be sought.

A13.5 Validation of water chemistry data

A13.5.1 Internal checks – general methods

- Monitor point identification.
  Especially important with multiple or clustered monitor points or where monitoring points have been renumbered.
- Missing data.
  Sample analysis request forms should be checked against returned data.
- Transcription errors.
  A proportion (5–10%) of data should be compared against raw data, to ensure transcription errors have not been introduced during copying or validation routines.
- Data outside valid range.
  Valid ranges can be based on detection limits of analyses, or logical limits (e.g. positive value only). In some instances checks based on determinand properties may be used (e.g. maximum solubilities).
- Incompatible constituents.
  Certain constituents can only exist in solution (in steady state) under particular pH or redox conditions. If the sample is in equilibrium, indicators of differing conditions should not occur in the same sample. For example, many metals have low solubility at moderate pH values; indicators of oxidising conditions (e.g. dissolved oxygen) would not be expected with indicators of reducing conditions (e.g. ammonia).

A13.5.2 Internal checks – major ion balance

Calculation of the ionic balance for dissolved ions in a water sample is a convenient check on the internal consistency of major ions in a laboratory analysis, but only where sufficient major ions have been analysed to enable this check to be carried out. An ionic balance does not provide any information on the reliability of any other chemical constituents (e.g. organics or minor inorganics).

Where laboratories quote major ion balances, it is important to confirm that all analyses used in the calculation have been carried out by analytical means, and not determined by back-calculation to achieve a perfect balance.

An ion-balance calculation compares the sum of the main cations and anions as milliequivalents/litre (meq/l). The formula for conversion of mg/l concentrations into meq/l concentrations is as follows:

$$\text{Equivalent concentration (meq/l)} = \frac{\text{concentrations in mgl/l x charge of ion}}{\text{molecular weight}}$$

Table A13.2 gives charges and molecular weights for the common major ions and some ions more commonly found in contaminated waters and leachates. The fifth column gives the factor (charge/molecular weight) that can be multiplied directly by the concentration in mg/l to give the equivalent concentration. Care must be taken to ensure that the molecular weight used is appropriate for the ion as reported. (For instance, a nitrate concentration reported as nitrogen must be divided by the weight of nitrogen not nitrate. Both factors are provided in Table A13.2.)

The formula for the calculation of ion balance is:

$$\textit{Ion balance (\%)} = \frac{\textit{Total cations (meg/l) − total anions (meg/l)}}{\textit{Total cations (meg/l) − total anions (meg/l)}} \; x100$$

For *uncontaminated waters*, ion balance can generally be calculated using major ions only (ignoring 'contaminant' ions, see Table A13.2). *In these waters ion balance should be within ±5%.*

[Note that some authors and/or laboratories calculate ion balance as a proportion of total cations (or anions) only, rather than the sum of anions and cations. It may also be calculated as a proportion of the average of cations and anions, which is the most logical method, but rarely used.

In both these cases the percentage ion balance is twice that produced from the above equation.]

Table A13.2 Charges and molecular weights for common major ions and some 'contaminant' ions

Ion	Major/Contam.	Charge	Molecular weight	Charge mol. wt.
Cations (+ charge)				
Calcium (as Ca)	M	2	40.08	0.0499
Magnesium (as Mg)	M	2	24.32	0.0822
Sodium (as Na)	M	1	22.99	0.0435
Potassium (as K)	M	1	39.09	0.0256
Iron (as Fe^{2+})	C	2	55.85	0.0358
Manganese (as Mn)	C	2	54.94	0.0364
Ammoniacal nitrogen (as N)[1]	C	1	14.01	0.0714
Ammoniacal nitrogen (as NH_4)[1]	C	1	18.04	0.0554
Anions (– charge)				
Chloride (as Cl)	M	1	35.45	0.0282
Sulphate (as SO_4)	M	2	96.06	0.0208
Nitrate (as NO_3)	C	1	62.01	0.0161
Nitrite (as NO_2)	C	1	46.01	0.0217
Nitrate or Nitrite (as N)	C	1	14.01	0.0714
Alkalinity (as $CaCO_3$)[2]	M	2	100.09	0.0200
Alkalinity2 or bicarbonate (as HCO_3)	M	1	61.02	0.0164
Phosphate (as P)[3]	C	3	30.97	0.0323
Phosphate (as PO_4)[3]	C	3	94.97	0.0316

Notes:

1. This value is actually the sum of two species: ammonium and dissolved ammonia. The latter is not an ion and should not theoretically be included in the ionic balance. However, in practice it may be included because dissolved ammonia also affects the alkalinity value and the two effects cancel each other.
2. Assumes alkalinity is caused entirely by bicarbonate/carbonate (but see note 1 above).
3. Assumes all phosphate present as orthophosphate.

An excessive ion imbalance indicates one of two effects:

- The water contains ions that have not been included in the calculation.
  In some uncontaminated waters (particularly groundwaters), other ions (e.g. iron, nitrate, borates, silicates and phosphates) may be present in sufficient quantity to merit inclusion in the ionic balance. In leachates and leachate-contaminated waters, all the contaminant ions in Table A13.2 above should be included when calculating the ionic balance, though other effects may also need to be considered (see below).
- Errors have been introduced during the analytical procedure.
  These may result from analytical errors, or from real changes in the sample or sub-samples during the analytical process. In either case, the poor ion balance implies uncertainty in the analytical results.

As stated in the first bullet point above, leachates and leachate-contaminated waters present additional issues for consideration before a poor ion balance can be attributed to poor laboratory QC.
In particular:

- Carboxylic acids ('fatty acids' such as ethanoic , propanoic and n-butanoic acids) are commonly present in leachate in biodegradable landfills.
  These compounds are described as 'weak' acids, meaning they are present partly in a 'combined' non-ionic form and partly in ionic form. To the extent that they are ionic, they will contribute to the ion balance.
- The presence of carboxylic acids also has an interference effect on the measured value of alkalinity.
  A correction can be made for the combination of this effect and the previous one, provided that pH and alkalinity have been measured accurately as soon as possible after sampling, and the concentrations of relevant carboxylic acids have been measured.
- Dissolved ammonia converts to ammonium ions as the pH is reduced during the alkalinity titration. This also affects the alkalinity measurement.
  This effect should be cancelled out in the ion-balance calculation by the inclusion of ammonia in the cation total.
- The presence of oxidisable or hydrolysable ions (e.g. ferrous/ferric iron, manganese and aluminium) can also contribute to alkalinity and may need compensation.

Many of the above complications surround the measurement of alkalinity. If ionic balance problems are experienced with leachates and leachate-contaminated waters, it may be appropriate to avoid dependence on alkalinity measurement by determining bicarbonate directly as total inorganic carbon (TIC).

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

A13.5.3 Internal checks – analyte ratios

Comparison of electrical conductivity with dissolved ion concentrations

The electrical conductivity of a solution is dependent mainly on the concentration and less so on the types of ions present in the solution. Thus:

EC (µS/cm) = k _ (total cations in meq/l), or

EC (µS/cm) = k _ (total anions in meq l-1)

where k is a constant that ranges from 90 to 125 depending on the average conductance of the ions present.

In relatively unpolluted groundwaters, k can be taken as 100. The presence of a high proportion of chloride ions tends to result in higher k values. In strong solutions (EC > 2000 S/cm), k will be lower.

Comparison of electrical conductivity with total dissolved solids

If total dissolved solids (TDS) have been determined experimentally, the reported value can be compared with a value calculated from the sum of individual ion concentrations (the value should be the same within a reasonable margin of error).

Using the same logic applied above, the electrical conductivity of a solution can be related to total dissolved solids using the relationship:

(TDS in mg/l) = C _ (EC in µS/cm)

where C is a constant that ranges from 0.54 to 0.96, depending on the average conductance of the ions present.

Empirical analyte ratios

Other empirical checks may be derived from experience of a particular monitoring environment. For example, in biodegradable landfill leachate and leachate-contaminated groundwaters, the following ratio ranges can be used:

- COD/BOD generally falls between 1 and 40;
- COD/TOC generally falls between 2 and 4;
- TOC/BOD generally falls between 0.5 and 10.

Empirical checks such as these may be used to highlight data for rechecking, but should not be used on their own to justify exclusion of data.

A13.5.4 Internal checks – scope and scheduling

It should be borne in mind that the chemical checks described above provide validation of the major ion chemistry of a sample, and a general check on quality, but provide little direct validation of trace constituent results, many of which are important in assessing contamination risks.

Wherever possible, an agreement should be made with the laboratory to carry out the chemical checks, and criteria set for repeat analyses when the checks fail.

A13.5.5 External checks

Laboratory quality assurance and/or quality control data

Evidence of satisfactory compliance with laboratory QA criteria should be obtained and checked. In the case of routine inorganic analyses, a simple statement of compliance may suffice. For non-routine and trace organic determinations, a QA report should be supplied with the analysis results. Apparent discrepancies, such as contamination of blank samples with solvents, should be referred to the laboratory.

Results of quality control sampling

QC sampling results should be separated according to type and each set referenced to the monitoring data to which it applies. Thus, a trip blank refers to all data from one trip, while a field blank refers to data from one sampling locality or monitoring protocol. A field standard generally refers to a single analyte.

Once collated, QC sampling results must be analysed to determine errors and compare these to tolerable uncertainty. The preferred method is to use a control chart (or automated equivalent) for each QC sample set, with action limits set on the basis of data from the initial characterisation monitoring period. Some examples are shown in Figure A13.1.

The errors determined from the interpretation of QC results should be compared with the tolerable uncertainty associated with each determinand, to decide whether the analysis result is acceptable, suspect or disqualified.

Sample history reports (field notes)

Sample history reports should be checked for evidence of unusual conditions or deviations from sampling or handling protocols (e.g. borehole ran dry before purging completed, delayed delivery to laboratory). Analyses susceptible to these conditions should be checked.

Equipment calibration checks

Calibration records for equipment used for field measurements should be checked against standardised criteria, which will classify the field data as reliable or unreliable. Where calibration records are not available at a suitable frequency, reliability is called into question (particularly applies to pH meters, which must be frequently calibrated).

Laboratory and field measurement comparisons

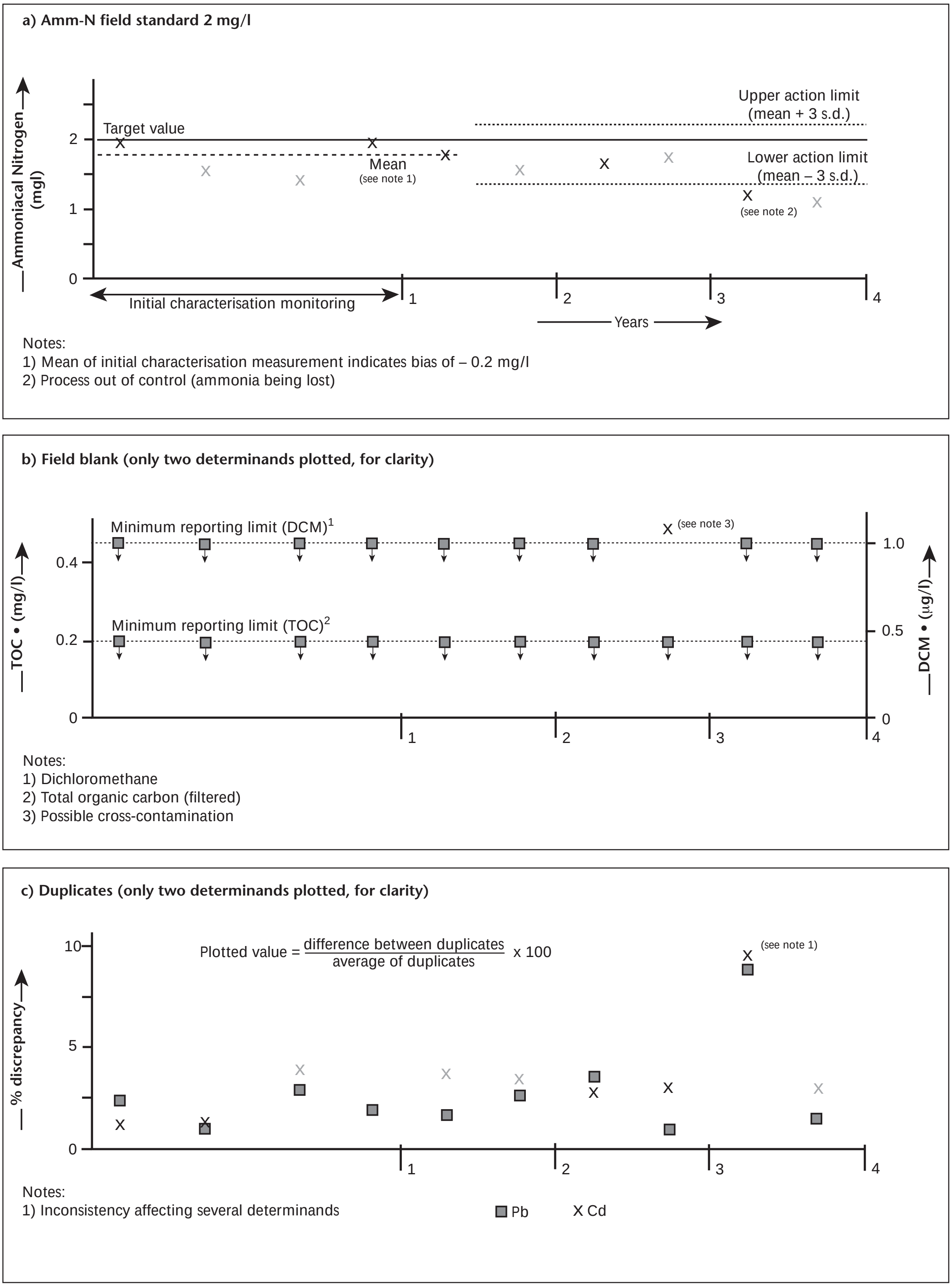
Provided field data are quality assured, this comparison can provide information on changes in the sample between collection and analysis. The following measurements are typically made both in the field and laboratory:

- Temperature.
  Only the field record is representative of the water body. Laboratory temperature indicates sample condition at the laboratory at the time of measurement. A max/min thermometer transported with the sample can be used for sensitive samples.
- pH.
  A change of 0.5 pH units or more may indicate a change in sample conditions (e.g. degassing of carbon dioxide, precipitation of carbonates, or oxidation reactions). This comparison is obviously not relevant for samples preserved with acid in the field or laboratory.
- Electrical conductivity.
  A change greater than 10% may indicate dissolution of suspended solids (increased EC), or precipitation of solids (decreased EC).
- Alkalinity.
  A change greater than 10% may indicate a change in sample conditions (e.g. degassing of carbon dioxide, precipitation of carbonates, or oxidation reactions); not relevant for acid preserved samples.

Comparison of data between related monitoring points

'Related' monitoring points are monitoring points in the same system (cell, sub-catchment or aquifer) that have been shown to behave similarly (by comparison of historical data).

Figure A13.1 Examples of the use of control charts with QC sample data



Comparison of data between related monitoring points

'Related' monitoring points are monitoring points in the same system (cell, sub-catchment or aquifer) that have been shown to behave similarly (by comparison of historical data).

If measurements in the two monitoring points fail to follow historical correlation on a single occasion, the cause should be investigated.

Comparison of historical data for the same monitoring point

This check involves preparation of a time-series plot, normally prepared as part of the data review, but is also a useful validation check. A measurement that deviates from an established trend should be investigated, particularly if other measurements in the same analysis conform to the established trend.

A13.6 Validation of biological data

The validation of biological monitoring data relies strongly on confirmation of the use of appropriate and consistent methodologies. Careful records must therefore be kept of the field and laboratory procedures used, and any deviations from standard practice. This information should be reviewed as part of data validation.

The basic checks for correct monitoring-point identification, missing data and transcription errors should be carried out. Similarly, data should be compared to historical and spatial trends to check for inconsistencies. However, because of the number of factors that affect species populations, apparently inconsistent data cannot be discounted without corroborating evidence, such as recorded problems with the sampling procedure.

QC sampling for macrobiological analysis is generally limited to the use of sampling duplicates, and even these may give more of an indication of natural variability rather than of errors. Microbiological analysis should include the use of blanks, standards and spiked samples, and these data require analysis in a manner similar to chemical QC sampling data.

A13.7 Automation of data validation

A number of the checks described above may be automated in a computerised data management system, by the use of validation rules (e.g. restricting data values to valid ranges, or making certain fields mandatory). Validation rules should be carefully written to avoid rejection of data that, although abnormal, are valid.

The use of automated validation rules cannot cover all the requirements of data validation. Certain checks (particularly the comparisons with historical data and with data from nearby monitoring points) require professional judgement. Furthermore, all validation-rule breaches and suspect data require follow-up action, which is again a matter for professional judgement.

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