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: Programme co-ordination	Management: Quality control	Management: Liaison with Agency	Management: Liaison with sub-contractors/laboratory	Risk review and specification of monitoring programmes: Risk-based monitoring review	Risk review and specification of monitoring programmes: Monitoring objectives	Risk review and specification of monitoring programmes: Monitoring schedules	Risk review and specification of monitoring programmes: Design of compliance/trigger tests	Risk review and specification of monitoring programmes: Contingency planning	Risk review and specification of monitoring programmes: Monitoring protocols	Design and certification of monitoring infrastructure: Leachate	Design and certification of monitoring infrastructure: Groundwater	Design and certification of monitoring infrastructure: Surface water	Field surveys: Routine monitoring surveys	Field surveys: Biological sampling	Field surveys: Volatile organic sampling	Data collation, interpretation and reporting: Data collation	Data collation, interpretation and reporting: Data validation	Data collation, interpretation and reporting: Data review and interpretation	Data collation, interpretation and reporting: 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.

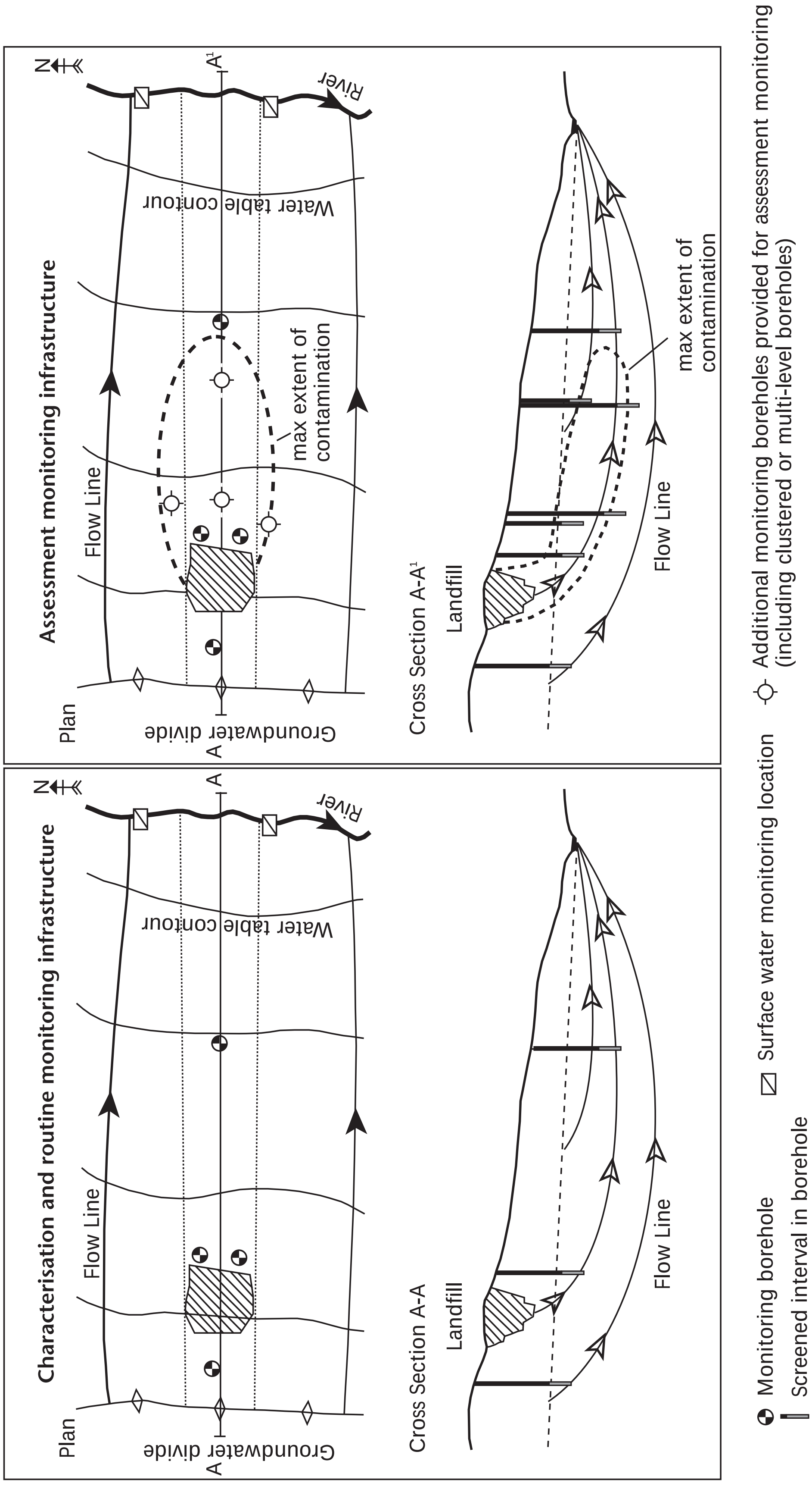
In determining the number of surface water monitoring points required at a site, the following guidance should be followed:

- 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 =

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

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[2]
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] A	Minimum reporting value[2] B	Tolerable uncertainty[3]
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.

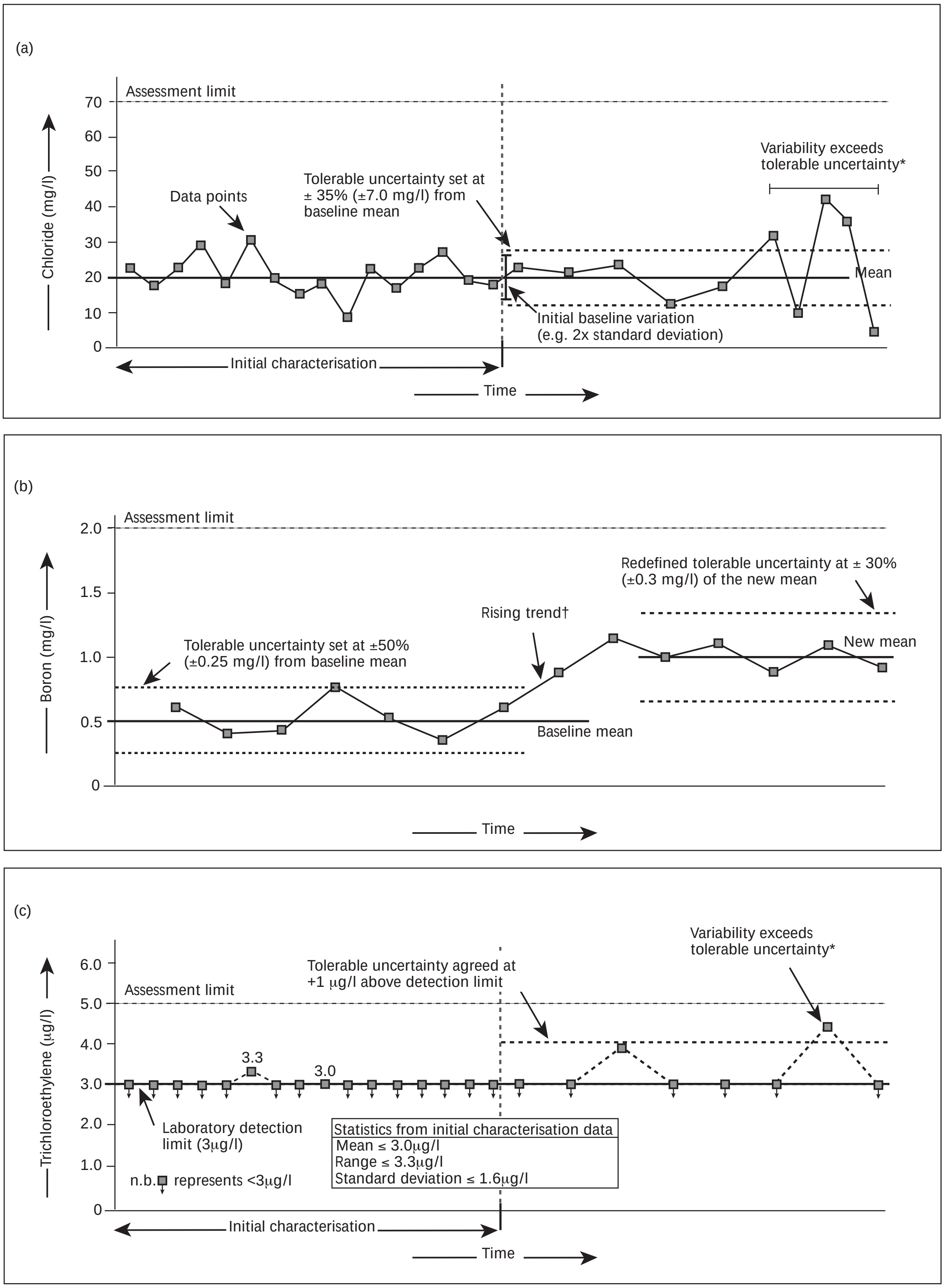
6.4 Specification of monitoring schedules

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.

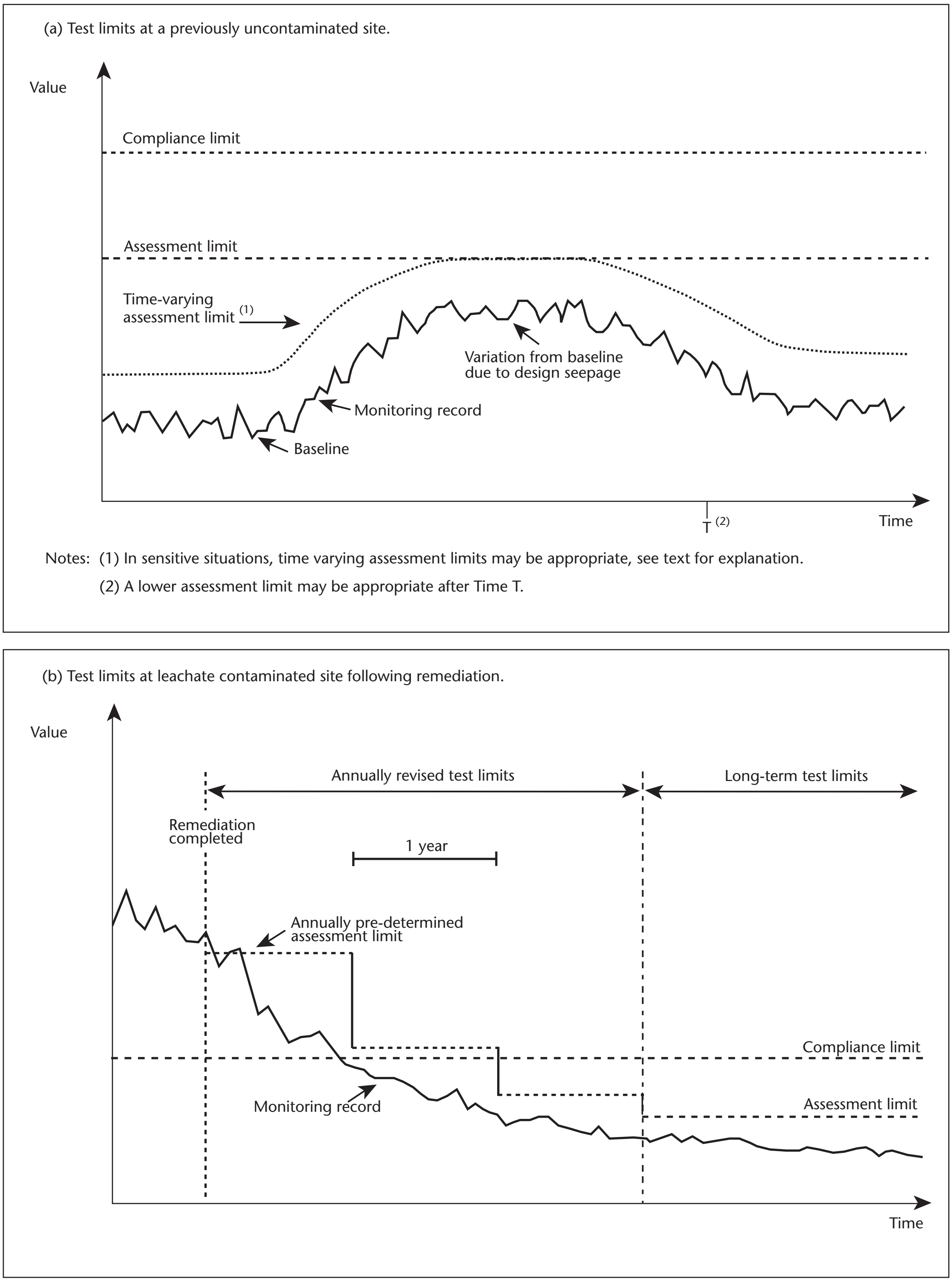
  A maximum specified time (measured from the date of a measurement that confirms a breach in the assessment criterion) in which to implement contingency actions.

- 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.

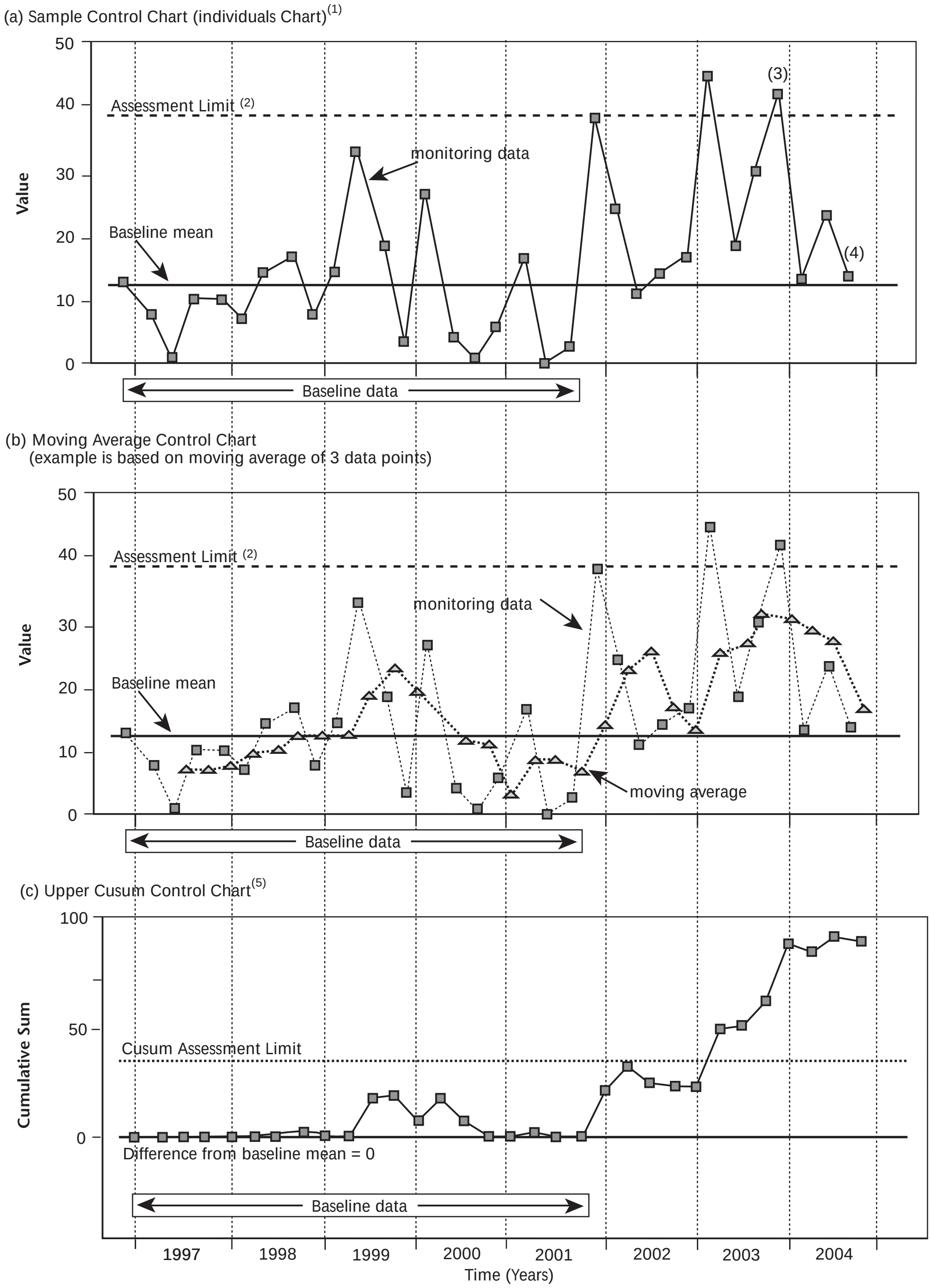
- Revise the compliance and/or assessment limit.
This can only be achieved by a deliberate alteration to the risk, for example by protecting or removing a receptor.
- Improve the reliability of the assessment of baseline behaviour by reducing uncertainty associated with sampling and analysis.
  This 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.

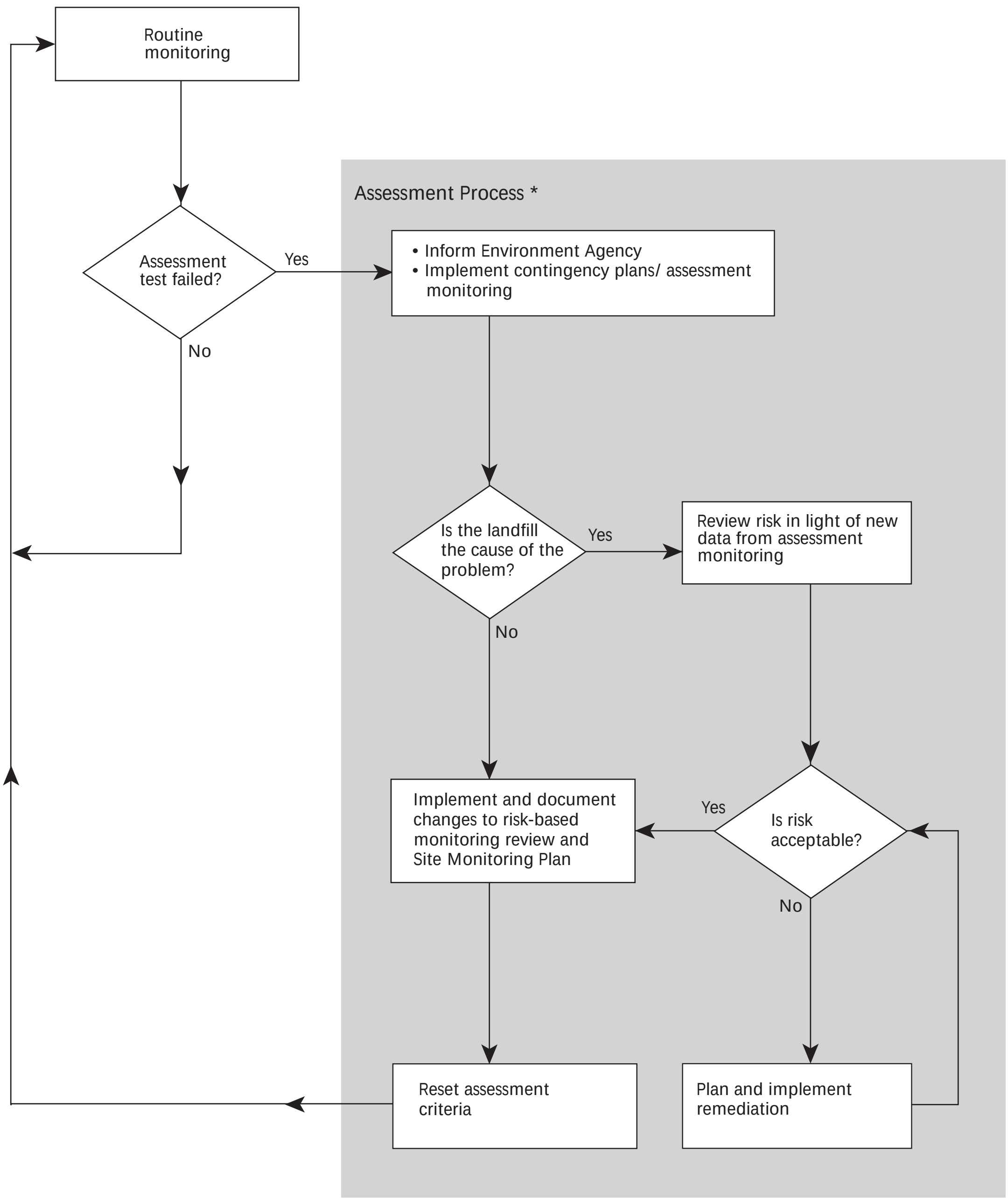
(2) An assessment limit is not necessarily the same as the 'action limit' defined in standard control charts.

(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

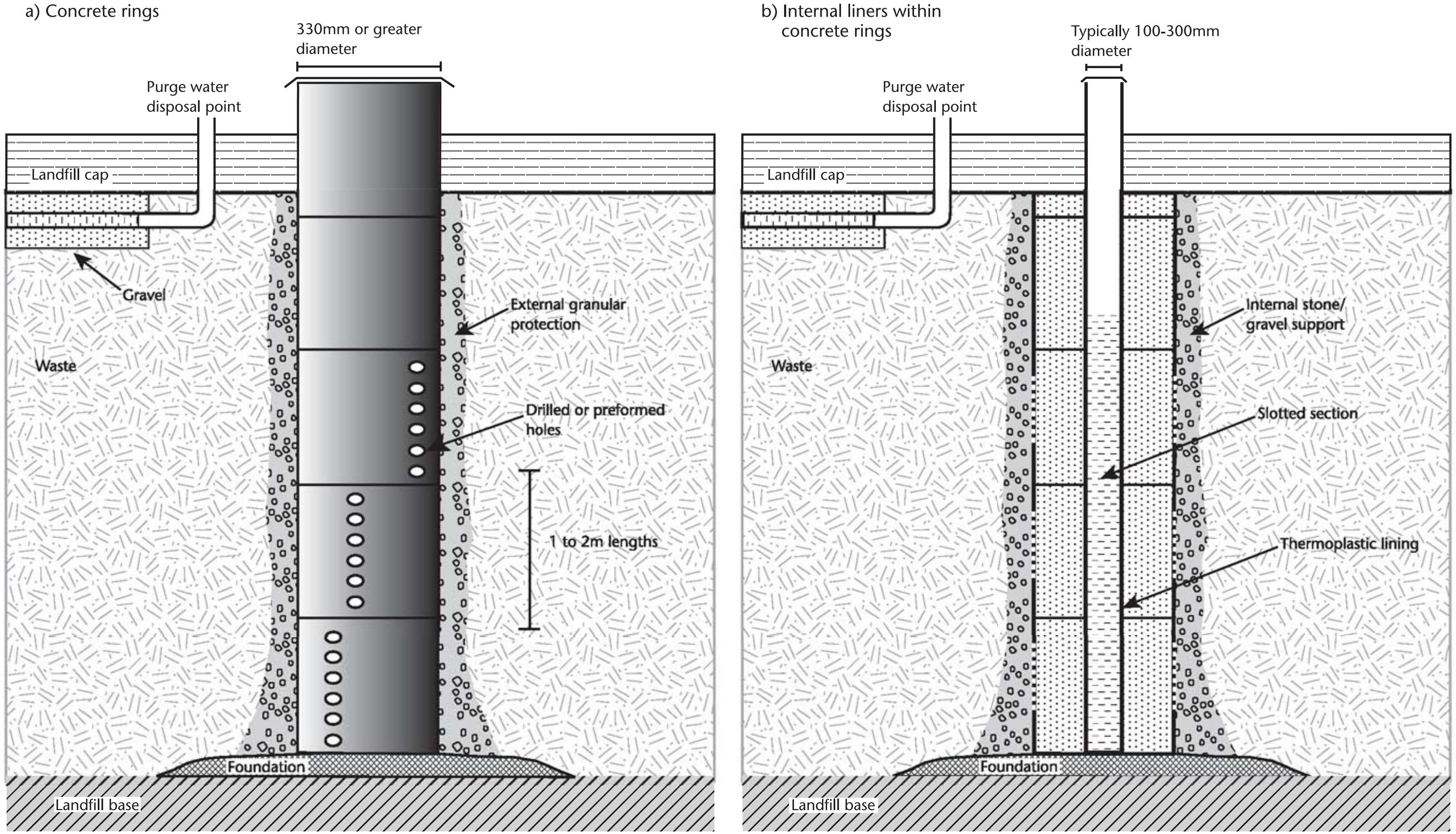
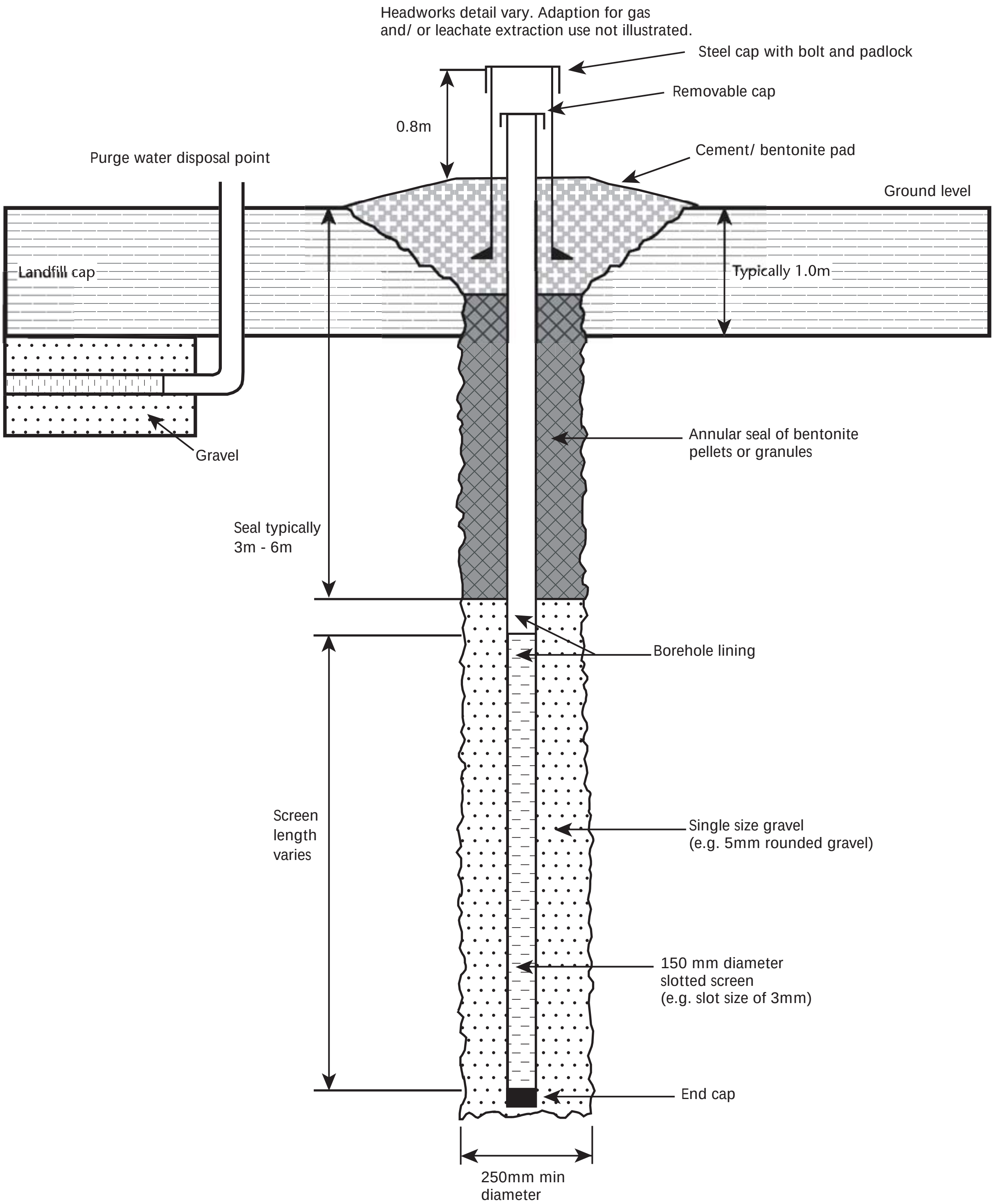


Figure 8.2 Example leachate borehole design completed with a 150 mm diameter lining



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

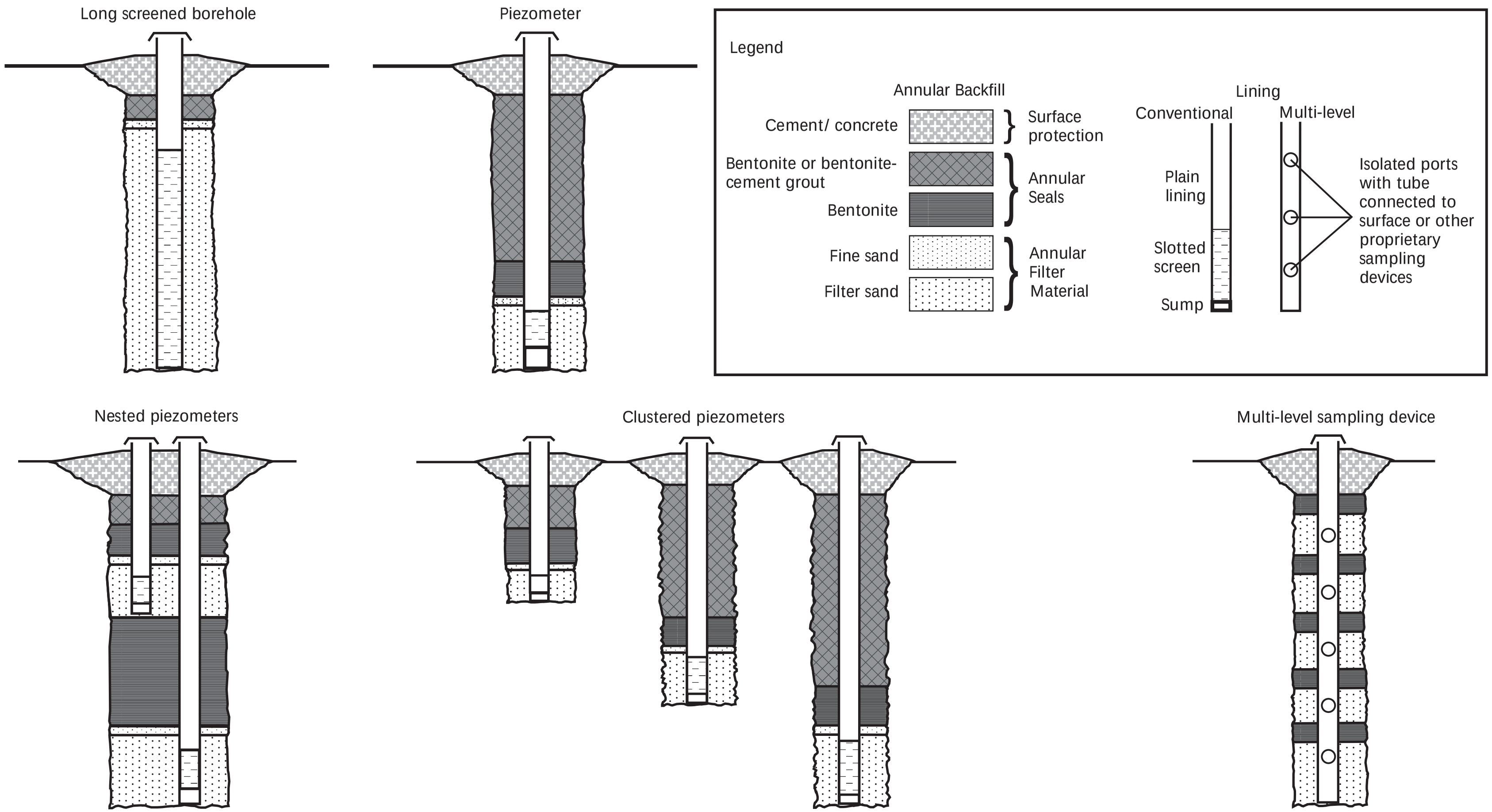
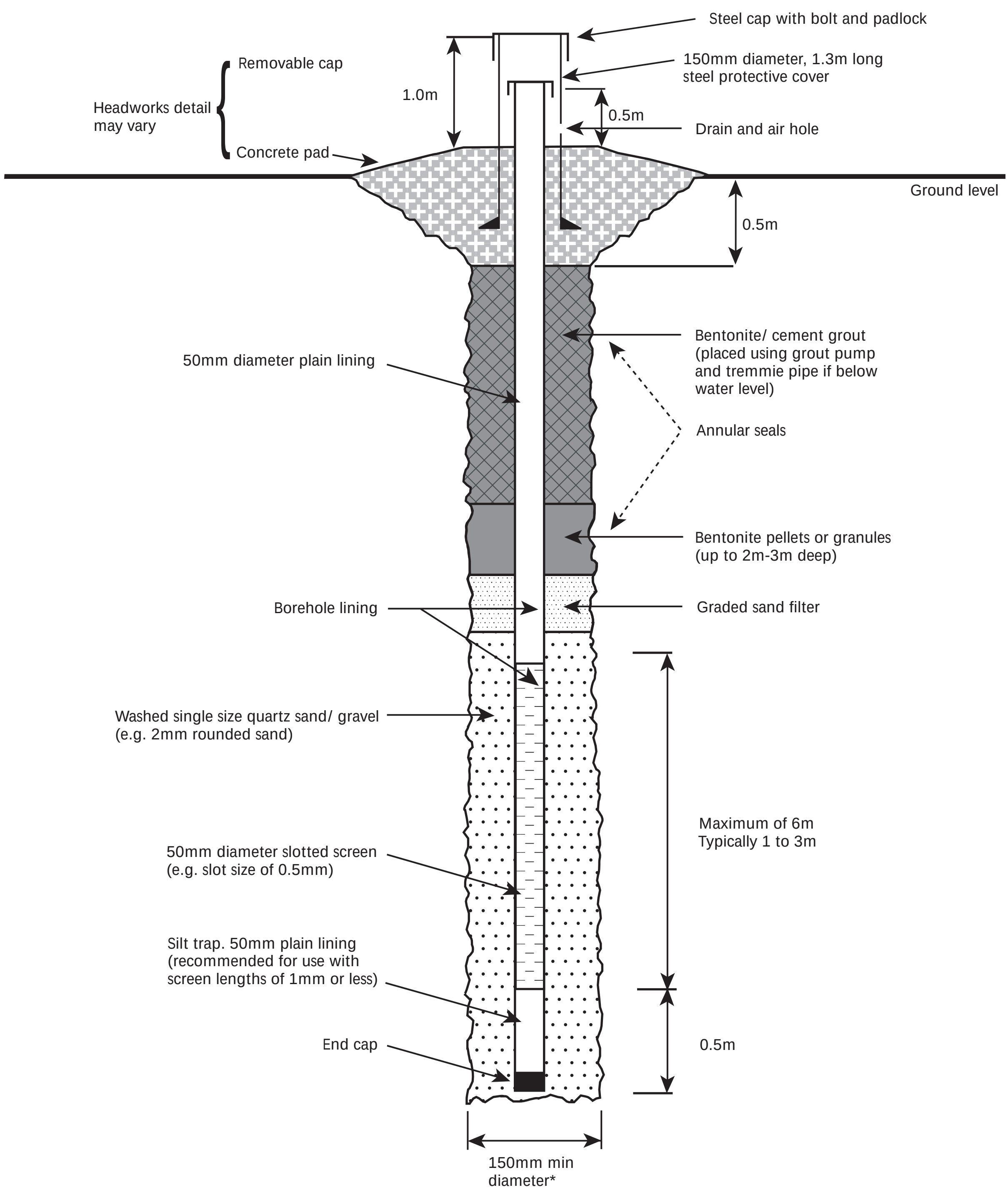


Figure 8.4 Example of a groundwater monitoring borehole (piezometer design) completed with a 50 mm diameter lining



* 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:

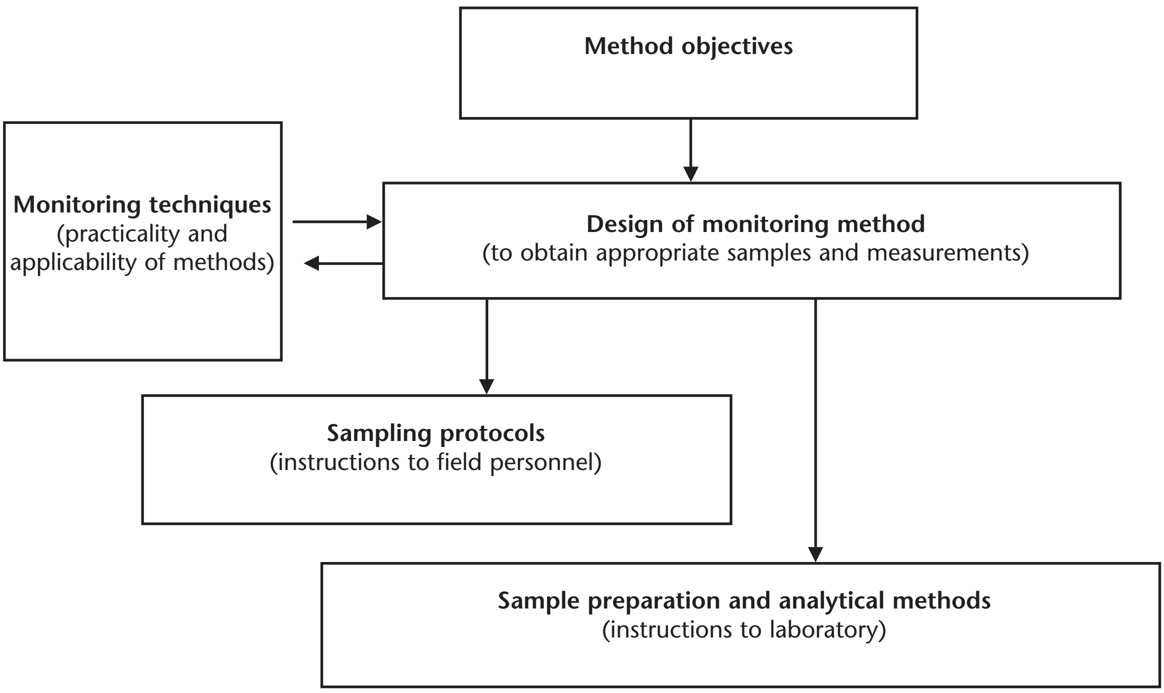
- the measurement method;
- a detailed protocol for sampling and/or measurement and record keeping;
- an appropriate level of QC sampling and measurement.

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.

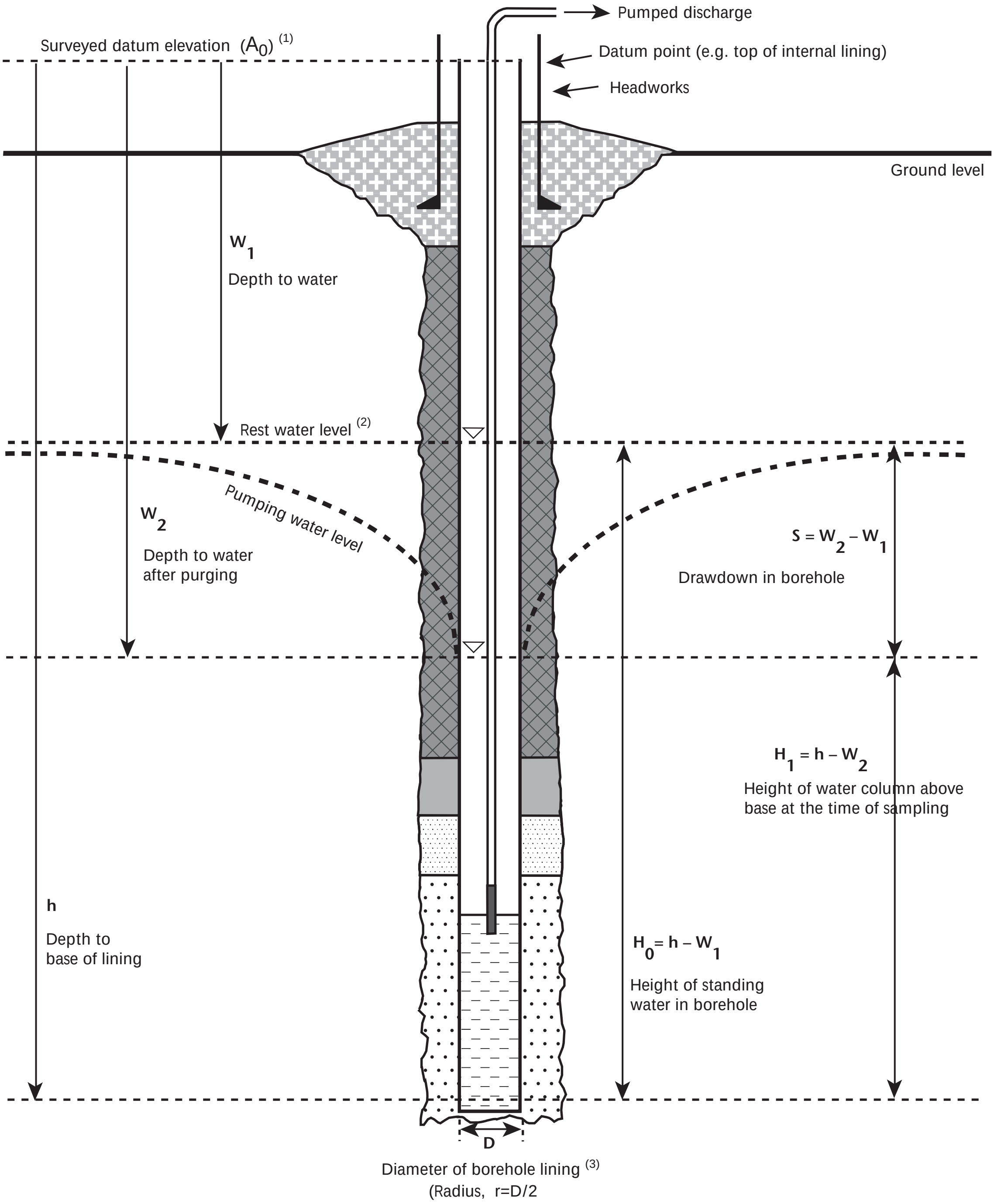
Surface water level measurements

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.

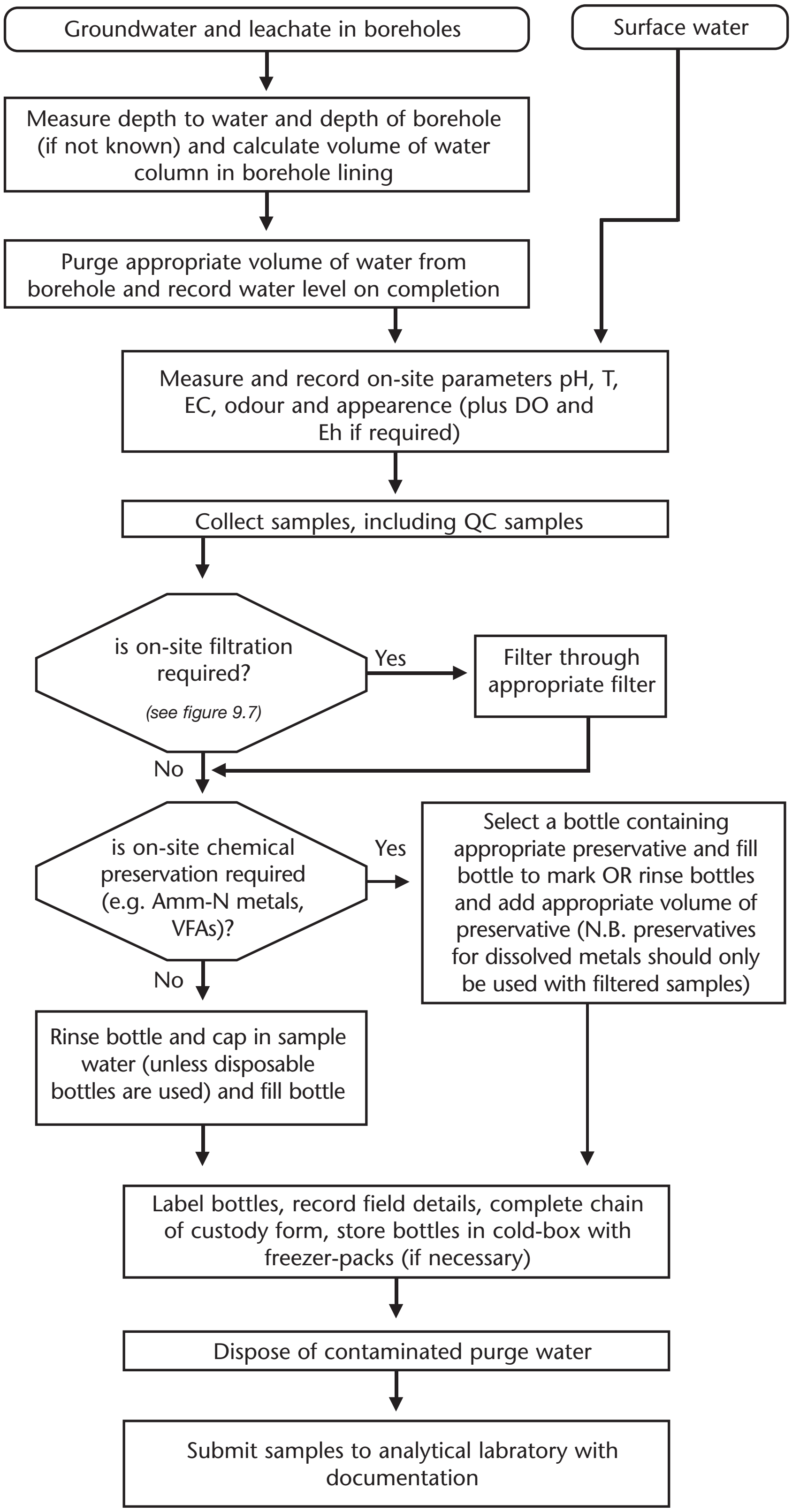
A review of equipment used to purge and sample monitoring points and for the collection of surface water samples is included in Appendix 10.

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.

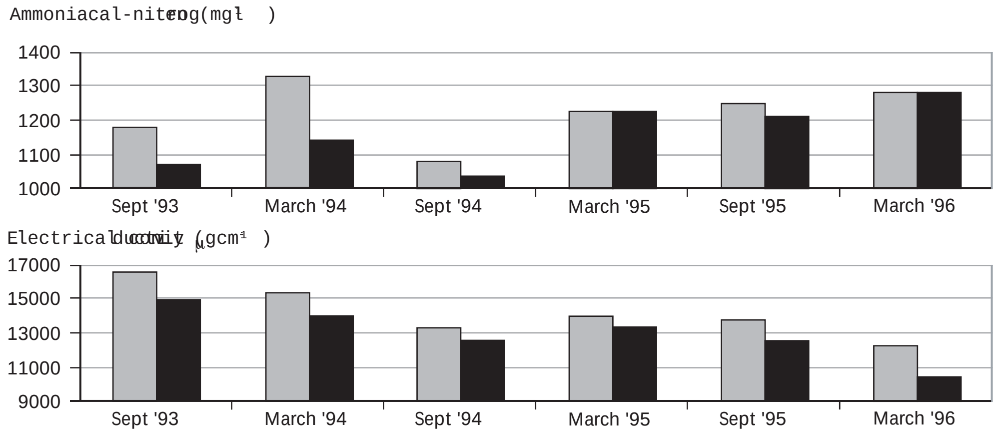
Table 9.2 Standing water volumes in the lining of a monitoring point.

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.

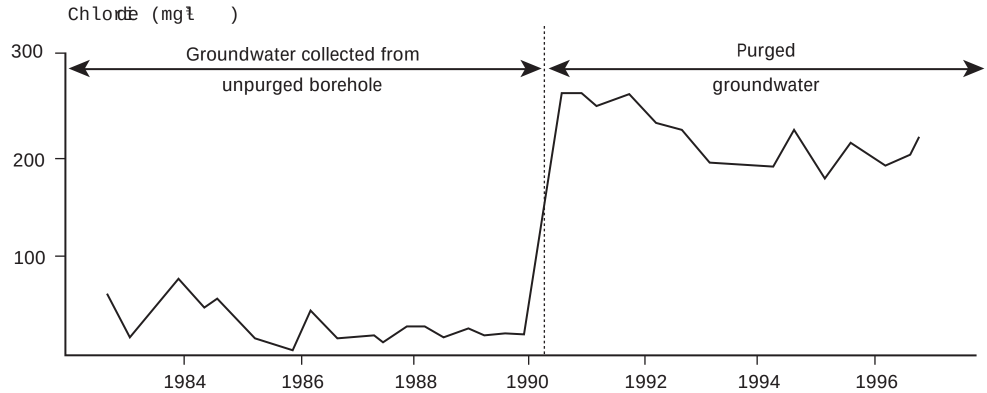
Figure 9.4 Comparison of chemical measurements before and after borehole purging.

a) Comparison between leachate samples from the same borehole collected before and after purging



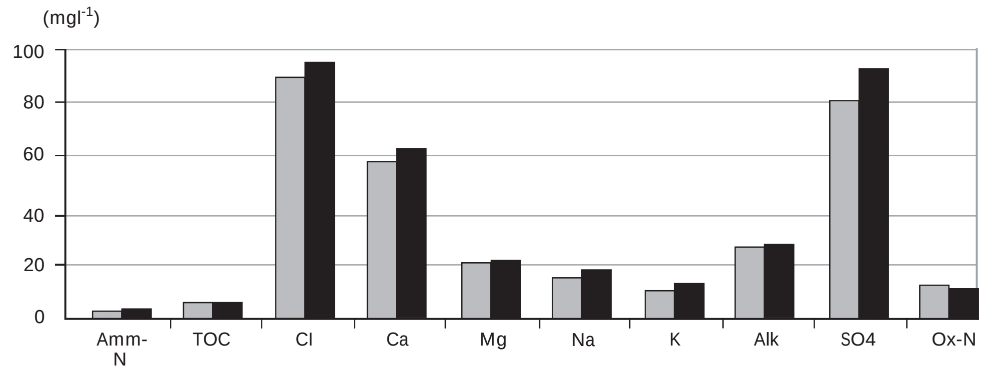
(Data courtesy of Waste Management Section, Shropshire County Council)

b) Illustration of significant discrepancy between unpurged and purged groundwater samples



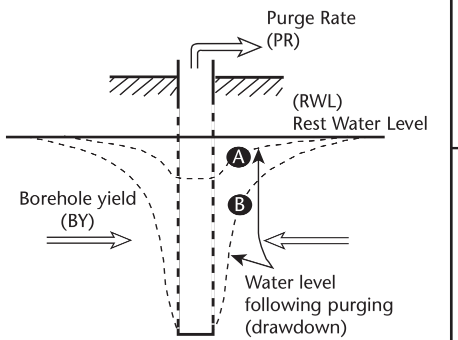
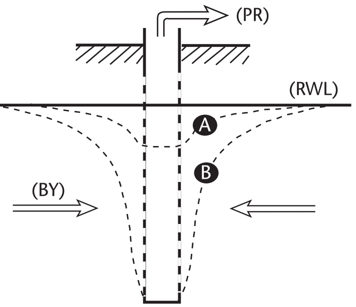
(Data from Environment Agency public register records)

c) Illustration of no significant difference between unpurged and purged groundwater samples collected on the same day



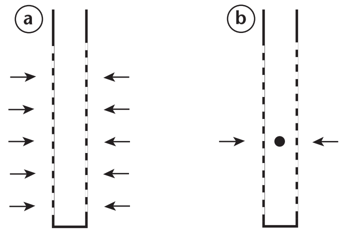
(Data courtesy of Waste Management Section, Worcestershire County Council)

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: (a) COMPOSITE SAMPLE	(b) SPOT SAMPLE
• Open and long-screened boreholes (see 8.5.1) • Water level below. within or close to top of screen 	A PR < BY	(1) or (4) use of alternative strategies (e.g. (2) (5) (6) (7) should be justified in comparative trials against (1) or (4)	(6) or (7) if spot sample required from water level. (5) in homogenous high permeability formations.
	B PR > BY	(6), (7) or (3) (allow water level to recover by at least 50% before sampling).	(6) or (7) if spot sample required from water level.
• Short-screened boreholes/ piezometers • Water level above top of screen (see 8.5.1) 	A PR < BY	(1) or (2) use of alternative strategies e.g. (4) (5) (6) (7) should be justified in comparative trials against (1) or (2)	(5) or (6) in homogeneous high permeability formations. (1), (2) or (4) if screen is very short (e.g. <3m)
	B PR > BY	(6) or (3) (allow water level to recover by at least 50% before sampling).	(6) or (4) if screen is very short (e.g. <3m)
unknown design ?	ANY	(1) or (3)	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

1. Stability of chemical determinands.[1,2]
2. 3x borehole volume[2].
3. Dewater and recover.

Replacement of water in screened section only

4. Low flow[3] timed purge based on hydraulic properties[4].

Sampling of water in screened section (assumed to be in continuity with aquifer)

5. Low flow[3] pumped sample[5].
6. Depth sample.
7. 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.

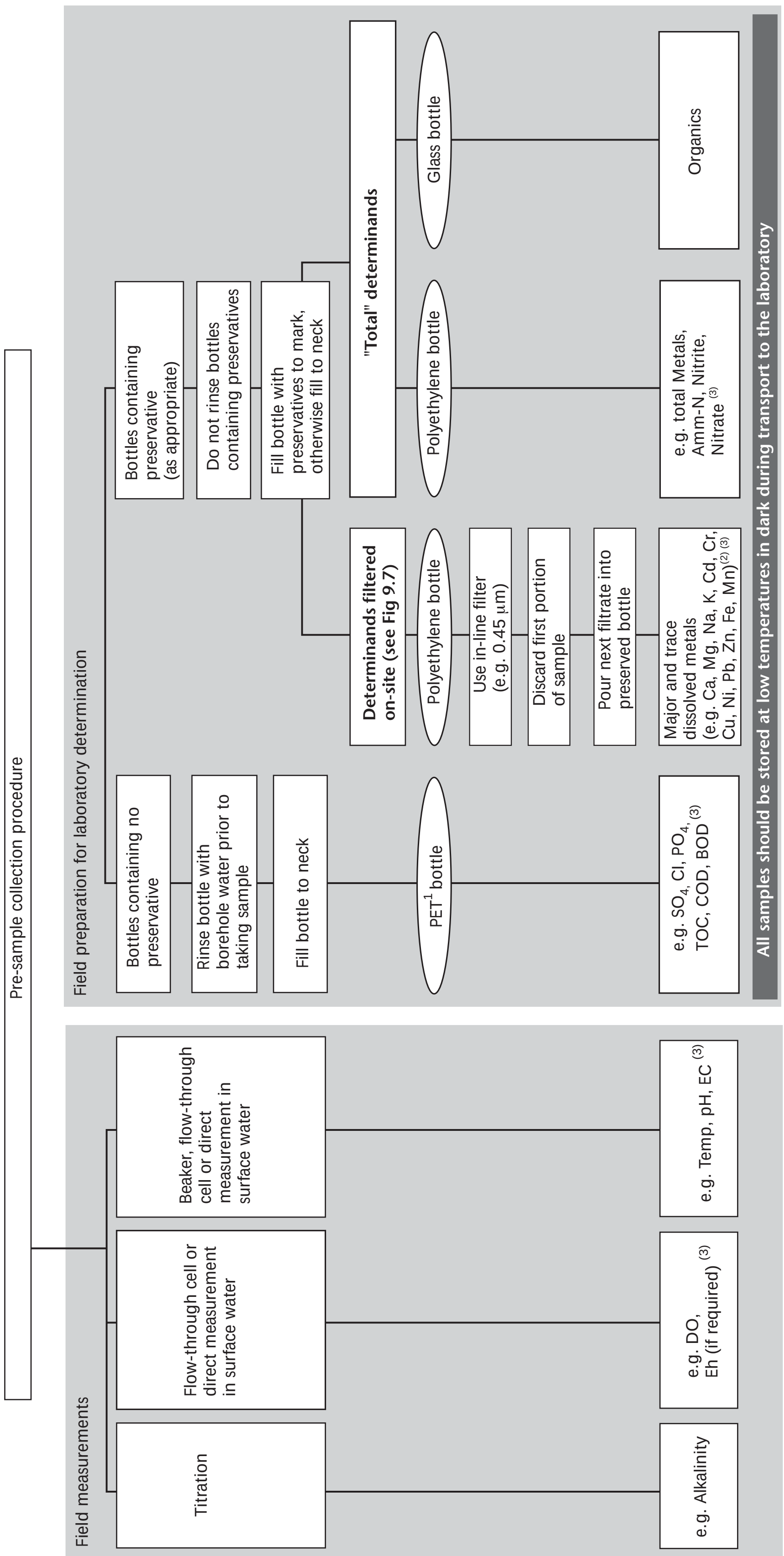
Many of these issues are subject to ongoing technical debate, and guidance presented in the following section reflects the need for a flexible approach.

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:

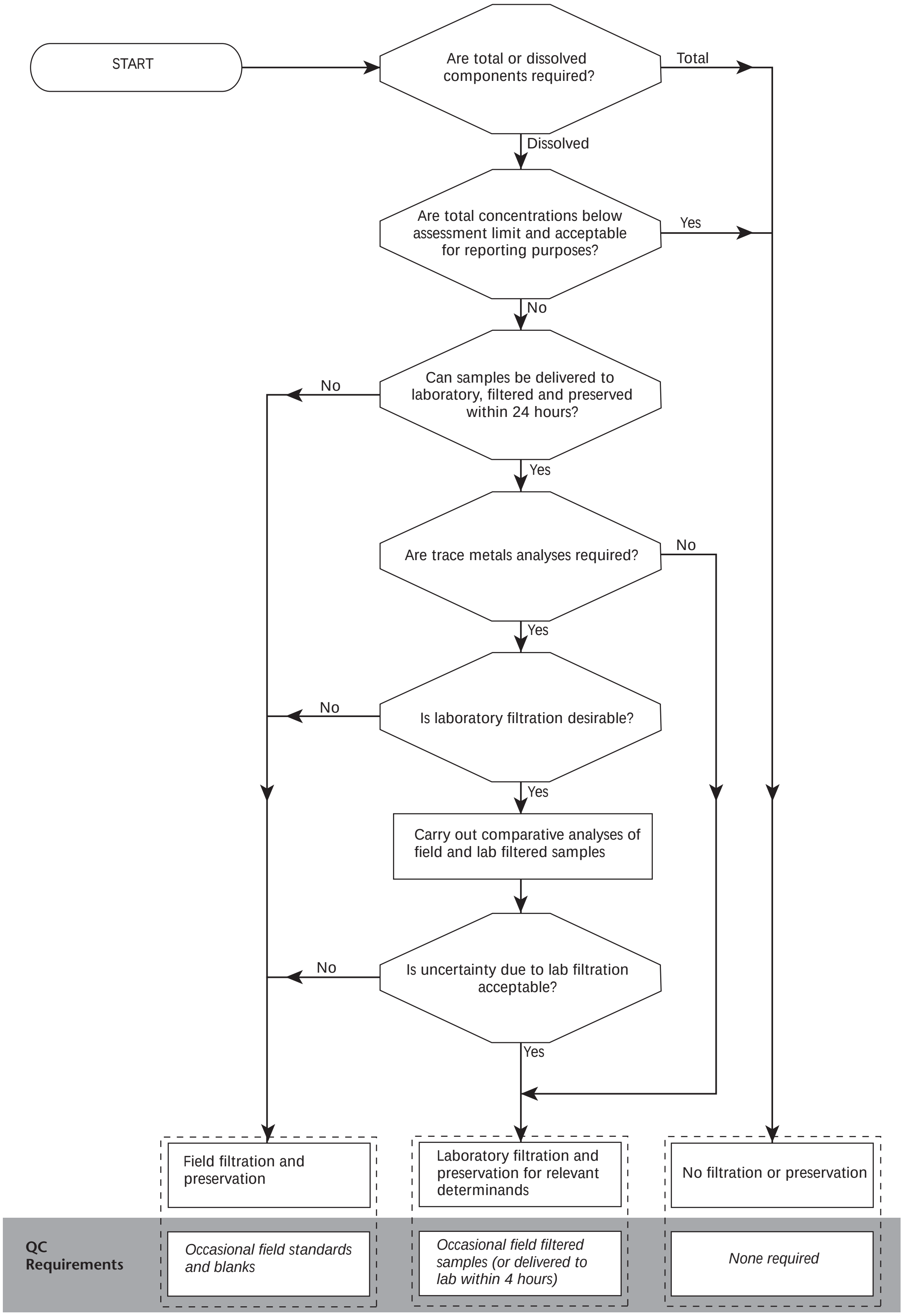
- unique monitoring point reference;
- depth of sample (where appropriate);
- sampling date and time;
- sampler identification.

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).

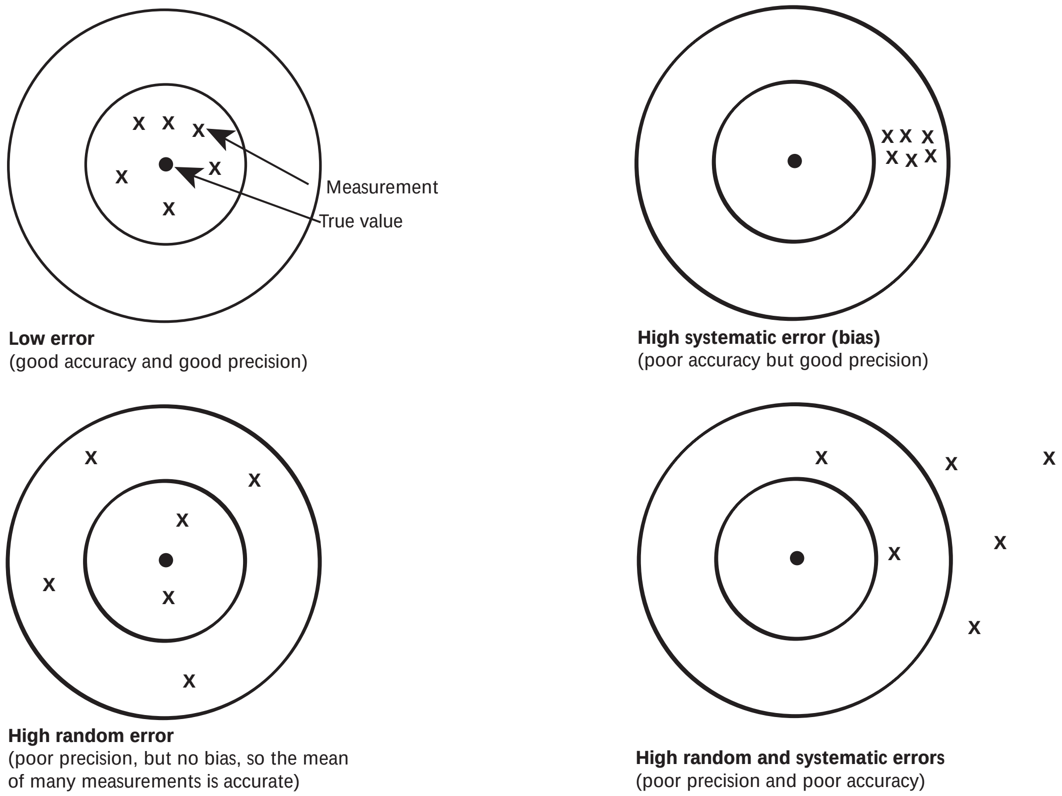
- Errors that arise from random variation
  These arise from variations in the behaviour of the sampling and measurement systems. These variations may or may not be evenly distributed around the actual measurement value. When such errors and/or variations are small relative to the measurement value, 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:

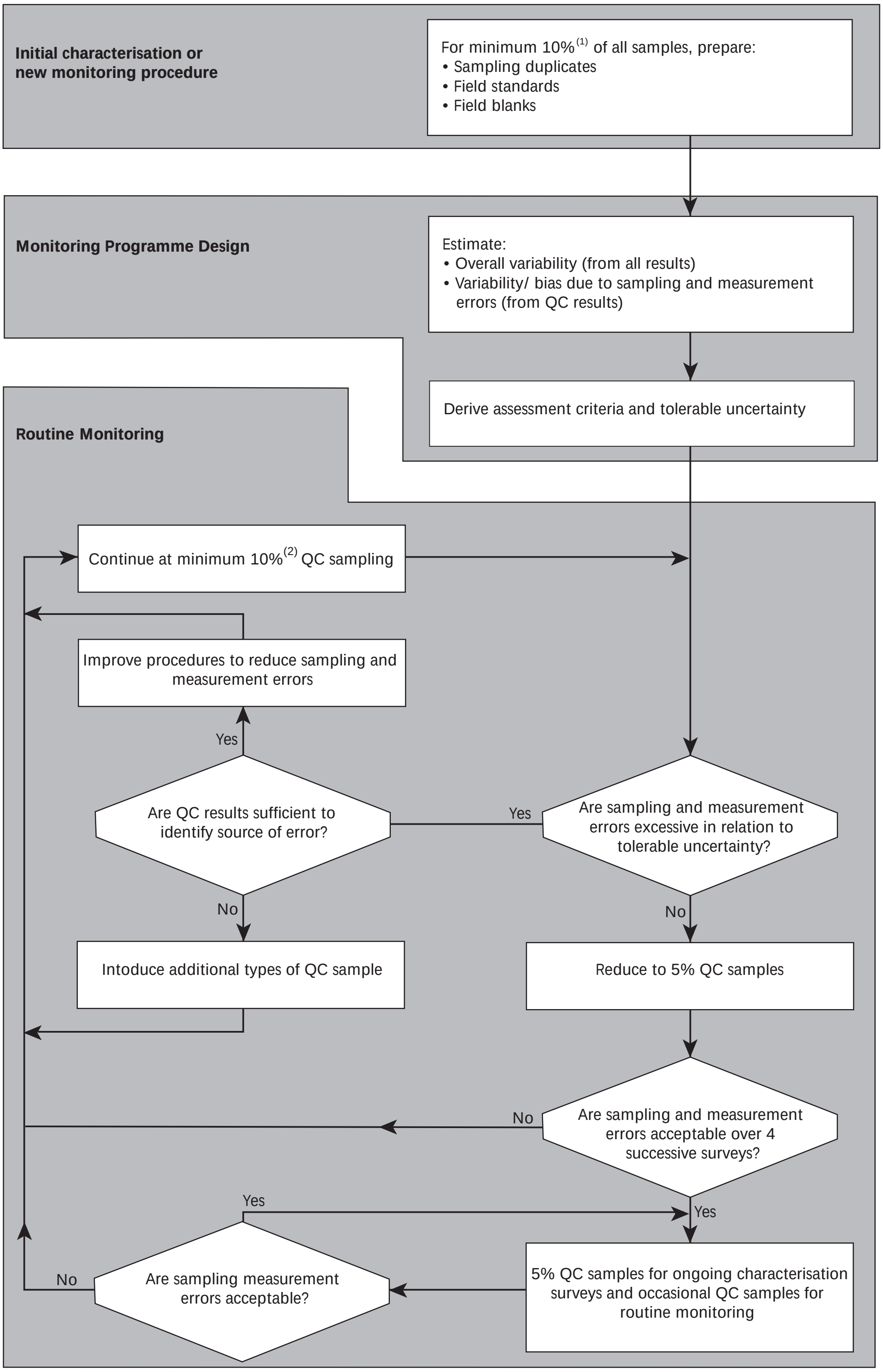
- field equipment calibration;
- purging of monitoring points;
- sample observations;
- field instrumentation measurements.

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

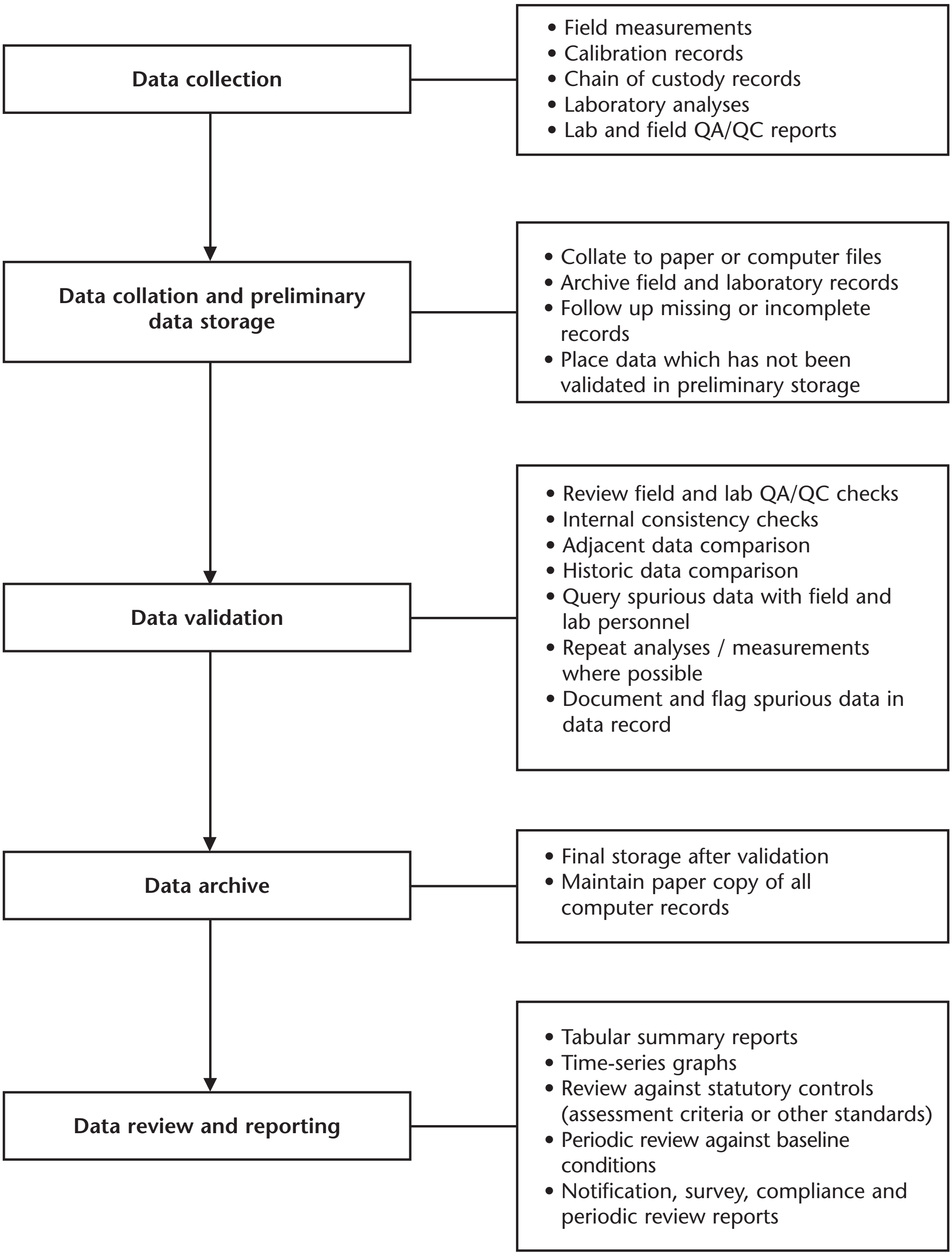
Adherence to good QC practices improves confidence in presented data. QC of monitoring data should be accomplished in two ways:

- 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

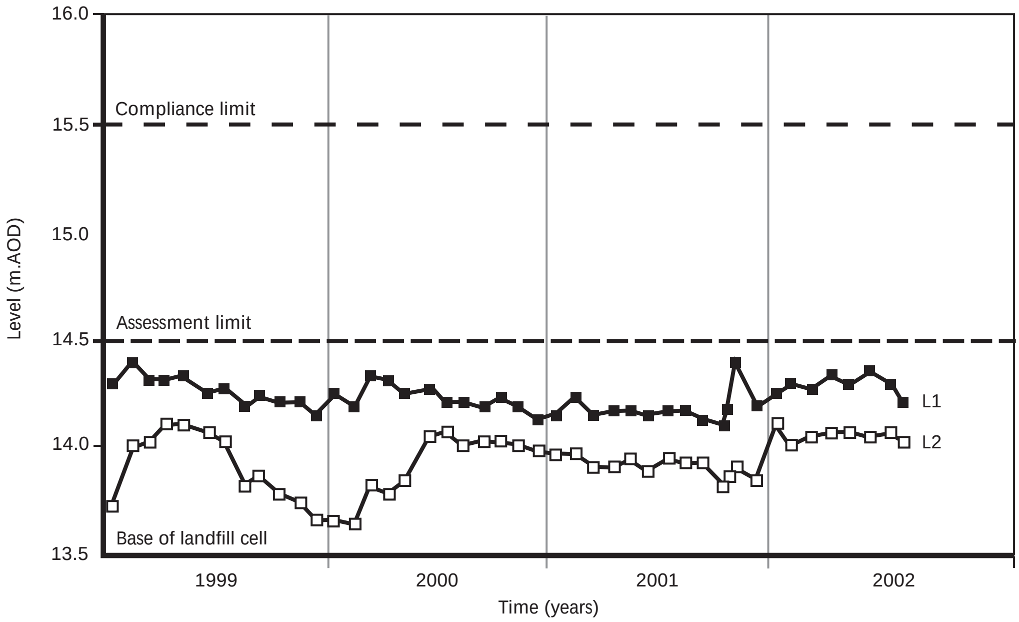
A number of specific review tasks should be implemented on validated data:

- 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

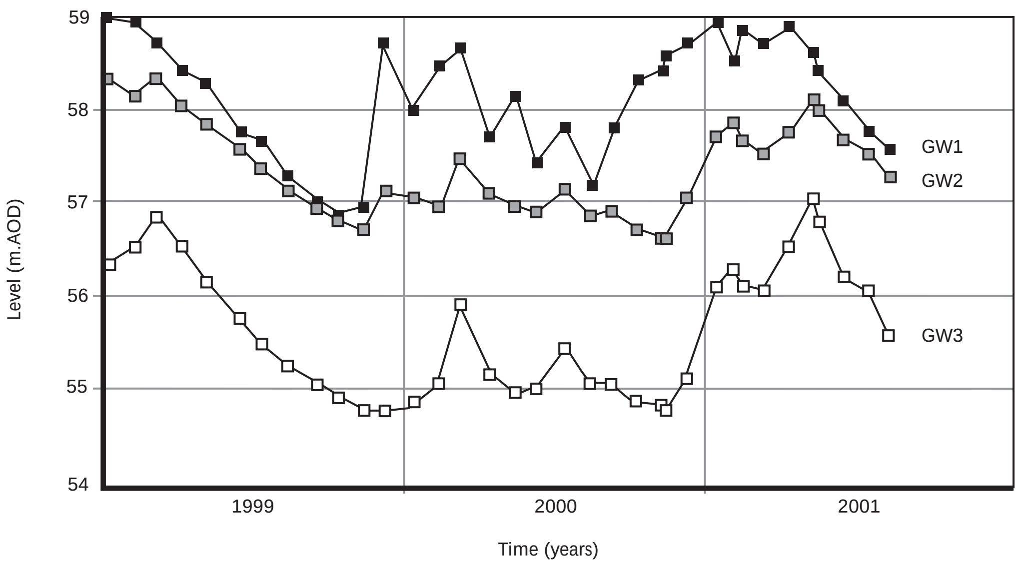


Figure10.3 Examples of presentation of water quality data for a single monitoring point using time-series charts

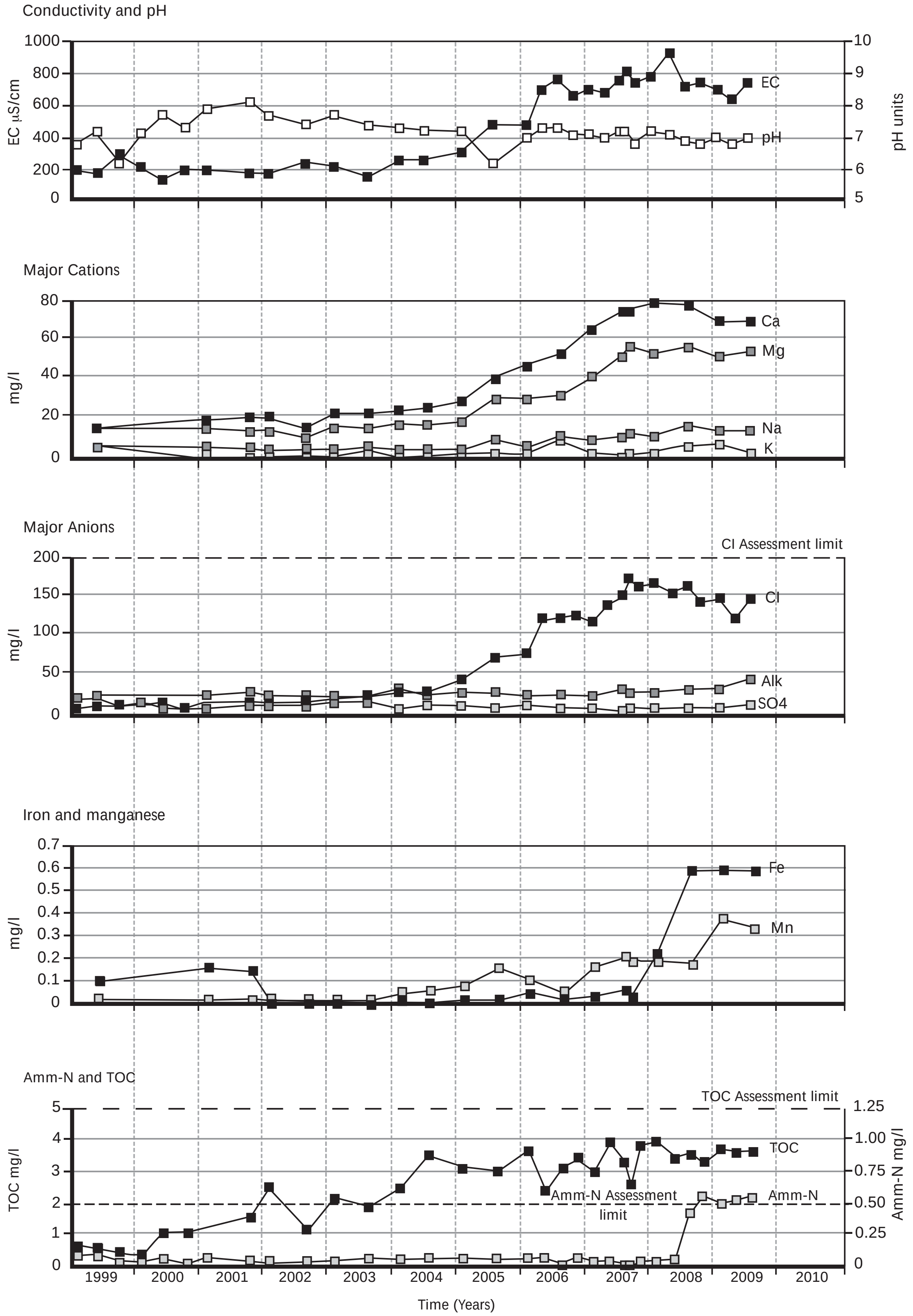
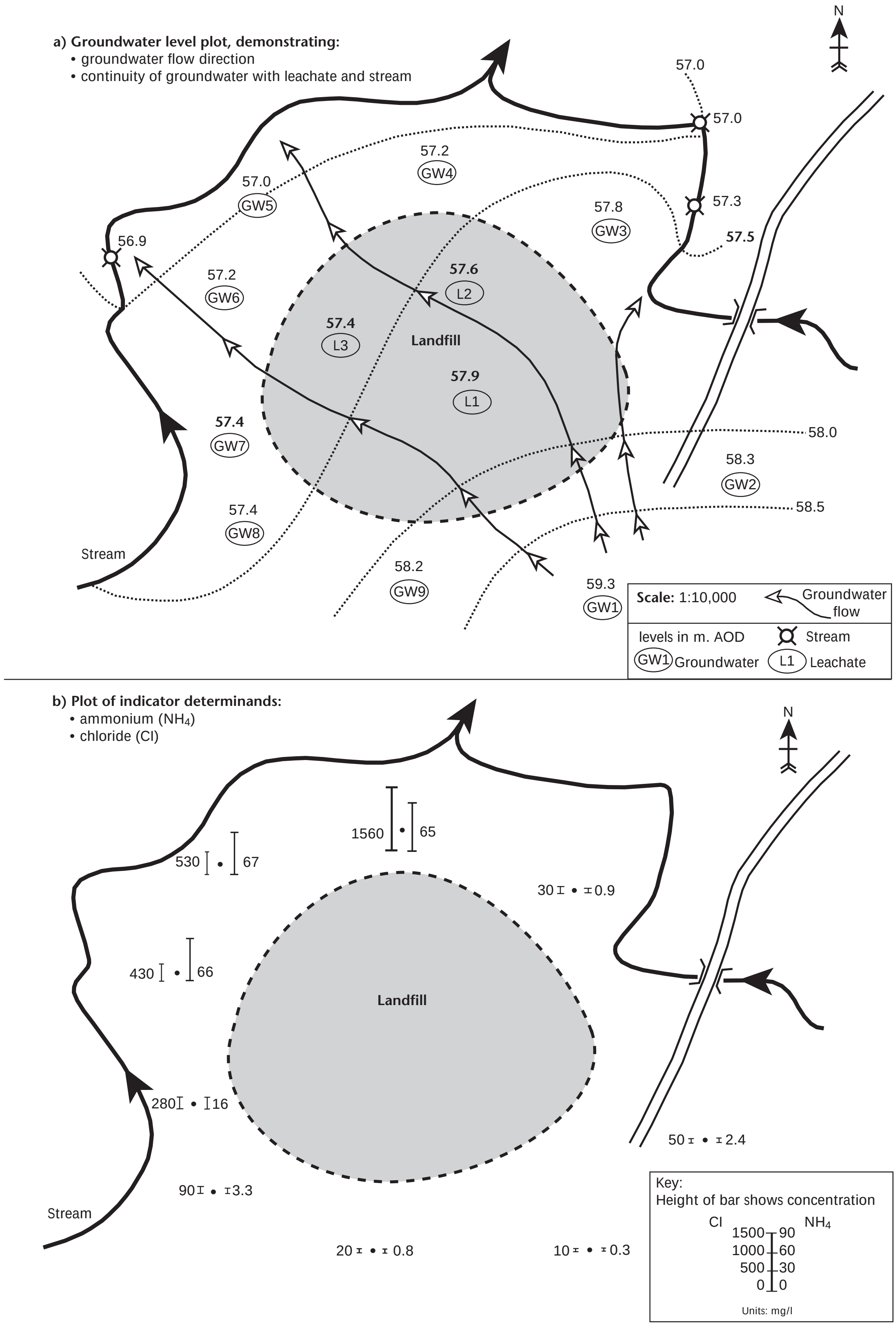


Figure 10.4 Examples of spatial presentation of data.



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.

Report and content	Timescale for reporting to:	
	Site management	Agency
Notification reports: breaches of assessment criteria contingency implemented	Within response time specified in assessment criteria	
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	Before next routine survey	Not normally required, but must be available for inspection
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	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)	
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	Annually	Annually – to be submitted within three months of end of reporting year
Environmental Management and Monitoring Programme: see Chapter 5 for contents	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	
Risk-based monitoring review	As necessary following breaches of assessment criteria	

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.

References

American Society for Testing and Materials (1992). *Pore-liquid sampling from the vadose zone.* ASTM Standard D4696-92. ASTM International, West Conshohocken, Pennsylvania, USA.

Association of Geotechnical Specialists (1992). *Safety manual for investigation sites.* PO Box 250, Camberley, UK.

Blakey N.C., Young C.P., Lewin K., Clark L., Turrell J., and Sims P. (1997). *Guidelines for monitoring leachate and groundwaters at landfill sites. Report No. CWM 062/97C.* Environment Agency, Bristol.

British Drilling Association (1981). *Code of safe drilling practice. (Part 1: Surface drilling).* Brentwood, Essex.

British Standards Institute (1993). *Water quality. BS6068:1993.* BSI, London.

British Standards Institution (1999). *Code of practice for site investigations. British Standard BS5930.* BSI, London.

Cheeseman R.V. and Wilson A.L. (revised, Gardner M.J.) (1989). *A manual on analytical quality control for the water industry. Manual NS30.* Water Research Centre plc, Swindon.

Christensen T.H., Bjerg P.L., Heron G., Williams G.M., Higgo J.J.W., Bourg A.C.M. and Altmann R.S. (1994). *Attenuation of landfill leachate pollutants in aquifers. Critical Reviews in Environmental Science and Technology, 24, 119–202.*

Commission of the European Communities (1976). *Directive on pollution caused by certain dangerous substances discharged into the aquatic environment (76/464/EEC).* Official Journal of the European Communities, L129, 18 May 1976, 23–28.

Council of the European Communities (1980). *Council Directive of 17 December 1979 on the Protection of Groundwater Against Pollution Caused by Certain Dangerous Substances (80/68/EEC).* Official Journal of the European Communities, L20, 26 January 1980, 43–47.

Council of the European Communities (1996). *Directive concerning Integrated Pollution Prevention and Control (96/61/EC),* CEC, Brussels.

Council of the European Communities (1999). *Council Directive 1999/31/EC of 26 April 1999 on the Landfill of Waste.* Official Journal of the European Communities, L182, 16 July 1999, 1–19Council of the European Communities (2000). *Water Framework Directive (2000/60/EC).* Official Journal of the European Communities, L327, 43, 1–73.

Department of the Environment (1995). *A review of the composition of leachates from domestic wastes in landfill sites. Environment Agency Report No. CWM 072/95.* DoE, London.

Environment Agency (1998). *Quality management system for environmental sampling. National Sampling Procedures Manual, Volume 25.* Environment Agency, Bristol.

Environment Agency (2000a). *Guidance on the assessment and monitoring of natural attenuation of contaminants in groundwater. R&D Publication 95.* Environment Agency, Bristol.

Environment Agency (2000c). *Internal guidance on the determination of applications to surrender waste management licences V1.0.* Environment Agency, Bristol.

Environment Agency (2000d). *Guide to good practice for the development of conceptual models and the selection and application of mathematical models of contaminant transport process in the subsurface.* Environment Agency, Bristol.

Environment Agency (2001a). *Pollution inventory discharges to sewer or surface water from landfill leachates. REGCON70, prepared by Enviros Aspinwall & Knox Associates.* Environment Agency, Bristol.

Environment Agency (2001b). *Integration of monitoring Data Management Systems for Landfill Sites R&D Technical Report p1-428.*

Environment Agency (2002a). *PPC Landfill Part B – application form for a permit.* Environment Agency, Bristol.

Environment Agency (2002b). *The management of landfill gas.* Environment Agency, Bristol.

Environment Agency (2002c). *Guidance note on the classification of sites under the landfill directive. Landfill Directive Regulatory Guidance Note 1.* Environment Agency, Bristol.

Environment Agency (2002d). *Development of techniques for the interpretation of landfill monitoring data, R&d Project p1-471.* Environment Agency, Bristol.

Environment Agency (2002e). *guidance on the disposal in landfills for non-hazardous waste of stable non reactive hazardous waste, asbestos and high sulphates waste. Landfill Directive Regulatory Guidance Note 11.* Environment Agency, Bristol.

Environment Agency (2003a). *Guidance on landfill completion.* Environment Agency, Bristol.

Environment Agency (2003b). *Hydrogeological risk assessments for landfills and the derivation of groundwater Control and Trigger levels.* Environment Agency, Bristol.

Environment Agency (2003c). *Improved definition of leachate source term from landfill. R&D Project P2-236.* Environment Agency, Bristol.

Environment Agency (2003d). *Technical guidance on the design, construction and operation of landfills.* Environment Agency, Bristol.

Environment Agency (2003e). *Guidance on the development and operation of landfill sites.* Environment Agency, Bristol.

Gibbons R.D., Dolan D.G., May H., O'Leary K., and O'Hara R. (1999). *Statistical comparison of leachate from hazardous, codisposal and municipal solid waste landfills. Ground Water Monitoring Review, 19, 57–72.*

Hem J.D. (1975). *Study and interpretation of the chemical characteristics of natural water.* US Government Printing Office, Washington DC.

International Standards Organisation (1980). ISO 5667-1: Water quality — sampling, Part 1: Guidance on the design of sampling programmes. British Standards Institution, London.

International Standards Organisation (1986). *ISO 8363: Liquid flow measurement in open channels: General guidelines for the selection of methods.* British Standards Institution, London.

International Standards Organisation (1987). ISO 5667-4: *Water quality — sampling, Part 4: Guidance on sampling from lakes, natural and man made.* British Standards Institution, London.

International Standards Organisation (1990). *ISO 5667-6: Water quality — sampling, Part 6: Guidance on sampling of rivers and streams.* British Standards Institution, London.

International Standards Organisation (1991). *ISO 5667-2: Water quality — sampling, Part 2: Guidance on sampling techniques.* British Standards Institution, London.

International Standards Organisation (1993). *ISO 5667-11: Water quality - sampling, Part 11: Guidance on sampling groundwaters.* British Standards Institution, London.

International Standards Organisation (1997) *ISO/TR 13530:1997: Guide to analytical quality control for water analysis.* British Standards Institution, London.

International Standards Organisation (1999). *ISO 5667-14: Water quality - sampling, Part 14: Guidance on quality assurance of environmental sampling and handling.* British Standards Institution, London.

International Standards Organisation (2001). *ISO 5667-18: Guidance on sampling groundwaters at contaminated sites.* British Standards Institution, London.

IWM Landfill Gas Monitoring Working Group (1998). *The monitoring of landfill gas.* Institute of Wastes Management, Northampton.

Keith L.H. (1996). *Environmental sampling and analysis: a practical guide. Lewis Publishers Inc.* Boca Raton.

Knox K., Robinson H.D., van Santen A., and Tempany P.R. (2000). *The occurrence of trace organic components in landfill leachates and their removal during on-site treatment. In: Proceedings of Waste 2000 Conference,* Stratford upon Avon, 2–4 October 2000. 263–272.

Mather J.D. (1977). *Attenuation and control of landfill leachates. In: Institute of solid wastes management 79th annual conference, 31 May – 3 June 1977, Torbay.* Institute of Wastes Management, Northampton.

Mather J.D., Banks D., Dumpleton S., and Fermor M. (1997). *Groundwater contaminants and their migration. Geological Society Special Publication No 128.* Geological Society, London

Mazor E. (1991). *Applied chemical and isotopic* *groundwater hydrology.* Open University Press, Milton Keynes.

Nielsen D.M. (1991). *Practical handbook of ground-water monitoring.* Lewis Publishers Inc, Bota Racon.

Oakland J.S. (1996). *Statistical process control - a really practical guide.* Butterworth–Heinemann, Oxford.

Price M. (1996). *Introducing Groundwater.* Chapman Hall, London.

Robinson H.D. (1996). *Tritium levels in leachates and condensates from domestic wastes in landfill sites. Journal of Chartered Institution of Water and Environmental Management, 10, 391–398.*

Robinson H.D. and Gronow J.R. (1995). *A review of landfill leachate composition in the UK.* Institute of Waste Management Proceedings, January 1995, 3–8. IWM, Northampton.

Standing Committee of Analysts (1996). *General principles of sampling waters and associated materials, Second Edition. (Estimation of flow and load. Methods for the examination of waters and associated materials.)* HMSO, London.

Thompson M. (1995). *Uncertainty in an uncertain world. Analyst, 120, 117–118.*