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# Hydrogeological Risk Assessments for Landfills

and the Derivation of Groundwater Control and Trigger Levels



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**Statement of use:**

This document presents guidance on best practice for hydrogeological risk assessment for landfills and the derivation of groundwater Control and Trigger levels at permitted landfill sites in England and Wales. It covers issues required by the EU Groundwater and Landfill Directives. It has been prepared for regulators and operators concerned with the development, operation, management, aftercare and regulation of landfill sites and assists in the determination of best practice.

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# Why this guidance should be used

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

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

Readers of this guidance are expected to be familiar with the Landfill Directive requirements and the national regulatory framework. Specifically, the Department for Environment, Food and Rural Affairs (Defra) (formerly Department of the Environment, Transport and the Regions) guidance document IPPC: A Practical Guide (DETR, 2000), which sets out how Government expects the PPC regime to operate.

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# Introduction

## 1.1 Purpose of the guidance and its regulatory context

This document provides guidance on the requirements for groundwater risk assessment of landfills and the setting of groundwater Control and Trigger levels. These requirements arise from implementing the EC Groundwater Directive (80/68/EEC) (Council of European Communities, 1980) and Landfill Directive (99/31/EC) (Council of European Communities, 1999). The guidance describes a tiered approach to hydrogeological risk assessment for landfill and sets out how Control and Trigger levels for groundwater (as required by the Landfill Directive) should be derived and used.

This guidance includes reference to the Water Framework Directive (2000/60/EC), which will be transposed into UK legislation in the near future. The Water Framework Directive includes new requirements for protecting and restoring surface water, groundwater and dependent ecological systems. There is provision within the Water Framework Directive (under Article 17) for a new directive on groundwater. Revisions to this document will probably be necessary to take account of these developments.

Hydrogeological risk assessment is a key process in evaluating future landfill developments. However, the process of site selection also needs to be set in the context of the Agency's *Policy and Practice for the Protection of Groundwater* (Environment Agency, 1998a), and specific guidance on the location and impact assessment of landfills (Environment Agency, 2002d). The latter sets out our approach to strategic waste planning, review of individual planning applications for new or extended landfill sites and the permitting of landfill sites in sensitive hydrogeological locations. Within this framework, we aim to direct new landfills away from areas where sensitive groundwater resources are present and into less vulnerable areas underlain by low-permeability geologic formations. It is important to note that landfill sites have the potential to pose a pollution risk for a very long period of time. The

hydrogeological risk assessment must consider the whole lifecycle of the landfill until it is in a condition that poses no further hazard to health or the environment, not just the comparatively short operational phase.

The Groundwater Directive was published in 1980 and has been implemented in the UK by the Waste Management Licensing Regulations 1994 and the Groundwater Regulations 1998. These regulations include a requirement for "prior investigation" of potential impacts on groundwater to be carried out before granting a licence or permit allowing waste disposal to land, where the wastes may contain certain polluting substances. Such "prior investigations" have commonly been referred to as "Regulation 15 risk assessments" since the requirement to conduct them, in respect of landfill developments, was implemented through Regulation 15 of the Waste Management Licensing Regulations 1994.

The Landfill Directive is implemented in England and Wales through the Landfill Regulations (England and Wales) 2002 (referred to in this document as the Landfill Regulations) and minor modifications to the Pollution Prevention and Control (PPC) Regulations 2000, both made under the PPC Act 1999. Equivalent legislation is anticipated in both Scotland and Northern Ireland.

The Landfill Directive is therefore implemented through the PPC regime. These regulations provide a comprehensive set of requirements that transpose the Landfill Directive into UK law. For existing landfills, they will replace the Waste Management Licensing Regulations 1994, although these regulations remain relevant to closed landfills and some other waste-management facilities. For PPC-authorized sites, the Groundwater Directive is implemented by the Groundwater Regulations 1998, (that is, the PPC permit acts as the authorisation for the Groundwater Regulations, hence it must include conditions to ensure compliance with the Groundwater Directive).

The full requirements of the Groundwater and Landfill Directives are given elsewhere (DETR 2001, DEFRA 2001). However, those that are particularly relevant to this document are set out below.

The regulations will be enforced by the relevant environment agencies (the Environment Agency in England and Wales, the Scottish Environment Protection Agency (SEPA) and the Environment and Heritage Service in Northern Ireland).

The Water Framework Directive also sets out requirements for the integrated management of surface and groundwater, both in terms of water quality and resources. This directive requires the protection of water quality and restoration of the status of water bodies where they fail to achieve "good status". More specifically, the directive requires that direct discharges of pollutants are prevented from entering groundwater, and that controls are placed on activities to prevent and limit (indirect) entry of pollutants into groundwater.

Within this guidance, the Landfill Directive is referred to as LFD, the Groundwater Directive as GWD and the Water Framework Directive as WFD.

### 1.1.1 Landfill Directive and definitions

#### *The requirement for hydrogeological risk assessments*

The Landfill Regulations provides for two separate risk assessments, as follows:

- Schedule 2(2)(c) of the regulations allows the Agency to waive the need for a landfill operator to collect contaminated water and leachate if an assessment, based on consideration of the location of the landfill and the wastes to be accepted, shows that the landfill poses no potential hazard to the environment. The risk-screening process described in Section 2.3 of this guidance addresses this particular requirement. We interpret this to mean that if there is no unacceptable risk of pollution, due to the low hazard of the waste and the low sensitivity of the location, then there may be no requirement to line the site for leachate collection.
- Schedule 2(3) to the regulations specifies engineering standards for the different classes of landfill. Schedule 2(3)(8) allows these to be reduced where assessment of environmental risks demonstrates, to the satisfaction of the competent authority (the Agency), that collection and treatment of leachate is not necessary (as above) or it has been established that the landfill poses no

potential risk to soil, groundwater or surface water. We interpret this to mean that the risk-assessment process must demonstrate that a proposed landfill design will not result in an unacceptable discharge at any stage of its lifecycle. Therefore, the detailed groundwater risk assessment (Section 3 of this guidance) and related assessments (for example, landfill gas control, stability) should be used to determine the engineering standards and other operational controls necessary to comply with the LFD and the GWD (see Environment Agency, 2002h for more information). Such risk assessments will need to be suitably robust and auditable, as they may be included in the Government's submissions to the European Commission to demonstrate implementation of the LFD.

Schedule 2(3) to the regulations requires that the protection of groundwater is achieved during the operational, active and post-closure (that is, pre-surrender) phases by the combination of a geological barrier and a bottom liner/artificial sealing liner. Subsequently, during the passive/post-surrender phase, it is achieved by the combination of a geological barrier and top liner/cap.

This means that the assessor should take into account the durability and longevity of the liner system to ensure that it will offer the desired degree of protection during the post-closure/pre-surrender period. In turn, this implies that the assessor may need to consider the probable length of the post-closure period, which will also be relevant to determining appropriate financial provision.

**The fundamental requirement for a geological barrier in all instances, and also a bottom liner wherever leachate needs to be collected, cannot be altered by the outcome of the risk-assessment process.** Both of these elements are always required wherever there is a need to collect leachate. It may not be a requirement to collect leachate at inert sites.

The geological barrier is a vital component in providing environmental protection. Its purpose within the LFD is to provide sufficient attenuation capacity to prevent a potential risk to soil and groundwater. The *attenuation* provided by the geological barrier is interpreted by the Agency as having the same meaning as the *purifying powers* of the soil and sub-soil referred to in the GWD. For the purposes of the hydrogeological risk assessment, the test as to whether the geological barrier provides sufficient environmental protection should be the same as that required by the GWD (that is, there should be no unacceptable discharge to groundwater at any point during the life of the site).

In the passive/post-surrender phase, the LFD requires environmental protection to be achieved by a geological barrier and a cap. It does not rely on the artificial sealing liner. This reflects uncertainties about the durability and longevity of artificial liners and other management systems. The hydrogeological risk assessment must cover the entire period during which the landfill presents a hazard (that is, the active and post-closure/pre-surrender periods. This means that the risk assessment must consider the degradation of artificial lining systems (and other management systems such as leachate collection) and the capacity of the geological barrier to attenuate the leakage of leachate for the whole lifecycle of the landfill. For biodegradable landfills, the changing pollution potential of leachate with time will be an important consideration in the long-term risk assessment and in determining completion criteria.

Further guidance on the Agency's interpretation of the engineering requirements of Annex I of the LFD is given in Environment Agency, 2002h.

### **Control and Trigger levels**

With regards to Control and Trigger levels, Schedule 2(5)(1) to the Landfill Regulations states that:

- *"Significant adverse environmental effects, as referred to in Regulations 14(3) and 15(5)(b), should be considered to have occurred in the case of groundwater, when an analysis of a groundwater sample shows a significant change in water quality."* Schedule 2(5)(2) goes on to state that: *"A Trigger level must be determined taking account of the specific hydrogeological formations in the location of the landfill and groundwater quality"* and Schedule 2(5)(3) requires that they *"are set out in the conditions of the landfill permit whenever possible"*.
- With regards to Control levels, the regulations state that *"observations must be evaluated by means of control charts with established control rules and levels for each down gradient well. The Control levels must be determined from local variations in groundwater quality."*

Control levels are specific assessment criteria used to determine whether a landfill is performing as designed. They are intended to draw the attention of site management and the Agency to the development of adverse trends in the monitoring data. If breached, they indicate that the landfill may not be performing as predicted. They should be regarded, therefore, as an early warning system to enable appropriate investigative or corrective measures to be implemented, rather than as an indication that groundwater pollution has occurred.

Control levels are directly comparable to assessment criteria as defined within the Agency's technical guidance on the *Monitoring of Landfill Leachate, Groundwater and Surface Water* (Environment Agency, 2002b).

Trigger levels are defined as levels at which significant adverse environmental effects, as referred to in Regulations 14(3) and 15(5)(b), have occurred. Such effects would be consistent with the aquifer having been polluted and would therefore be consistent with the Environmental Assessment Limit (EAL) relevant for the specific groundwater receptor having been breached. It follows, therefore, that the trigger level for a particular contaminant will be the most stringent EAL for that substance, given the environmental setting of the site. Where there is poor baseline quality due to other anthropogenic impacts, the Trigger levels should be derived to take these into account, but they must not bring about a delay in improving water quality as other sources of pollution decline. Section 2.6 of this guidance deals with setting Trigger levels.

Trigger levels are to be set at the point (as a concentration and a location) at which pollution can be said to have occurred. They can therefore be used in the risk-assessment process to define the point at which an unacceptable discharge would have occurred.

Trigger levels are directly comparable to compliance levels as defined within current Agency technical guidance (Environment Agency, 2002b).

Different actions are required for breaches of groundwater Control and Trigger levels at landfills. These actions, as well as the derivation and use of groundwater Control and Trigger levels, are considered in more detail in section 4.

### **1.1.2 Groundwater Directive and definitions**

The GWD requires the management of activities, including the discharge or disposal of listed substances, or materials containing listed substances, so as to prevent groundwater pollution. The general purpose of the GWD is:

- "to prevent the pollution of groundwater by the substances listed in the Annex to the Directive. More specifically, Member States are obliged to take the necessary steps to:*
- (a) prevent substances in List I from entering the groundwater, and*
  - (b) limit the introduction of List II substances into groundwater so as to avoid pollution."*

Furthermore, the GWD requires disposal activities to be subject to “prior investigation” demonstrating that groundwater pollution will not result before the activity can be authorised. This investigation should also establish whether the discharge “*is a satisfactory solution from the point of view of the environment*”. The authorised activity must also be subject to “*essential and technical precautions*” to prevent pollution, and the Agency must ensure that “*requisite surveillance of groundwater*” is undertaken. In the UK, for many processes including landfilling, this is achieved through the PPC permitting process.

The Groundwater Regulations 1998 encompass the following activities:

- (a) any disposal or tipping for the purposes of disposal of a substance in List I or List II that might lead to an indirect discharge into groundwater of such substances; or
- (b) any direct discharge into groundwater of a substance in List I or List II.

The terms “substances in Lists I and II”, “groundwater” and “direct and indirect discharges” should all be construed as described in the subsequent sections of this guidance.

These regulations also require authorisations to be reviewed at least every four years. This is reflected in permit conditions requiring the review of hydrogeological risk assessments on a four-yearly cycle. This review is an important part of the overall risk-assessment process and is covered in more detail in Section 5.

This technical guidance considers the requirements of the GWD. Appendix 1 presents both List I and List II substances as included within the GWD. The Agencies are considering, through the Joint Agencies Groundwater Directive Advisory Group (JAGDAG, 2001), specific compounds that fall within the groups or families of substances listed in the directive. To date, more than 500 substances have been considered and provisionally classed as being List I, II or not-listed for the purpose of the Groundwater Regulations. Following ministerial approval, confirmed List I and II substances will be published. The first 79 confirmed List I substances were published in the *Statutory Guidance on the Groundwater Regulations* (DETR, 2001).

### 1.1.3 Water Framework Directive

The WFD (2000/60/EC) was published in December 2000. It seeks to set a framework for revising a wide range of existing water-focussed EC directives to

ensure integrated management of surface waters and groundwater, water quality and water resources.

With regards to water quality, the WFD aims to protect groundwater from pollution, and significantly reduce the entry of certain hazardous substances to surface waters. Where a body of water fails to achieve “good status” – which takes account of the chemical and quantitative status of groundwater and ecological and chemical status of surface water – provisions are included that require restoring the status of the water body.

As part of the initial characterisation of groundwater bodies, pressures on groundwater must be identified. The WFD identifies pollution from point and diffuse sources, abstractions and intrusions being of specific interest. Where a groundwater body is found to be at risk of failing to achieve good status, further characterisation is necessary to assess the significance of the different pressures. A programme of measures must be developed to restore groundwater bodies to good status and to prevent future deterioration of groundwater bodies. Article 17 of the WFD provides further requirements for groundwater. It is anticipated that a new Directive on groundwater will be drafted that will ultimately replace Directive (80/68/EEC) (GWD). The WFD requires that all pollutants are prevented from directly entering groundwater, and that there are controls on indirect discharges that prevent or limit their entry. A list of main pollutants given in the WFD is reproduced in Appendix 2.

As implementing the WFD must achieve a level of protection at least equivalent to the existing GWD (80/68), the new Groundwater Directive will probably contain similar provisions on substances that are to be prevented from entering groundwater. However, details are unlikely to be clear until formal proposals have been submitted to the European Parliament in 2003.

It will be necessary to revise this guidance as the WFD is transposed into UK legislation and when the details of the proposed new Groundwater Directive are agreed.

## 1.2 Scope and applicability of the guidance

This document describes techniques that are considered to be good practice. It provides guidance on the related issues of hydrogeological risk assessment and the derivation of groundwater Control and Trigger levels for new and existing landfills. It supersedes previous guidance on Regulation 15 hydrogeological risk assessment (Environment Agency, 1999a).

The Agency has to ensure an appropriate risk assessment is undertaken for each site as part of the permitting and/or review process. We require the submission of a relevant, technically robust and auditable risk assessment that provides support and justification for the design of:

- engineered containment measures (including geotechnical justification as required);
- environmental monitoring systems;
- management control systems.

We expect a tiered framework to be adopted in assessing environmental risks. Accordingly, the greatest effort and resources are likely to be focussed on data collection and quantitative assessment at the most environmentally sensitive sites, or where there is significant uncertainty in understanding (of processes or data) combined with the potential for significant environmental damage to occur.

The risk-assessment framework should subsequently be used to develop Control and Trigger levels for the landfill that will indicate, with confidence, when it is not performing as expected or designed, and when remedial action is necessary.

This guidance is specific to landfill activities and may not be applicable to other activities that must comply with the GWD.

## 1.3 Other guidance

This guidance should not be viewed in isolation. The inter-relationship between this and other current technical guidance is illustrated in Figure 1.1. As well as the specific requirements of the Groundwater, Landfill and IPPC Directives (and respective UK regulations), assessors should take note of other policy and guidance documents that deal with related matters, such as our *Policy and Practice for the Protection of Groundwater*, landfill gas guidance and stability considerations. Other requirements of the PPC regime relating to landfill construction, design and operation (Environment Agency 2002c, 2002h) must also be addressed.

## 1.4 The risk-assessment process

Risk assessment should be a structured, transparent and practical process that aids decision-making. The Government's recommended framework for environmental risk assessment and management is described in DETR et al., (2000), as illustrated in Figure 1.2. It comprises a tiered approach where the level of effort put into assessing risks is proportionate to their magnitude and complexity. This basic framework has been used to develop this guidance.

This approach also emphasises the:

- importance of developing a robust conceptual site model that is continually reviewed and updated as new information is collected;
- need to screen and prioritise all actual and potential risks before quantification;
- need to consider risks posed by the landfill during the post-closure, aftercare phase of its life as well as during its operational phase;
- need to match effort and resources in evaluating potential risks to the magnitude of environmental damage that could result from each hazard;
- need for an appropriate level of essential and technical measures to manage the risks;
- iterative nature of the process, with Control and Trigger levels and the annual and four-yearly reviews being an integral part of that process.

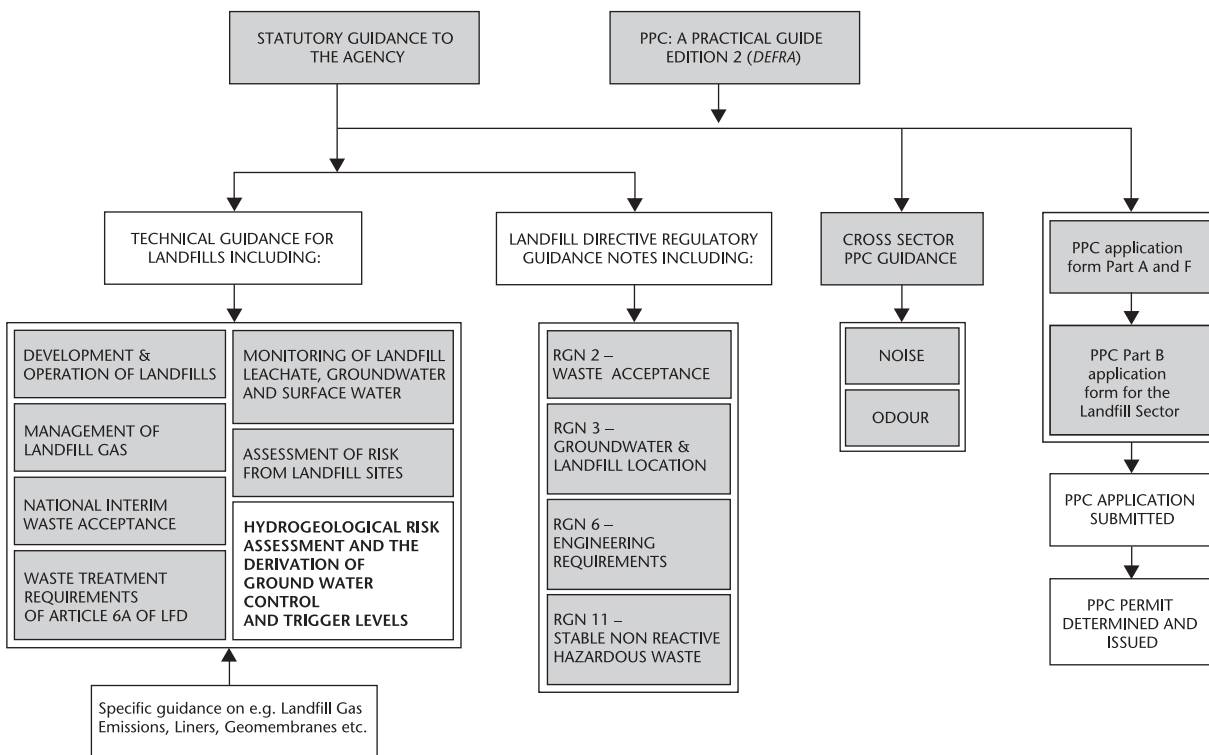
## 1.5 Structure of this guidance

This guidance sets out a tiered and structured approach for the hydrogeological risk assessments of landfills. The outcome of an assessment should be a decision on whether landfill development is an acceptable option at the site in question and, if so, to identify an appropriate degree of containment engineering. The process will also derive groundwater Control and Trigger levels that will subsequently be used to indicate whether the landfill is performing as initially designed.

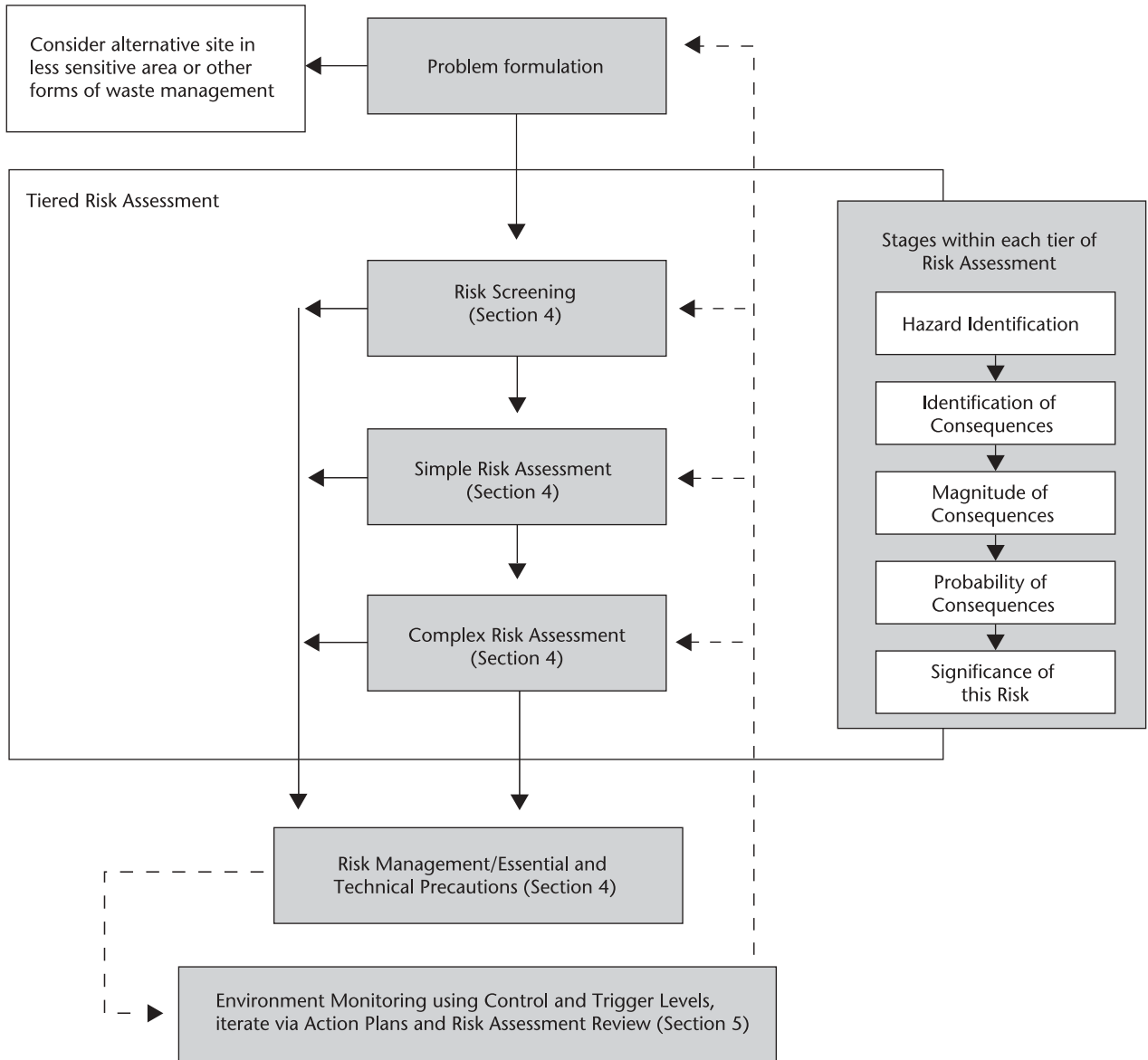
This approach is reflected in the structure of the guidance, which is:

- developing the conceptual model and risk screening (Section 2);
- carrying out detailed risk assessments (Section 3);
- the derivation and use of control criteria and use of Trigger levels (Section 4);
- reporting requirements (Section 5).

Figure 1.1 | The inter-relationships between this document and related guidance



**Figure 1.2** | Framework for a tiered approach to risk assessment





# Risk Screening and Trigger Level Development

## 2.1 Introduction

This section describes the development of an understanding of a landfill site in its surroundings and the initial consideration of the risks from a landfill. These two elements are respectively known as developing the conceptual model and risk screening. Development of the conceptual site model involves defining the nature of the proposed landfill and its hydrogeological setting. More specifically, it should describe the design, construction and operation of a landfill, and the nature of baseline environmental conditions. It should identify possible sources, pathways and receptors, and the processes that are likely to occur along each of those source-pathway-receptor linkages.

Conceptual model development is important as it forms the basis for all of the subsequent risk assessment. The development of the conceptual model should commence at the initial strategic planning and pre-planning assessment phases for a new development, to ensure that all the relevant information is available at an early stage. Detailed refinement of the conceptual site model may not be required for the planning application stage. It will, however, be required at the pollution control permitting stage, to allow robust understanding of relevant processes acting on contaminating substances, and in most cases their simulation by quantitative modelling.

Risk screening is used to determine whether the landfill represents, or potentially represents, a hazard to ground and surface water resources. This process typically involves identifying possible source-pathway-receptor (S-P-R) linkages from the conceptual model, and an initial assessment of the likelihood and magnitude of any effects associated with each S-P-R linkage. Based on this assessment, the risk-screening stage should also prioritise the risks so that any subsequent, more detailed risk-assessment can focus on the most significant risks.

Risk screening can be undertaken as the first stage of the risk-assessment process for an application for a PPC permit or as part of a scoping document for an Environmental Impact Assessment. Where it is prepared as part of the permitting process, it should form part of the pre-application discussions (see Section 5), which should also include discussions on the assumptions included within the conceptual model.

## 2.2 Developing The Conceptual Site Model

Preparing a robust conceptual model is a critical element in successfully evaluating environmental risks. Its development underpins each stage of risk assessment, such that its development and refinement is an iterative process within each level of risk assessment. We have published guidance on developing conceptual site models (Environment Agency, 2001a and 2002b), and recommend that users refer to these documents during the hydrogeological risk-assessment process.

The conceptual site model should describe potential environmental impacts associated with the site. It should be recognised that developing a conceptual site model must be an iterative process, with the model being reviewed and updated as new information becomes available or as understanding of the system improves.

The initial conceptual site model should include reference to our *Policy and Practice for the Protection of Groundwater* (Environment Agency, 1998) (PPPG) and specific guidance on the location and impact assessment of landfills near sensitive groundwater resources (Environment Agency, 2002d).

There are three key stages in developing a robust conceptual site model:

- a desk study and site reconnaissance followed by the initial development of a conceptual model;
- site investigations that may be needed to test and refine the initial model;
- environmental monitoring needed to validate any modelling.

In relation to the GWD and WFD, the following must be identified in the conceptual model:

- whether there is the potential for a direct discharge of listed substances or pollutants into groundwater;
- whether the application for a PPC permit is made on the basis that the groundwater is “permanently unsuitable for other uses”.

The above requirements are dealt with in subsequent sections.

### 2.2.1 Desk Study and Initial Appraisal

The objectives of the desk study and initial appraisal are as follows:

- to collect all available, relevant information to characterise the site and its surroundings from literature, public registers and site reconnaissance;
- to develop an initial conceptual site model for both the site and its hydrogeological setting. This should include summaries of available information, such as maps, plans, cross-sections, schematic diagrams and the like, which allow an easy understanding of the environmental setting;
- to determine, using the initial conceptual site model, the necessary site investigations and to develop a plan for them. Note that leachate characterisation is required for all levels of risk assessment complexity;
- to obtain preliminary views of the Agency and other interested parties (for example, local authorities), using the initial conceptual site model as a basis for discussion.

Table 2.1 lists many of the issues that need to be addressed and sets out the information that should be reviewed at the initial conceptual site model formulation stage. Appendix 3 sets out the possible sources of information that relate to determining the potential or actual leachate quality. Appendix 4 details the specific information requirements that relate to site geology and hydrogeology. The data-collection exercise, and specifically the degree

of site-specific data analysis, is likely to reflect the environmental sensitivity of the site and the nature of the hazard posed by the wastes.

When the desk study is completed, it should be possible to develop an initial conceptual site model that relates the landfill to its environmental setting. This model should be used to identify the uncertainties in defining the system behaviour, both in the landfill and the site’s hydrogeological setting. The nature and scale of these uncertainties will determine the need for site investigations and will guide the site-investigation programme.

Note that adequate leachate characterisation is required for all levels of risk assessment. Appendix 3 presents some of the potential sources of information that could be used to predict likely leachate chemistry. However, wherever possible, representative samples of leachate from either the landfill or representative analogue sites that take similar waste streams should be tested. The presence of listed substances is discussed in 2.3.2.

Once the initial conceptual site model has been developed, the landfill developer/operator should discuss its findings and interpretation with the Environment Agency. This is considered desirable to:

- obtain feedback relating to the conceptualisation of the site;
- determine whether assumptions made are consistent with Agency officers’ understanding of the local hydrogeology and environmental setting;
- agree the current uncertainties present within the conceptual site model.

And with regard to these uncertainties, to:

- agree the objectives of any site investigations;
- discuss the level of risk-assessment complexity that may be required for the site.

For a landfill developer to maximise feedback from the Agency, relevant documentation should be submitted to us for consideration before discussions take place. Information presented in tabular and graphical forms is an effective way to provide summaries of information gathered during the review. Similarly, tables clearly illustrating the potential sources, hazards and pathways, and drawings showing schematic cross-sections through the landfill development, plus the locations of potential receptors are useful.

**Table 2.1** | Issues that need to be considered during the development of the initial conceptual site model

	Information that should be reviewed	Potential sources of information that should be consulted
<b>Site context</b>	<p><b>For all sites:</b></p> <ul style="list-style-type: none"> <li>• <i>Policy and Practice for the Protection of Groundwater</i>, Groundwater Vulnerability and Source Protection Zone maps, and guidance on the location and impact assessment of landfill sites;</li> <li>• Waste Local Plan designation.</li> </ul>	<p><b>From the Environment Agency:</b></p> <ul style="list-style-type: none"> <li>• discussions with the relevant Agency officers and review of relevant Technical Guidance.</li> </ul> <p><b>From the local authority:</b></p> <ul style="list-style-type: none"> <li>• discussions with the relevant local authority waste planning officer and review of relevant Waste Local Plan.</li> </ul>
<b>Identification of the potential hazards</b>	<p><b>For all sites:</b> Relevant and available information on the following (where appropriate):</p> <ul style="list-style-type: none"> <li>• history of development;</li> <li>• site surveys and local topography;</li> <li>• details of the proposed site design, including any containment engineering, leachate drainage, leachate collection systems, a water balance and prediction of the quantities of leachate generated.</li> </ul> <p><b>For sites already in operation:</b></p> <ul style="list-style-type: none"> <li>• actual waste types deposited (current and historical) and proposed waste types;</li> <li>• actual data on leachate quality and likely future leachate quality (including whether the site may give rise to the discharge of listed substances);</li> <li>• existing lining/drainage systems in current cells;</li> <li>• data from any monitoring, including any leak detection layers.</li> </ul> <p><b>For sites not yet in operation:</b></p> <ul style="list-style-type: none"> <li>• proposed waste types to be deposited;</li> <li>• likely leachate quality (including whether the site may give rise to the discharge of potential pollutants) (DoE, 1995; Environment Agency 2001e; Knox et al, 2000).</li> </ul>	<p><b>From a site visit:</b></p> <ul style="list-style-type: none"> <li>• a site visit by the person(s) carrying out the risk assessment provides valuable information that should not be ignored. This visit should include a meeting with relevant operational and technical staff.</li> </ul> <p><b>From the landfill operator:</b></p> <ul style="list-style-type: none"> <li>• site surveys showing progressive site development;</li> <li>• planning permissions and Environmental Statements;</li> <li>• Waste Management Licence applications and supporting information, such as Working Plans (for existing sites that have not transferred to the PPC regime);</li> <li>• PPC permit applications and supporting information;</li> <li>• leachate-quality information for existing phases and/or landfills that receive similar waste streams, leachate-level information and Environmental Monitoring Reviews;</li> <li>• Construction Quality Assurance reports;</li> <li>• previous correspondence with Agency and other third parties.</li> </ul> <p><b>From the Environment Agency:</b></p> <ul style="list-style-type: none"> <li>• discussions with the relevant Agency officers;</li> <li>• the Public Register may hold leachate-quality information for similar sites near the landfill undergoing assessment that are operated by a different waste management company.</li> </ul> <p><b>From miscellaneous sources:</b></p> <ul style="list-style-type: none"> <li>• technical guidance and relevant publications.</li> </ul>

Issues	Information that should be reviewed	Potential sources of information that should be consulted
<p><b>Definition of the source, pathway and receptor terms and the establishment of the baseline conditions</b></p>	<p>Relevant and available information on the following (where appropriate):</p> <ul style="list-style-type: none"> <li>• geology;</li> <li>• hydrogeology, including aquifer status from Groundwater Vulnerability maps and groundwater Source Protection Zone status;</li> <li>• location of surface water bodies;</li> <li>• flood plain designation;</li> <li>• environmental monitoring of both groundwater and surface waters, including the location and construction details of all monitoring points;</li> <li>• groundwater and surface water quality (including variation over time and analyses for Listed substances);</li> <li>• the identification of receptors and their sensitivities. This may include groundwater resources in aquifers, groundwater abstractions currently being used for industrial, agricultural, potable and other legitimate uses and surface waters recharged by, or in hydraulic continuity with, groundwater. Groundwater fulfils a dual role of being both a receptor and a pathway to other receptors in the wider environment;</li> <li>• existing conceptual site model and/or Regulation 15 groundwater risk-assessment report previously prepared.</li> </ul>	<p><b>From a site visit:</b></p> <ul style="list-style-type: none"> <li>• a site visit by the person(s) carrying out the risk assessment provides valuable information that should not be ignored. This visit should include a meeting with staff who are involved with the environmental monitoring of the site.</li> </ul> <p><b>From the landfill operator:</b></p> <ul style="list-style-type: none"> <li>• site surveys showing all monitoring locations;</li> <li>• planning permissions and Environmental Statements;</li> <li>• Waste Management Licence applications and supporting information, such as Working Plans (for existing sites that have not transferred to the PPC regime);</li> <li>• PPC permit applications and supporting information;</li> <li>• groundwater and surface water monitoring data and environmental monitoring reviews;</li> <li>• previous correspondence with Agency and other third parties.</li> </ul> <p><b>From the Environment Agency:</b></p> <ul style="list-style-type: none"> <li>• discussions with the relevant Agency officers;</li> <li>• information relating to rainfall, licensed abstractions, groundwater vulnerability, Source Protection Zones, Discharge Consents, surface water flows/quality, groundwater levels/quality, designated conservation areas and flood potential;</li> <li>• the Public Register may hold groundwater and surface water monitoring information for sites that may be adjacent to the landfill undergoing assessment.</li> </ul> <p><b>From miscellaneous sources:</b></p> <ul style="list-style-type: none"> <li>• details relating to public water supplies, such as water quality, water levels and abstraction volumes, may be available from private water companies;</li> <li>• information relating to private water supplies may be available from local authority Environmental Health Officers or from water users themselves;</li> <li>• information relating to rainfall and other meteorological parameters can be obtained from the UK Meteorological Office;</li> <li>• technical guidance and relevant publications (for example, EA/BGS <i>Aquifer Property Manuals</i>);</li> <li>• geological and hydrogeological data from the British Geological Survey;</li> <li>• information on sites of ecological importance or for nature conservation (English Nature, Countryside Council for Wales and Scottish Natural Heritage).</li> </ul>

## 2.2.2 Site investigations

The objectives of site investigations are to increase the assessor's understanding of the site-specific conditions, thereby reducing uncertainty within the conceptual model. Site-specific data should be used to challenge and refine assumptions incorporated within the conceptual model. **It will invariably be necessary to carry out some site investigations at some stage in the development of the conceptual site model, to test the conceptual site model critically and to provide site-specific data for use in any risk evaluation.**

The level of site investigation carried out should be adequate to provide sufficient confidence in the conceptual site model (or to allow it to be refined) and to provide site-specific data for the risk assessment. Information likely to be obtained during the site investigation includes the form of the site, waste types/leachate concentrations, and the groundwater/surface water quality and flow regimes (see Appendix 5). Site investigation should be undertaken in accordance with current good practice. It should be sufficiently comprehensive to give all interested parties a level of confidence in understanding the site that is appropriate to the overall magnitude of the risks. It follows that a landfill development in a sensitive area will require a more comprehensive and detailed site investigation and assessment than a similar site in a less sensitive area. It is likely, however, that site-specific data for key parameters will be required for all sites where potentially polluting wastes are to be deposited.

Whatever investigations are carried out, the quality and reliability of the information gathered should be ensured, otherwise the investigation could represent an expensive outlay that might not be suitable for use within the final risk-assessment process. Quality should be maintained by using good practice procedures, the supervising and reporting of the investigations by suitably trained and experienced professionals, and adopting a robust QA/QC method and audit trail. General guidance on site investigations is available in a number of other documents (British Standards Institute, 1999 and 2001; Environment Agency, 2002b). Some of the potential investigations that may be required at this stage are summarised in Appendix 5.

Where appropriate, site investigations undertaken to characterise the hydrogeological conditions may be combined with investigations required for geotechnical or landfill gas assessment purposes. Careful design of investigations will be necessary to

ensure they are fit for all the purposes for which they are undertaken.

## 2.2.3 Monitoring

Environmental monitoring plays a central role in environmental risk assessment and management. It is undertaken to gain information before the landfill begins operating (that is, to determine the baseline conditions, impacts during landfill operation, and continued performance post-closure). We have published *Guidance on the monitoring of landfill leachate, groundwater and surface water* (Environment Agency, 2002b), and its use is paramount for this stage of the project.

Information from monitoring programmes should be integrated into environmental risk assessment and management in various ways:

- as a baseline against which to compare actual or predicted impacts;
- as an input to models, predictions and quantitative assessments;
- as feedback into the risk assessment in an iterative review process (for example, to test assumptions in the conceptual model);
- to compare observed impacts against predicted effects, to validate model assumptions and selection;
- as confirmation that risk-management measures are performing as designed (*using Control levels*);
- as a mechanism of determining whether significant adverse environmental impacts have occurred (*using Trigger levels*);
- as a means of determining whether a landfill meets completion criteria.

With regard to the conceptual model development, monitoring must provide a high level of confidence in the baseline conditions at the landfill, and additional data to test and revise the assumptions incorporated within the conceptual model. Where monitoring data is collected for other purposes (for example, landfill gas monitoring), the data should be reviewed to ascertain whether it provides information useful to the hydrogeological assessment.

## 2.2.4 Direct and indirect discharges

The conceptual model must explicitly identify whether there is potential for a direct discharge of any polluting substances, including listed substances under GWD, or pollutants under WFD.

Direct discharges are:

*"the introduction into groundwater of substances in Lists I or II [or pollutants] without percolation through the ground or subsoil".*

Indirect discharges are:

*"the introduction into groundwater of substances in Lists I or II [or pollutants] after percolation through the ground or subsoil".*

The seepage of landfill leachate through a natural geological barrier, such as an unsaturated zone, to the water table is an indirect discharge, whereas seepage directly into groundwater without the benefit of a geological barrier is a direct discharge. This distinction is important because, except in the circumstances set out in section 2.2.5 below, the direct discharge of List I substances and pollutants to groundwater is, for all practical purposes, prohibited by the GWD and WFD respectively.

A key output from the conceptual model should be whether the landfilled waste would lie below the groundwater at any stage of its lifecycle and, therefore, whether there is the *potential* for a direct discharge. This will have a bearing on the level of detail required in the risk assessment as well as the nature of the landfill development.

Groundwater levels fluctuate, typically as a result of seasonal variations or abstraction. Where this results in the groundwater alternating between levels that lie above and below the base of a site, or where groundwater ingress into the site occurs on a seasonal basis, discharges should be treated for the purposes of the GWD and WFD as being potentially direct. In locations where the water table is artificially depressed through pumping, consideration should be given to the possibility of rebound occurring during the biologically and/or chemically active life of the site. If the area has a long history of mineral extraction and there are no accurate data on past rest levels, operators should seek the advice of a groundwater resource hydrogeologist. Where the local water table is likely to rebound above the level of the base of the site, any discharges may become direct at some time in the future.

Where the base of the waste body is, or will be, below the water table, there is the potential for both direct discharges into groundwater and for

groundwater ingress into the wastes. As with all landfills, sufficiently rigorous risk assessments will be required to establish the site's suitability. As well as the hydrogeological risk assessment, these will include stability (Environment Agency, 2002i) and landfill gas (Environment Agency, 2002k) risk assessments.

Where landfill is the best environmental option for waste management, the Agency encourages the location of sites where they do not have the potential to cause direct discharges of pollutants into groundwater, or for ingress of groundwater to the wastes. From the perspective of groundwater protection, sites on low-permeability strata that are also remote from any groundwater resource or surface water body are preferred. Sub-water table sites in permeable strata are likely to be viewed least favourably in this context.

The passage of leachate through a substantial and intact mineral barrier (that is, an artificially established geological barrier) can be regarded as analogous to percolation through the ground. As such, any discharge should be viewed as indirect. It also follows that if there was a substantial breach of this barrier, the hydraulic discontinuity would be removed and the discharge may become direct.

Hydraulic containment works on the principle of maintaining a hydraulic gradient into the landfill site. Under these conditions, operators typically seek to reduce hydraulic gradients into the site to minimise inward seepage that will add to leachate production. In these circumstances, the intention is often to control leachate head to a fixed depth below the surrounding groundwater levels, rather than at a fixed height above the base of the cell, as is common for sites that are not hydraulically contained. Depending on the relative elevations of groundwater and leachate, this may result in a relatively large volume of leachate within the waste body relative to above water table sites.

In the short-term, or in one part of the site, the hydraulic or chemical conditions may prevent a discharge to groundwater. In the long-term, or elsewhere in the site, however, conditions may differ such that a hydraulic gradient out of the site could develop. The long-term relative hydraulic conditions within and outside the site must be taken into consideration, together with the sustainability of any artificial controls on these conditions. In a typical heterogeneous waste body, an idealised simple leachate level is unlikely to be achievable. Also, the nature of the mineral components of the landfill containment and attenuation system need to be considered, as noted above. The relative roles of

diffusive and advective mass transport through the liner need to be carefully evaluated.

Where any proposal would result in a significant leachate head (that is, more than a few metres above the base of the cell), then the implications for gas management and stabilisation of the landfill, and the length of the post-closure pre-surrender period, must also be carefully considered. The saturation of the waste may inhibit biodegradation as a result of consequent lower temperatures (for example, groundwater in the UK is typically around 10°C). Any future abstraction of groundwater that would lower the water table is likely to be accompanied by an increase in gas generation. The completion and surrender of a hydraulically contained landfill may therefore be difficult unless there is careful control over the hydraulic gradient and the volume/depth of leachate that the site will contain in the pre-surrender period. The long-term integrity and effectiveness of engineering and management structures would also be more difficult to guarantee, since the duration that hazardous substances remain undegraded is increased.

In sub-water table sites relying on an engineered under-liner collection system to remove water and/or leachate, the engineered collection layer/system is regarded as part of the landfill engineering system, and the water within it does not constitute groundwater. The compliance point for assessing the acceptability of any discharge will generally be taken as the groundwater in the (natural) strata immediately adjacent to the engineered barrier system and/or the point at which water abstracted from the engineered layer is discharged back into the environment.

Where the potential for a direct discharge is identified in the conceptual model and risk-screening stage, the subsequent risk assessment will generally be correspondingly more detailed (see Section 3.2.1). Issues such as failure scenarios are considered in more detail in Section 3.5.

The Agency has prepared further information on the relative impacts to groundwater associated with different sub-water table landfill designs (Environment Agency, 2002g). This document should be consulted when considering site investigation and risk assessment for any sub-water table location.

### 2.2.5 Permanently unsuitable groundwater

Under the terms of the GWD, direct or indirect discharges of List I substances into groundwater can be authorised if the Agency is satisfied that, in the

light of prior investigation, the groundwater is:

*“permanently unsuitable for other uses, especially domestic and agricultural”.*

It is clear that any such designation must be preceded by prior investigation (that is, risk assessment). Our *Groundwater Regulations Process Manual* (Environment Agency, 2000c) provides guidance on the necessary procedure for declaring a body of groundwater as permanently unsuitable for other uses. However, the classification of groundwater as permanently unsuitable is rarely straightforward. Even in the rare cases where groundwater is deemed to be permanently unsuitable, it will not avoid the need for all technical precautions to be taken to ensure that the listed substance does not reach other aquatic systems or harm other ecosystems as required by Regulation 4(5)(a) of the Groundwater Regulations. Future increases in demand and improvements in technology may make abstraction viable from what are currently considered marginal waters; even poor quality water may have potential uses (the implications of artificial recharge and recovery must be taken into account). Nevertheless, it is important to maintain a sense of proportion when determining the status of the groundwater as a resource.

Both quality and yield are likely to be key and due regard must be given to existing uses of the groundwater, including small abstractions by farms and isolated dwellings. However, other considerations, such as the designation of the aquifer under the PPPG, the Agency’s policy of encouraging the location of landfills in areas where groundwater is least vulnerable (PPPG and associated guidance relating to the location of landfills) and the proximity to alternative groundwater resources should not be ignored.

Where appropriate, the Agency must be prepared to decide that certain groundwater is permanently unsuitable for other uses. Each decision will be site-specific and we will restrict the designation to as small a part of the formation as possible. It may be possible to demonstrate, for instance, that minor bodies of perched water are sufficiently small to be discounted as a resource. Similarly, some low-permeability deposits may, at least in part, be designated as permanently unsuitable on the basis of their inability to yield usable quantities of water. This would be subject to a site-specific assessment showing that the groundwater has no practical use. (See also Section 2.2.4 ).

For groundwater to be regarded as permanently unsuitable on the basis of quality alone, the operator

will have to show that the existing contamination levels preclude its use both now and in the future. Also, it will be necessary to demonstrate that any discharge from the landfill will not inhibit or extend the time for any potential remediation that may occur (for example, the natural attenuation associated with declining pollutant sources, such as old landfills).

The conceptual model may include the initial identification that the groundwater at the site could potentially be permanently unsuitable. The decision by the Agency as to whether a given body of groundwater is "permanently unsuitable for other uses" must always be made in consultation with Agency staff responsible for managing groundwater resources. Any application to have a permit determined on the basis that the groundwater is permanently unsuitable needs to be accompanied by evidence to support that position. This is likely to take the form of a detailed risk assessment demonstrating that discharges from the site will not impede the exploitation of ground resources (for example, mineral exploitation or agriculture), harm other ecosystems or be transported to other aquatic systems. If approved, a justification for the decision will have to be provided as part of the three-yearly report to the European Commission on the implementation of the GWD.

## 2.3 Risk screening

Risk screening is the process used to determine whether a landfill development represents, or potentially represents, a risk to groundwater and surface water resources. It should also broadly identify the likely severity of any environmental impact the landfill could cause. This is to prioritise and inform resource allocation for more detailed site assessment. A worked example of risk screening for landfills is presented within Appendix 11.

To ensure transparency throughout the risk-assessment process, the risk screening and prioritisation assessment should be submitted to the Agency along with the initial conceptual model (see Section 5 for the reporting requirements). The prioritisation should be agreed with us to ensure that it is clear and documents where the subsequent risk-assessment effort should be directed. Of course, as subsequent work is undertaken and the conceptual model is refined, some of the assumptions made about the relative importance of the risks may have to be re-evaluated.

### 2.3.1 Risk-screening objectives

The objectives of risk screening are to:

- determine whether the development falls within the scope of, and therefore needs to be authorised for the purposes of, the GWD 80/68/EEC;
- determine whether leachate needs to be collected, in accordance with Schedule 2(2)(1) to the Landfill Regulations. That is, to assess on the basis of the wastes to be taken and the location of the site, whether the site is likely to require a liner;
- determine whether a natural geological barrier is present and to make an initial assessment of the likely attenuation that this could provide;
- determine the status of the landfill development with regard to the Agency's "landfill location and impact assessment" position statement (Environment Agency, 2002d);
- provide an initial indication of the appropriateness of the other essential and technical precautions proposed for the landfill site. This would include an initial indication as to the engineering standards and other operational controls necessary to protect the groundwater and surface water;
- prioritise the risks posed by the landfill development by assessing the short- and long-term consequences of any pollution on the identified receptors, and identify site-specific compliance points;
- determine the appropriate level of complexity for any further risk assessment.

Also, Trigger levels need to be set for all landfills. This will require:

- identifying site-specific compliance points;
- determining the most appropriate Environmental Assessment Levels;
- deriving site-specific Trigger levels.

### 2.3.2 The Groundwater Directive / Regulations

Regulation 2 of the Groundwater Regulations states that they "shall not apply to any discharges which are found by the Environment Agency to contain substances in Lists I or II in a quantity and concentration so small as to obviate any present or future danger in the quality of the receiving groundwater".

The findings or assessment by the competent authority must be made solely on the basis of the characteristics of the source leachate and cannot take into consideration the nature of the underlying strata

or the groundwater environment. The assessment determines whether the discharge (or potential discharge) comes within the scope of the GWD. In paragraph 12 of the statutory guidance on the Groundwater Regulations (DETR, 2001), it is indicated that for the regulations not to be applicable, the quantity and concentrations of listed substances “are likely to be very small indeed, and likely to be similarly stringent to drinking water standards”.

If the actual or predicted leachate volume and chemistry are likely to exceed the thresholds of quantity and concentration noted above, then the discharge must be authorised under the regulations. The subsequent assessment (prior investigation) must demonstrate that the geological, engineering and operational controls are adequate to prevent pollution of the groundwater.

In practice, for most landfills, the assessment of whether the potential or actual discharge comes within the scope of the GWD will be made solely on the concentration of listed substances as the volume of discharge will be significant in GWD terms.

If it is considered likely that the leachate will contain listed substances, then the concentration of listed substances in the leachate should be compared to their respective drinking water and environmental quality standards (see Appendix 8). In the case of List I groups of substances, an analytical framework for screening leachates has been developed to assess whether there are likely to be List I substances present in the leachate (see Appendix 6). Where concentrations of the core determinands exceeds the lower reporting level for those substances in leachate, the subsequent assessment and authorisation must have regard to the requirements of the GWD. Additionally, where the GCMS scan provides greater 80 per cent confidence of the presence of such substances, they must be reported and it may be necessary to undertake further quantification of individual identified compounds.

### 2.3.2.1 Listed substances

Lists I and II, as given in the Annex to Directive 80/68/EEC, are reproduced in Appendix 1 of this guidance along with further discussion of the likely presence of listed substances in landfill leachate. More information on the classification of substances as List I and II is given in the DETR *Statutory Guidance on the Groundwater Regulations* and in reports from the Joint Agency Groundwater Directive Advisory Group (JAGDAG), which advises on the classification of substances for implementing the GWD.

Inert landfills fall outside the scope of the GWD since, by definition, the total leachability and pollutant content of the wastes, and the ecotoxicity of the leachate, must be insignificant and, in particular, not endanger the quality of groundwater.

The majority of leachates from other types of landfill, including those from wastes that were previously described as being “inert” but which fall outside the LFD definition, should be regarded as having the potential to contain List II substances. Landfills that accept municipal (non-hazardous) waste should be assumed to have the potential to have List I substances in the leachate. The situation for Hazardous landfills is less clear at present, but the presumption should be that both List II and List I substances would be present.

The initial presumption for the presence of listed substances in leachate from the three classes of landfill should be as set out in Table 2.2.

Where the risk screening identifies that the GWD does not apply, there will often be no need to conduct any further hydrogeological risk assessment. However, for inert landfills that are located in a sensitive situation, some further consideration of risks due to the accidental acceptance of contaminated material would be required. Regardless of whether the GWD applies or not, the disposal activity must still comply with the requirements of the LFD and Control and Trigger levels must be set and environmental monitoring will be required.

**Table 2.2** | Listed substances in landfill leachates

Landfill class	Likely presence of listed substances	Groundwater Directive likely to apply
Inert	No listed substances (that is, will contain List I and List II substances only in quantities and concentrations so small as to obviate any present or future danger of deterioration in the quality of the receiving groundwater).	No
Non-hazardous	Likely to contain List II substances and may contain List I substances. Landfills receiving municipal waste (including treatment residues) should initially be assumed to contain List I substances.	Yes
Hazardous	The waste and/or leachate is likely to contain List I and List II substances.	Yes

### 2.3.3 The collection of leachate

The risk screening may indicate that there is no need to collect contaminated water and leachate as the assessment, based on consideration of the location of the landfill and the wastes, shows that the landfill poses no potential risk to the environment (LF Regs, Schedule 2(2)). The Agency is likely to decide that collecting leachate is unnecessary only if the waste is inert or if there is no potential receptor. In these situations, there would be no requirement for installing leachate management systems or collecting leachate. Nor would there be any need to provide artificial containment (that is, an artificial sealing liner), but some form of geological barrier would still be necessary. The Agency has issued guidance on the engineering requirements of the LFD (Environment Agency, 2002h).

Determining whether a landfill presents a potential risk to groundwater resources should be based upon the:

- types of waste accepted, and hence leachate chemistry;
- sensitivity of the receiving environment.

The leachate chemistry should be compared to water-quality standards (Appendix 8) to assess its potential hazard. Only where the actual or predicted leachate quality presents a low hazard should the sensitivity of the hydrogeological setting be considered. The only non-hazardous landfills that will not need to collect leachate will be those accepting a very limited range of low-hazard wastes. This is likely to be limited to landfills receiving homogeneous, well-characterised, low-hazardous materials from a single or very limited number of sources, and in locations where there is no potential receptor.

### 2.3.4 Geological barrier

The need for a geological barrier is an absolute requirement in the LFD. It must provide sufficient attenuation between the landfill source and any potential groundwater receptor to ensure compliance with the GWD. It therefore follows that a geological barrier can act only as a pathway and not as a potential receptor.

If inert sites do not pose a hazard to groundwater, then the required attenuative properties of the geological barrier need only be nominal to ensure compliance with the requirements of the GWD. However, for a non-hazardous or hazardous site, significantly greater attenuative properties will be necessary. Because of the potential presence of discontinuities, such as lenses of higher permeability materials and other natural variations in the geological barrier, it should not be automatically assumed that a non-aquifer will provide a sufficient natural geological barrier for non-hazardous and hazardous sites. In these circumstances, the need for active control of groundwater inflow into the site, either during construction or landfilling, could indicate whether the in-situ materials may act as a natural geological barrier or not.

Provision exists within Schedule 2(3)(5) to the Landfill Regulations to complete and reinforce the geological barrier artificially. However, in certain sensitive hydrogeological situations (see Environment Agency, 2002d), the Agency is unlikely to accept artificial enhancement of the geological barrier.

The existence and extent of any natural geological barrier is therefore an important consideration at the risk-screening stage. This consideration should include the potential presence of discontinuities and other natural variations in the geological barrier. As outlined above, assessing the attenuation that the

natural or artificial geological barrier would provide is vital. This assessment of attenuation is the same as considering the purifying powers of the soil and sub-soil to ensure that the attenuation capacity is sufficient to prevent a risk to groundwater (that is, to avoid pollution of groundwater by ensuring there is no unacceptable discharge).

The risk screening should be sufficient to indicate whether the natural geological barrier would meet the LFD requirements in terms of there being sufficient attenuation capacity to protect groundwater.

### 2.3.5 Landfill location

As part of the consideration of sources, pathways and receptors, the risk-screening stage should identify the aquifer classification, any groundwater Source Protection Zones, the presence of drift above an aquifer and the likely water table level(s). Alongside details of waste types and landfill operations, this will enable an assessment to be made against the Agency's landfill location position statement (Environment Agency, 2002d) and the *Policy and Practice for the Protection of Groundwater*. In complex situations, it may be necessary to consider issues such as the presence and extent of drift at a more detailed level of risk assessment.

### 2.3.6 Essential and technical precautions

In the context of Groundwater Regulations, essential and technical precautions include limitations on both the rates of input and concentrations of permitted waste types, loading rates and methods of disposal, the engineering systems of the site associated with drainage, containment and leachate management, and the monitoring of leachate. The conceptual model must include the proposed essential and technical precautions, which should be based on good practice requirements from guidance such as Environment Agency 2002c. The risk-assessment process must determine the acceptability of the proposed measures. In practice, the Agency would expect to see an assessment of indicative precautions in the conceptual model and the risk screening at the PPC pre-application stage. Furthermore, at the PPC application stage, details of the engineering standards for those precautions should be presented, together with any quality-control and assurance plans. The risk assessment accompanying the permit application must be conducted on the basis of the proposals detailed in the application. Risk assessment is an iterative process. Between the production of the

conceptual model and the submission of the PPC application, the design and operation of the landfill will almost certainly have been revised on a risk basis. The Agency does not routinely expect to see all the iterations between a submitted conceptual model and the final PPC application.

Where a mineral material is used for a sealing liner or geological barrier (for example, clay, colliery spoil, bentonite enhanced sand and the like), an assessment of the attenuation potential of the mineral component should be acceptable as part of the review of technical precautions, but only if the operator can provide evidence of that attenuation. This should be provided via testing of site materials for attenuative properties rather than relying on literature-based values, though this depends on the level of risk assessment being undertaken. Some literature-based values are likely to be acceptable at the risk-screening stage.

In the case of sub-water table landfills (see Section 2.2.4), although a substantial, intact mineral barrier may be viewed as preventing a direct discharge, the risks and consequences of direct discharges resulting from potential breaches in the containment system can be serious. The long-term effectiveness of the lining system and practicability of remedying any defects in it must be considered in all situations.

Risk screening may also indicate the engineering standards and other operational controls necessary to comply with the LFD and GWD (see Environment Agency, 2002h, for more information). It is unlikely that the risk screening will provide sufficient confidence to determine the appropriate engineering requirements apart from in a limited number of low-sensitivity locations.

### 2.3.7 Risk prioritisation

The output from the risk-screening assessment should include a prioritisation of the identified risks. It is likely that, of the Source-Pathway-Receptor (S-P-R) linkages, some will be more important than others. For instance, if the groundwater in strata below and around the site supports a sensitive wetland (where small changes in quality or level could be detrimental), then the future risk-assessment work could concentrate on quantifying and mitigating that risk. This process is directly linked to considering the consequences of leachate pollution. The S-P-R linkages should clarify which are the most sensitive receptors. In this context, sensitive should be taken to mean the receptors most easily and significantly affected by the constituents of the leachate. Depending on the

site-specific circumstances, this could be any type of receptor from a private water supply borehole to a surface watercourse.

### 2.3.8 Further risk assessment requirements

One output from the risk-screening process should be a recommendation of the appropriate level of further risk-assessment work. The level of complexity and the sensitivity of the location of the landfill development should be apparent from the conceptual model and the risk screening. Section 3 discusses complex and simple risk assessments and indicates in which circumstances each may be appropriate.

## 2.4 Compliance points

A principal requirement of the GWD is to assess the actual or potential impact of the disposal on groundwater in the vicinity of the site (that is, prior investigation and requisite surveillance). An important element of the risk-screening process is choosing the points at which compliance with the GWD will be evaluated.

### 2.4.1 List I substances

To ensure that no List 1 substances enter groundwater, the point of assessment should be the point of entry into groundwater. It follows that there should normally be no allowance for mixing with groundwater and only unsaturated zone processes should be taken into account. However, where there is a specific exclusion or relaxation of the List I prohibition (for example, the groundwater has been classed by the Agency as “permanently unsuitable for other uses” – see Section 2.2.4), some consideration of the impact on groundwater will be needed. In this case, the point of assessment may move to below the water table.

As stated above, the receptor for modelling of potential discharges of List I substances should be the groundwater at the point of entry of the discharge. This will usually be directly beneath or adjacent to the site, depending upon site geometry and hydrogeological setting. However, the monitoring point for List I substances (and the point at which compliance with Control and Trigger levels is assessed) will be a borehole(s) directly adjacent to the landfill. This reflects the practical problems in collecting samples from beneath a landfill. A consequence is that the landfill design should ensure

that no List I substances enter groundwater (since the compliance point is immediately above the water table), whereas a breach of the Trigger level will occur only when contaminant concentrations in the groundwater (after dilution) exceed those levels.

### 2.4.2 List II substances

The choice of the compliance point for assessing whether groundwater pollution by List II substances is likely to occur is an important consideration. Regard to dilution and attenuation processes immediately around the landfill is normally acceptable for List II substances, where a change in water quality may be permitted as a result of the discharge, but pollution must be prevented. Thus the assessment of the pollution risk can take into consideration dilution in groundwater in the immediate vicinity of the site.

The purpose of the GWD is to prevent pollution of the groundwater so, in most instances, the compliance point for List II substances will be monitoring boreholes adjacent to the landfill. LandSim, for example, simulates the effects on water quality five metres from the cell edge. In some cases, where groundwater has no resource value, boreholes further from the site may be appropriate, or the compliance point could be a surface water feature near the landfill. Selecting a compliance point other than at the perimeter of the site will have to be based on consideration of the sensitivity of the landfill’s location. Factors such as the status of the site under the Agency’s guidance on the location and impact assessment of landfill sites (which considers the vulnerability of groundwater) and our aspirations for the receiving groundwater should also be considered. Selecting a surface water feature as a compliance point is likely to be acceptable only where consideration of all the source-pathway-receptor linkages has identified the surface water as the highest priority risk. The Agency must also agree that it represents the most significant (water) receptor for any contamination from the landfill (that is, where groundwater is not a useable resource). The risk-screening and prioritisation process is fundamental in determining the appropriate point of compliance for each individual landfill.

## 2.5 Selecting Environmental Assessment Limits (EALs)

To determine the sensitivity of the groundwater near a landfill, the conceptual site model and risk

screening should identify the most appropriate water-quality standards that apply to the groundwater. These quality standards and baseline water chemistry should be used to derive Environmental Assessment Limits (EALs) for potentially polluting substances that might be present within the landfill leachate. A decision can then be made, based on these EALs, as to whether the impact of the landfill on water quality is acceptable. Groundwater would normally need to be considered as the primary receptor for this purpose, although secondary receptors, such as surface watercourses and ecologically sensitive features, should also be considered (see Section 2.4.2). It is important that water-quality standards and compliance points are considered in tandem. Identifying the location(s) (in three dimensions) where a standard applies is an integral part of determining an appropriate water-quality standard.

Some of the standards that should be considered in developing the most appropriate EALs for groundwater are presented in Appendix 8. Whatever water-quality standards are applicable to a particular site, the appropriate EAL should be the most stringent applicable standard available for the considered contaminants. This will therefore provide, the greatest level of protection.

Four problems typically arise in selecting an EAL:

- **No water-quality standard is readily available for the relevant chemical species in the leachate.** In these circumstances, an appropriate EAL should be developed having regard to baseline groundwater chemistry and taking account of other published information. Determining baseline groundwater quality therefore becomes a crucial part of the risk-assessment process. Operational Environmental Quality Standards (non-statutory working levels) may be derived by the Agency.
- **Baseline groundwater quality is naturally inferior to the most stringent water-quality standard available.** In this case, operators should consider selecting other chemical species for use in setting Control and Trigger levels, or the appropriate EAL should be developed having regard to baseline groundwater chemistry. As above, determining baseline groundwater quality is an extremely important aspect of this development.

Note: In setting a water-quality standard where there is a significant natural background concentration, operators should consider the temporal and spatial variation in the natural background and the ease of discriminating any anthropogenically induced component of the

water quality from the natural background. Exceedence of the standard should be a clear indication of unacceptable anthropogenic input.

- **Baseline groundwater quality is inferior to the most stringent water-quality standard available owing to contamination from other anthropogenic activities.** In these conditions, the EAL should be determined using the principle that the landfill development must not impede any future improvements in groundwater quality, or pollute it further. The existence of historic pollution (for example, from past landfilling operations) is not in itself a justification to permit future discharges. Operators should consider selecting chemical species not arising from the historical contamination. The appropriate EAL should be developed with regard to natural baseline groundwater chemistry together with the likely sources and duration of the historical contamination. Adopting this approach now will guard against potential improvements in groundwater quality being hindered by the presence of the new or modified landfill.
- **Baseline concentrations of the substances in groundwater are substantially lower than all applicable water-quality standards and deterioration of groundwater quality to the water-quality standard is considered environmentally unacceptable.** Selecting an EAL may take account of the baseline levels of those substances in the receiving groundwater. The selected EAL is likely to be set at a point between baseline concentrations and the water-quality standard. This approach is likely to be most appropriate for assessing the effects in sensitive aquifer systems from certain major ions such as chloride (for example, baseline ~50mg/l, Drinking Water Standard (DWS) 250mg/l) and some metals, where there are no discharges to surface waters. For example, both copper and zinc are present as trace elements in groundwater, but have DWSs of 2000 and 5000µg/l respectively. Environmental Quality Standards (EQSs) for copper (1 - 28µg/l) and zinc (8 - 500µg/l) are considerably lower.

In many cases, the EAL for groundwater in Major and Minor Aquifers will be equivalent to either the DWS or the EQS, subject to consideration of natural hydrochemistry. In the future, Groundwater Quality Standards may be developed for certain pollutants for the WFD (2000/60/EC).

In the case of low-permeability formations that do not represent a groundwater resource locally (or a potential groundwater resource), the EAL may be applied at the point at which groundwater enters other water receptors. For example, the EAL may be

selected to ensure there is no deterioration in river water quality, or harm to an ecosystem. In adopting this approach, assessors must ensure that it will not result in pollution of water. An acceptable concentration at the landfill site can then be back-calculated using methods set out in Environment Agency *R&D Publication 20* (Environment Agency, 1999b). The most stringent, relevant EAL for the receptor should be used as the basis for the calculations. This recognises that, in these circumstances, the low-permeability formation is not in itself a water resource, but it may still support important water resources or features such as wetlands or surface watercourses. Typically, baseflow into the nearest surface water body should be protected to ensure no deterioration against baseline quality. Where baseline quality is currently impaired, baseflow into the surface water should not exceed the relevant EQSs.<sup>1</sup>

In such circumstances, it is important that assessors confirm with the Agency's local hydrogeologist that low-permeability formations, such as some non-aquifers, have no water resource value, or potential resource value. Some non-aquifers may have negligible permeability at depth, but are permeable in the near-surface weathered zone, or contain permeable horizons locally. These features may support numerous small abstractions, particularly in remote rural areas where there may be no alternative source of water. In these circumstances, the water bearing and transmitting horizon is likely to be considered the primary receptor.

## 2.6 Deriving Trigger levels

Trigger levels for potentially polluting substances are to be set at the point where pollution can be said to have occurred and can be detected by monitoring (that is, Trigger levels represent the level of contamination that constitutes pollution). It is important to determine these at this stage of the risk-assessment process as the Trigger levels should be used to demonstrate that the landfill site will not cause pollution. This means that a change in water quality to a concentration below the Trigger levels would be acceptable, but one at or above the Trigger level would be unacceptable. Note that this statement should not result in too great a reliance being placed on the numbers generated by any quantitative assessment.

There are three main considerations in setting Trigger levels:

- the substances for which the Trigger levels should be set;
- the levels (concentrations) at which they should be set;
- the (monitoring) locations for which they should be set.

### 2.6.1 Selection of substances for which Trigger levels are required

Trigger levels have a role both as a performance standard for monitoring and as the success criteria for the risk assessment. The selection of substances should reflect this dual role. The important principle to apply is the need to select the minimum number of substances that are representative of the compounds present (or predicted to be present) within the leachate. To fit the Trigger levels within the monitoring regime of the landfill, refer to the Agency's guidance on landfill monitoring (Environment Agency, 2002b). Section 4 deals with the relationship between Trigger and Control levels and the site's monitoring in more detail.

Generally, Trigger levels should be set for the same substances that are considered in the risk assessment, particularly where those substances are present in the highest concentrations in leachate and are most mobile in the subsurface. This will be a site-specific determination depending upon the proposed waste types and the baseline water quality. Section 3.2.2 gives some examples of both the categories of parameters and substances with these categories. Operators should take the specialist advice of a chemist in determining the selection of appropriate indicator species. As a general rule, Trigger levels should be set for at least three, but no more than ten substances. In addition, they should not be set for substances where resultant (following development of the landfill) levels within groundwater would be at, or below, normal levels of detection.

### 2.6.2 Selection of levels (concentration limits)

For List I substances, Trigger levels should be set at a value that represents a concentration of the substance above which it would be considered discernible in groundwater (that is, after dilution in groundwater), while having regard to baseline water chemistry. That is to say, the test for pollution by List I substances is whether the discharge into groundwater is discernible. For practical purposes, the Minimum Reporting Values (MRVs) for analyses of List I substances in groundwater (Appendix 7)

<sup>1</sup> An EQS is a water quality standard that is protective of aquatic life in surface watercourses.

should be used as the Trigger level for List I substances. These should be applied at the closest monitoring points to the waste body, unless baseline groundwater chemistry exceeds these levels.

The Trigger levels should be set:

- at the MRV for List I indicator substances that are predicted to be present or detected in the leachate, but not present in the baseline water chemistry;
- at the concentration of the current baseline water quality, on an agreed statistical basis (that is, the landfill cannot be permitted to cause a discernible increase to the baseline contamination).

More details on appropriate statistical methods can be found in other guidance (for example, Environment Agency, 2002f). Where a declining historical source is present, the Trigger levels should be set at reduced levels in the future to ensure the permitted landfill cannot inhibit any improvement in water quality. This could be in the form of a table with Trigger levels specified for discrete time periods.

Trigger levels for List II substances should be set at the most appropriate EALs, which will have been determined with regard to baseline hydrochemistry and the identified compliance points. Of course, EALs may change in time, as either water quality standards or the quality of the upstream groundwater alter. However, pragmatism is required when evaluating the ongoing performance of existing phases of the site against revised EALs/Trigger levels that may have either increased or decreased.

Where the compliance points are external monitoring boreholes, the Trigger levels should be set at the EAL for each of the indicator substances.

Where the compliance points for List II substances are remote from the landfill, the Trigger level should be set for on-site monitoring boreholes at a level back-calculated from the selected EAL at the compliance point. This means that where a remote receptor is selected as a compliance point, a calculation is required to produce a Trigger level for a perimeter monitoring borehole. The calculation has to determine the Trigger level at the perimeter borehole, which means the EAL should not be exceeded at the more remote receptor. In practice, this means that a higher level of contamination would be acceptable at the monitoring borehole. This is to take account of the dilution and attenuation that would occur between the monitoring boreholes at the perimeter of the site and the compliance point.

The only circumstance where the Trigger level for a List II substance will not be equal to an EAL used for risk-assessment purposes is when the baseline groundwater quality is impaired by anthropogenic inputs. In such circumstances, the EAL will normally reflect the natural baseline or relevant use-based standard (that is, to ensure that the landfill does not cause additional/future pollution), but the Trigger level will normally take account of the other pollutant inputs (and thereby be a higher concentration). This is necessary to ensure that compliance against the Trigger level can be assessed practically.

Trigger levels at inert sites should be derived based on baseline groundwater quality. By definition, inert landfills should not produce leachate containing listed substances. So deterioration in groundwater quality, attributable to the landfill, would require contingency actions to be undertaken.

### 2.6.3 Selection of locations

The overall groundwater-monitoring programme for the landfill must be developed on the basis of the Agency's guidance on landfill monitoring (Environment Agency 2002b). It must therefore be based on the understanding of the source-pathway-receptor linkages. The monitoring must take place in each identified groundwater receptor and pathway.

As set out within the worked examples (Appendix 11), Trigger levels should be set for each of the down-gradient, or potentially down-gradient, monitoring points that are included in the overall groundwater groundwater-monitoring programme. This could include both monitoring wells and relevant groundwater resurgences (for example, springs). Since the Trigger levels represent the point at which pollution can be said to have occurred, the levels will normally be the same for each monitoring point in the same water body. Only where baseline quality or an EAL relevant to a remote receptor (which varies in distance from the monitoring boreholes) form the basis for the Trigger level should individual boreholes be allocated specific (different) Trigger levels.

# Simple and Complex Risk Assessment

## 3.1 Introduction

Following the formulation of a robust conceptual site model and risk screening, subsequent hydrogeological risk assessment comprises a more detailed (quantitative) risk assessment. This should be carried out at a level of complexity that is proportional to the potential environmental impacts the site could cause, the level of uncertainty and the likelihood of a risk being realised. This important principle means that the level of risk assessment required should be that which is sufficient to provide confidence in the predicted impacts. The more sensitive the setting, the greater the level of confidence required. This Section provides technical guidance on quantitative risk assessment and worked examples are presented within Appendix 11. Section 5 deals with the reporting requirements of the risk assessment and how this fits into the PPC application process.

## 3.2 Simple and complex risk assessment

Two levels of subsequent risk assessment may be used: simple and complex.

**Simple risk assessments** should consist of simple quantitative calculations, typically analytical solutions solved in a deterministic fashion using conservative input parameters, assumptions and methods. The use of conservative (worst-case) assumptions results in a generic assessment. Simple assessments should be carried out for landfills when the previous risk screening is insufficient to make an informed decision on the risks posed by the site. It can be used when the potential source, pathway and receptor terms can be defined with sufficient certainty as to be confidently represented by conservative inputs, models and assumptions. Simple risk assessments will generally be applicable in less sensitive locations

where the risk screening and prioritisation have not identified any receptors that would be particularly susceptible to the consequences of leachate pollution. Where there is uncertainty regarding any of the source, pathway and receptor terms, undefined groundwater patterns including the potential for fissure/conduit flow or long-term liner integrity, and a robust decision cannot be made using conservative inputs, methods and assumptions, then a complex risk assessment should be carried out.

The assessment should include simple assessments of the predicted impact of the landfill on water quality, including groundwater. Many non-aquifer formations are underlain by, or contain, water-bearing horizons that may not be apparent from either geological maps or the Agency's groundwater vulnerability maps. If the site poses a long-term pollution threat, it is important to identify whether there is a geological barrier between the site and sensitive waters. In such cases, the assessment will need to demonstrate whether the environmental protection of this barrier is sufficient, or if it will need to be artificially enhanced.

In all cases, the assessment will need to demonstrate that the proposal poses little likelihood of unacceptable discharges. In so doing, it will demonstrate compliance with the GWD and the LFD.

**Complex risk assessments** should be carried out in a quantitative manner using stochastic, (that is, probabilistic) techniques to analytical solutions, or numerical solutions. Within complex assessments, use of more site-characterisation data is key to a more detailed site-specific assessment. It should be carried out when the site setting is sufficiently sensitive to warrant detailed assessment and a high level of confidence needs to be provided to ensure compliance with both the LFD and the GWD.

Worked examples of simple and complex risk assessments are presented within Appendix 11.

### 3.2.1 The appropriate level of risk assessment

The appropriate complexity of assessment for a site should be determined from the potential risks presented by the site. These are linked to the nature of potential hazards, the sensitivity of the surrounding environment, the degree of uncertainty and the likelihood of a risk being realised. The tiered approach set out in DETR 2000 seeks to match the effort associated with the risk assessment to the potential severity of the risk. Figure 3.1 illustrates the tiered risk-assessment framework that should be used, such that if a high level of confidence is provided by simple risk assessment, then more complex work may not be necessary. Equally, if there is not sufficient confidence in the assessment when considered at a simple level, more complex work must be carried out to refine the risk assessment and test compliance with both the LFD and the GWD. However, an operator can proceed immediately to a higher level of complexity of risk assessment if that is considered appropriate.

There are numerous low-permeability formations, with sites remote from surface water bodies, where risk screening or simple risk assessments will be adequate. However, careful judgement needs to be exercised, supported by site-investigation information, to determine the predictability of the site's geology and hydrogeology. It also needs to be established whether the formations are a water resource locally or support secondary receptors (for example, wetlands, surface water bodies) that justify more detailed assessment methods. In general, simple risk assessments are applicable for less sensitive locations and complex risk assessments where the risk screening has identified the presence of sensitive receptors. A proposal for a sub-water table landfill receiving any potentially polluting wastes will normally require a complex risk assessment.

*Simple risk assessments* should be carried out where feasible source-pathway-receptor linkages are identified, or in preparation for conducting a more complex assessment, and where:

- it is clear from the conceptual model and the risk screening that the hazards are relatively low and the environmental setting is sufficiently insensitive to negate the possibility of significant impacts (for example, sites on low-permeability strata remote from abstractions and surface waters);
- the potential source, pathway and receptor terms can all be defined with sufficient certainty so as to be confidently represented by conservative inputs, models and assumptions (for example,

a single homogenous source of in-house waste, well-defined flow characteristics and directions or worst-case inputs for variable parameters and the like).

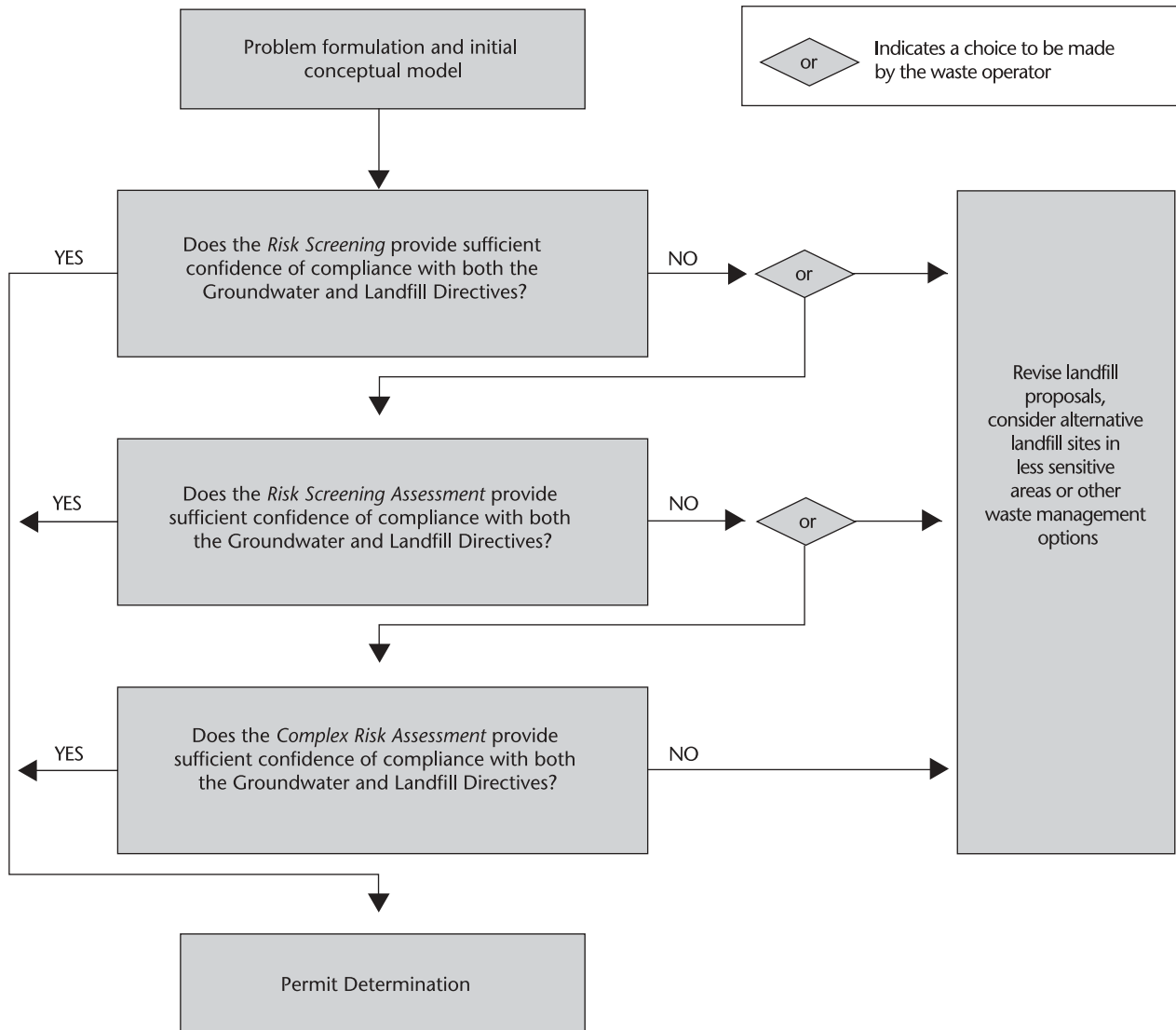
*Complex risk assessments* should be carried out where complete source-pathway-receptor terms are present and where:

- the site setting is sufficiently sensitive to warrant detailed assessment (for example, on permeable strata such as a Major Aquifer), is within a Source Protection Zone or is close to surface water bodies;
- there is uncertainty relating to any of the source, pathway or receptor terms (for example, variable leachate quality, undefined groundwater flow pattern) that cannot be overcome by adopting conservative inputs or assumptions.

**Table 3.1** | Indicative risk-assessment levels for a range of scenarios

Landfill setting <sup>2</sup>	Indicative risk-assessment levels for a range of scenarios		
	Inert	Non-hazardous	Hazardous
<b>Low-permeability strata (for example, non-aquifer)</b>			
No surface water or other receptors (for example, springs or abstractions)	RS	RS/S	S/C
Surface water, springs, abstractions and the like present or significant uncertainty	RS/S	S/C	C
Below the water table	RS/S	S/C	C
<b>Moderate permeability strata (for example, Minor Aquifer)</b>			
Outside SPZ, no surface water receptors, above the water table	RS	S	S/C
Outside SPZ, no surface water receptors, below the water table	RS	S/C	C
Outside SPZ, surface water receptors, below the water table or uncertainties	RS/S	C	C
Within SPZ II or III, no surface water receptors, above the water table	RS/S	C	C
Within SPZ II or III, no surface water receptors, below the water table	RS/S	C	C
Within SPZ II or III, surface water receptors, below the water table or uncertainties	S	C	C
<b>Highly permeable strata (for example, Major Aquifer)</b>			
no surface water receptors, above the water table	RS/S	C	C
no surface water receptors, below the water table	S	C	C
surface water receptors, below the water table or uncertainties	S	C	C
Within SPZ II or III	S	C	C
<b>Note:</b>			
1 RS – Risk screening; S – Simple risk assessment; C – Complex risk assessment			
2 This table is intended only as an indicative guide to the level of risk assessment that may be required to provide the necessary confidence. Not all the circumstances listed above may be acceptable for a landfill facility, irrespective of the detailed nature of a site-specific risk assessment. Reference must also always be made to the Agency's Groundwater Protection Policy and our position on the location of landfill facilities.			

Figure 3.1 | Illustrative risk assessment framework



### 3.2.2 Quantitative risk-assessment objectives

More detailed risk assessment is required if the risk-screening process has not provided sufficient confidence about the potential risk to groundwater resources. The objectives of the detailed risk-assessment phase are as follows:

- to determine whether the development complies with the GWD (that is, the disposal of wastes into the landfill will not result in List I substances entering groundwater and will not cause pollution of groundwater by List II substances over the whole lifecycle of the landfill);
- to provide the basis for deciding whether the engineering measures and other proposed essential and technical precautions fulfil the requirements of the LFD and the GWD.

The two objectives are directly inter-linked as the test for whether the proposed landfill design is acceptable is whether it will provide compliance with the GWD. That is, by demonstrating, via the risk assessment, that the landfill will not result in an unacceptable discharge to the environment.

It is important to stress that the risk-assessment process should ensure that the development complies with both the GWD and the LFD. Compliance with the engineering standards set out in the LFD does not necessarily ensure compliance with the GWD.

To meet the above objectives, the following tasks must be undertaken:

- confirm the hydrogeological and hydrological settings in which the site is located;
- investigate the sensitivity of water receptors;
- investigate and quantify the likely magnitude of environmental impacts arising from leachate generation and migration;
- investigate the likelihood of environmental impacts over the whole lifecycle of the landfill;
- quantify the source-pathway-receptor linkages over the whole lifecycle of the landfill;
- investigate the likely impact of accidents;
- investigate means of limiting the transport of pollutants along the source-pathway-receptor linkages over the short- and long-term;
- develop indicative completion criteria with respect to groundwater.

## 3.3 Requirements of all risk assessments

A number of general requirements need to be satisfied in a quantitative risk assessment. These are considered in detail in the following sections.

### 3.3.1 Emissions to groundwater

The hydrogeological risk-assessment process should estimate the potential magnitude of pollution threat presented by a landfill to groundwater resources and other resources that groundwater supports in both the short- and long-term. In the majority of cases, this will mean the predicted concentrations of contaminants at each receptor following the development of the landfill (that is, the impact of emissions on the groundwater).

More specifically, the risk assessment needs to establish whether the predicted discharge from the landfill complies with the requirements of the GWD at all stages of the landfill's life.

For **List I substances**, the assessment must demonstrate that the technical precautions would *"prevent substances in List I from entering groundwater"*. Consequently, it will consider whether there is likely to be a discernible discharge of List I substances to groundwater. The test shall be applied at the point at which leachate enters groundwater and **shall not take account of the effects of dilution** in that groundwater.

The assessment may take account of attenuation processes in any landfill liner and unsaturated zone, but may not take account of dilution or attenuation in groundwater.

The criteria applied shall typically be whether List I substances (normally those identified during the screening procedure described in Appendix 6, or predicted on the basis of the proposed waste stream) are present in the leachate at concentrations that would give rise to a discernible discharge to groundwater. This will involve comparison of predicted leachate chemistry (at the point of entry to the groundwater) with Minimum Reporting Values for the substance in clean water (Appendix 7) and *natural* baseline water chemistry.

For **List II substances**, the assessment must demonstrate that the technical precautions would *"limit the introduction of List II substances into groundwater so as to avoid pollution"*. Consequently, it will consider whether the predicted concentrations of List II substances are likely to exceed relevant use-

based standards, other relevant environmental quality criteria, or cause an unacceptable deterioration in water quality, in the groundwater following dilution. For practical purposes, this will typically comprise assessing whether concentrations of List II exceed the relevant EALs at monitoring boreholes at the downstream boundary of the landfill (that is, after dilution in the groundwater).

For some substances, such as chloride, deterioration from baseline levels (typically less than 50mg/l) to the drinking water standard (250mg/l) may be unacceptable (the standard is not appropriate to protect the groundwater resource). The Agency hydrogeologist will advise on these aspects, taking account of the local hydrogeological system in which the landfill is located.

The exact nature of the calculations required to support the assessment depend on the environmental setting of the site and the development proposals. Examples of calculations that could be used are as follows:

- the travel time for the leachate to migrate either through any lining systems and/or natural geological barriers to a potential receptor (normally groundwater, but possibly a surface water receptor);
- the potential retardation and decay of contaminants as they migrate through the lining systems and/or natural geological barriers, provided there is evidence that these processes are likely to occur;
- the predicted concentrations of contaminants at appropriate assessment points in the subsurface (this is necessary to derive relevant Control levels);
- the potential attenuation of contaminants within the liner and the geological barrier (for example, the retardation of ammonium,  $\text{NH}_4^+$ ) due to cation exchange or sorption of organic compounds;
- the predicted decline in the leachate strength over time;
- the predicted degradation of any artificial components of the liner and engineering systems;
- the proposed completion criteria for the leachate quality, given the long-term attenuation capacity of any mineral liner and geological barrier;
- the predicted time when active management of the landfill will cease (for example, extraction of leachate and maintenance of leachate collection systems).

For complex risk assessments, additional data collection and calculations, or more sophisticated numerical analyses, will need to be carried out to provide sufficient confidence that it is appropriate to locate the landfill development in a sensitive, or uncertain, environment. Additional considerations could include issues such as detailed stability analysis for engineered structures.

As well as the predicted contaminant concentrations, the risk assessment should estimate the likelihood of these concentrations being realised. This could be a qualitative description or the output from a probabilistic quantitative assessment. The Agency can authorise activities only where it is shown, *by prior investigation* (that is, risk assessment) that there will not be any pollution or other unacceptable risks. In making this judgement, we will consider the robustness of the conceptual model and risk-assessment method used, the data reliability and the treatment of uncertainty.

**It is important to note that the risk-assessment process is not an abstract exercise but must be closely linked to the actual landfill design and operations (that is, the essential and technical precautions).** There is no point in conducting a complex risk assessment for a liner design that, in reality, could not be constructed or would be unstable. Similarly, assumptions about long-term leachate management should take account of the inevitable deterioration in the performance of engineered leachate collection and extraction systems.

#### ***Degradation of engineering and management systems***

The risk assessments must be carried out for the whole lifecycle of the landfill. That is to say, from the start of the operational phase until the point at which the landfill is no longer capable of posing an unacceptable environmental risk. This means that the changes in leachate quality with time must form part of the evaluation of the likely pollutant concentrations. The risk assessment must consider the changes in leachate quality over time, (inevitable) degradation or removal of management systems and the ability of the geological barrier to provide long-term environmental protection. Any models used will need to be able to reflect the different phases of the landfill's lifecycle. The risk assessment must explicitly identify and document the different assumptions used to simulate the lifecycle of the landfill. A simple example would be three stages: operational phase with all management systems working as designed; post-closure with a capping system working as designed but with some

degradation of leachate collection systems; and long-term (just prior to completion) post-closure with degradation of management systems, including artificial lining systems.

In this context, the term “degradation” (of liner and engineered systems) is used to refer to inevitable processes that will occur to the non-mineral liner materials and structures within the landfill environment over time. These effects cannot be prevented, and the landfill design should take this into account to ensure adequate long-term performance. Also, pollution may result from the failure of engineered systems due to poor design, assessment or construction, or from accidents as described in Section 3.5. These issues need to be addressed independently.

The approach to degradation of different components of the engineering and management systems that is being incorporated into the future releases of LandSim (v2.5+) is outlined below:

#### ***Geomembrane liners (for example, HDPE)***

The material is expected to degrade over time as antioxidants are exhausted. This will lead to a gradual increase in the total area of the defects until the geomembrane will be effectively absent and leakage will be controlled by the underlying mineral component of the liner and geological barrier.

Based on a review of available information, after an initial period when the geomembrane performs as designed, the area of defects is likely to increase on a “half-life” basis such that the area through which leakage occurs doubles with each half-life. After a period of time (hundreds to thousands of years), the geomembrane will no longer affect the leakage rate.

#### ***Mineral liners (for example, engineered clay)***

The hydraulic performance of clay liners (both as artificial geological barriers and as artificial sealing liners) is generally assumed to remain unchanged throughout the lifetime of a site. However the potential for high ionic strength leachates, poor construction or other factors to adversely affect the performance of mineral liners must be explicitly considered at the design stage. The attenuation capacity of the mineral liner decreases as sorption/retardation sites are exhausted. Long-term attenuation capacity depends on contaminant flux through the liner and the geochemical properties of the liner materials.

#### ***Drainage system***

This is expected to perform as designed only while financial provision is available to remedy any

blockages. After this, it is assumed that no management or institutional control will be available to maintain the drainage system. Thus it will become clogged very quickly (effectively instantly) due to biological, chemical and physical reactions. It will subsequently have a permeability equal to that of the overlying waste.

#### ***Cap***

It is expected that all caps will be affected by settlement of the waste, particularly in the first few years after cap installation, and so remedial works should be allowed for in the management plan. For the purposes of the risk assessment, it is presumed that any remedial works that are necessary will be undertaken. Therefore all capping systems are assumed to allow their design infiltration after they are installed. Geomembrane caps will then degrade in a linear fashion over a long time period (hundreds of years) due to oxidation, with the final recharge being equal to the effective rainfall on a grassed site (assuming final restoration is to grassland). Subject to adequate consideration of the potential impact of waste settlement and index cation exchange, clay or GCL caps are expected to continue to perform to their design specification without degradation.

### **3.3.2 Confidence levels**

Stochastic analysis is likely to be a commonly used assessment tool during a **complex risk assessment** and predictions may be made at a range of confidence levels. These outputs indicate the degree of confidence that an assessor can have about a particular outcome. To provide greater confidence in the outcome of the assessment, assessors should use representative site-specific data and present sensitivity analyses.

The acceptable probability of an undesirable outcome occurring is commonly set at the 95 percentile for stochastic estimations carried out for complex risk assessments. The 95 percentile represents the point at which the assessor can be 95 per cent certain that the actual outcome will be less than the maximum acceptable level (assuming the model and data are representative of the real system). For example, in a LandSim2 assessment, the 95 percentile of the predicted concentration on water quality represents the level at which the assessor can be 95 per cent certain that the actual concentrations will be less than the maximum acceptable concentrations (for example, EALs for List II substances). The 95 percentile is commonly selected as a reasonable worst case, against which it is acceptable to make

decisions, taking into account the assumptions and limitations of the modelling process.

For **simple risk assessments**, low-probability conditions (that is, reasonable “worst-case”, as agreed by all parties) are suitable. The assumptions behind these conditions should be made clear and provided as evidence within the risk-assessment process.

Due regard should be given to an assessor’s experience and knowledge of the processes being simulated in any model (that is, the assessor’s ability to determine whether the assumptions made are conservative, and whether the estimated resultant concentrations could be regarded as realistic maxima). To provide greater confidence in the outcome of a risk assessment, assessors should present a comprehensive sensitivity analysis of any deterministic models used.

All models used with the risk-assessment process, at any level, are simplified representations of reality and should be viewed as aids to the decision-making process. Consequently, decisions as to whether the site complies with the LFD and the GWD must be made using the professional judgement of the assessor, using the model results together with an understanding of the assumptions within each model.

If the risk-assessment process fails to provide sufficient confidence that the landfill site will comply with both the LFD and the GWD, the waste operator can consider the following options:

- to collect additional site-specific data (for example, for attenuation properties or groundwater levels) to reduce uncertainty and allow the use of less conservative assumptions in the model;
- to carry out risk-assessment work at a higher level of complexity (only applicable if the risk assessment has been carried out at a simple level);
- to alter the nature of the development so it presents a reduced hazard and/or risk to the groundwater environment (this could include altering the proposed waste types to be deposited, relocating the facility to a less sensitive environment or upgrading the engineering);
- to identify alternative waste-management options not involving landfill.

This approach seeks to match data-collection and risk-assessment complexity to the environmental sensitivity of the site (that is, to the level of harm that could result if the landfill fails). However, it should be noted that even a complex risk assessment

may not provide sufficient confidence in a landfill project with a long-term pollution potential if it is in a particularly sensitive location. Such locations are identified in the Agency’s *Groundwater Protection Policy* (Environment Agency, 1998a) and guidance on the location and impact assessment of landfills (Environment Agency, 2002d).

### 3.3.3 The priority contaminants to be modelled

The families and groups of substances that constitute Lists I and II of the GWD are set out in Appendix 1. The list of Main Pollutants from the WFD is presented in Appendix 2. The actual contaminants that should be modelled at a site will depend upon the nature of the wastes deposited. This will influence the substances present, the potential hazard associated with the landfill and the severity of the potential risks presented by individual contaminants.

Consequently, the number and range of potentially polluting substances that should be modelled should be determined on a site-specific basis. The screening process that should be used to determine which substances to model is as follows:

- the presence of **List I substances** within a landfill leachate should be established using the analytical screening procedures set out in Appendix 6. This involves a combination of six different analytical methods that must be used to gather information on the likely presence of List I substances. Where the screening procedure identifies elevated concentrations of List I substances (thresholds are given in Appendix 6), the individual compounds should be speciated. The results of these analyses will indicate candidate compounds for modelling. However, this does not necessarily mean that they should be modelled individually as a limited number of (conservative) surrogate substances could be used instead;
- as set out in Appendix 3, there are a number of different ways to obtain information on **List II substances** in leachate. The number of modelled compounds should be carefully selected and limited to a range of indicator species that will act as a realistic surrogate for the leachate as a whole. It may prove to be extremely time consuming, unnecessary and difficult to model an exhaustive range of List II substances. If an appropriate selection of indicator species is made, including conservative and persistent species, it is normally possible to assess the site using fewer than 10 substances.

If the operator decides to model in detail a limited number of indicator List I and II substances, then the screening process should be subject to scrutiny and assessment by a competent chemist and hydrogeologist. This is to ensure that the modelling carried out and the conclusions reached are reasonable.

The exact contaminants that may be appropriate for a risk assessment should be waste-stream and landfill site-specific. Examples of the contaminant categories that may be appropriate for a non-hazardous landfill are set out in Table 3.2.

**Table 3.2** | Examples of chemical species that may be appropriate for modelling typical domestic (non-hazardous) landfills

Category of parameter	Examples
Inorganic cations	ammonium, potassium
Inorganic anions	chloride, cyanide
Hydrophilic organic chemicals	phenol
Hydrophobic organic chemicals	PAH, such as benzo[a] pyrene, naphthalene
Acid herbicide	mecoprop
Highly mobile metallic ions	nickel
Less mobile metallic ions	mercury
Organo-metallic substances	organo-tin compounds

## 3.4 Available risk-assessment tools

A number of assessment tools, including computer models, can be used to aid the hydrogeological risk-assessment process. Given that the choice of tool is highly dependent upon the nature of the proposed development, the setting of the site and the volume of available information, it is not appropriate for this guidance to be prescriptive. The appropriate choice of assessment tool is ultimately a matter of professional judgement that should be agreed between the assessor and the Agency. Nevertheless, where site conditions are consistent with the conceptual model incorporated into LandSim2 (Agency, 2001b), it is our preferred model for assessing the risks to groundwater from landfill sites. Table 3.3 presents some examples of the types of software assessment tools that are currently available.

LandSim2, a software package that uses Monte Carlo (stochastic) techniques, is a customised risk-assessment tool that has been produced specifically for assessing risks to groundwater from landfills. LandSim2 represents a significant development from its forerunner, LandSim, which was introduced in 1996. LandSim was introduced by the Agency to: try to achieve a consistent approach to the estimation of hydrogeological risks in respect to landfills and groundwater; provide an audited and verified code that is widely accessible; and aid comprehensive reporting of input values, assumptions and results.

It is important to remember that the modelling must be relevant for the whole lifecycle of the landfill from operational phase through aftercare to completion. Input parameters that are relevant for one phase of a site's life may not be applicable for another. For example, an operational cell where the liner has recently been installed is likely to be very different from the same site 50 years post-closure (where there may have been degradation of the engineered liner, cap, leachate-management systems and changes in the leachate quality). A variety of scenarios should be developed to reflect different phases of the landfill's life.

**Parameter values used in any model should, as far as possible, be based on site-specific data.**

Literature or default values should only be used where they are relevant to the site, and site-specific data collection is not possible. **Site-specific data should, however, be collected for the key parameters that control contaminant fate and transport in the subsurface, such as hydraulic**

**conductivity, controls on contaminant sorption (for example, soil-water partition coefficients,  $K_d$ ) and, ideally, contaminant degradation rates.**

It is stressed that although LandSim2, and other modelling software, are useful tools, they comprise only one component in the assessment process. The models are aids to decision-making – they do not make any decisions themselves. The assessor must make the decisions, using the model results together with his understanding of the assumptions within each model to reach a professional judgement.

All models that are relied upon within a risk-assessment process should be supplied to the Agency in an electronic format. If the models have been constructed by the assessors and have not been independently verified, then the models need to be supplied with the appropriate quality-assurance information to allow their verification before the risk assessment outputs are reviewed.

## 3.5 Accidents and their consequences

The inevitable degradation, over time, of engineered and management systems should form part of the normal risk-assessment process, as described in Section 3.3.1. This aims to ensure that risks to the environment and human health do not become unacceptable at any point during the lifecycle of the landfill. For example, the degradation of synthetic landfill liners or leachate-collection systems should be considered in assessing the long-term flux of pollutants discharged from the landfill.

The risks associated with accidents and their consequences must be considered separately from the risks arising from normal operations. Accidents are considered to be unintentional incidents that could reasonably occur, which are unforeseeable at their time of occurrence. However, with adequate foresight, design and mitigation (preventative measures), they can normally be avoided.

The process of evaluating environmental risks should include consideration of the impact of accidents and resulting damage to liner systems, leachate management and other engineering and management structures. It is important that the likely impact of such eventualities is understood (at least in qualitative terms), even if the likelihood of the occurrence is low. A variety of potential site-specific failure scenarios should be considered. Where the consequences of accidents are found to be severe, efforts should be made to identify appropriate

risk-mitigation measures that will minimise the likelihood of the incident occurring. Table 3.4 gives some examples of scenarios that should, according to site-specific circumstances, be considered.

Identification of possible accident scenarios should, where possible, be provisionally agreed at the PPC pre-application stage. The conceptual model will be essential in this process for identifying feasible accident scenarios (for example, whether flooding could occur at the site due to the proximity of a river).

**Table 3.3** | Summary of some available risk-assessment tools

Available risk-assessment tools	Applicability to differing levels of complexity used for risk assessments		
	Risk-screening	Simple	Complex
Qualitative assessment	✓		
Proprietary spreadsheets (for example, MS Excel™) used for calculations such as mass balance estimations, analytical and semi-analytical flow/transport solutions and the like, based on worst case (generic data)		✓	
LandSim2 (using worst-case (generic) assumptions)		✓	
Event and fault tree analysis	✓	✓	✓
LandSim2 (using site-specific data)			✓
Proprietary spreadsheets solved in a stochastic fashion using software packages such as @Risk™ or Crystal Ball™ and relying on site-specific data			✓
Numerical groundwater flow models			✓
Numerical contaminant fate and transport models			✓

**Table 3.4** | Examples of accidents and possible failure scenarios

Accident	Direct consequence of accident
Fire / vehicle accident / compactor driver error	Damage to geomembrane side or basal liner
Fire / structural failure / compactor driver error / subsidence / flooding	Destruction / degradation of leachate-management system
Drilling / penetration by waste	Perforation of artificial sealing liner
Stability failure / unforeseeable pore water pressure / subsidence / landslides	Failure of side-wall liner
Drilling / stability failure / subsidence / void migration / landslides / sub-grade failure / fault reactivation*	Failure of artificial sealing liner and /or artificially established geological barrier
Waste slippage / vehicle accident	Waste outside contained area

\* It is recognised that incidences of fault reactivation in the UK are extremely rare and assessment will be required only if there is evidence of recent near-surface seismic activity.

There have been a number of recorded incidents of damage to liner systems. Other structures, including leachate extraction wells and drainage pipework, are also prone to damage from accidents. To produce a transparent and robust risk assessment, it is necessary to understand and document the likely magnitude of the consequences of such accidents and failures. Predicting the likelihood of these is more difficult than estimating their consequences.

A key outcome of this process is the identification and design of mitigation measures that will prevent accidents occurring, and preparation of suitable incident response plans in the event that those controls fail.

## 3.6 Completion

Landfill completion requires a consideration of whether the site, as a result of the disposal of controlled wastes, is likely or unlikely to cause pollution of the environment or harm to human health. This determination needs to take into account all of the potential hazards and risks associated with the site and the Agency is preparing guidance on this matter (Environment Agency, 2002I). As the hydrogeological risk assessment must be undertaken for the whole lifecycle of the landfill, it follows that the process should result in the initial production of hydrogeological completion criteria for the landfill.

Completion relating to hydrogeological risks will essentially have been achieved when there is no unacceptable risk of pollution from the landfill. This depends on considerations of leachate quality over time, degradation or removal of management systems and the ability of the geological and hydrogeological conditions of the landfill (that is, the geological barrier) to provide long-term environmental protection. Landfills with a declining source term will eventually reach a stage where the quality and quantity of the leachate can be attenuated by the geological barrier and active management of the landfill is no longer required.

The risk assessment should determine the levels of leachate quality and quantity at which the unmanaged landfill would not pose an unacceptable pollution risk. These would be the indicative completion criteria with respect to groundwater. The estimated time taken to reach these criteria should also be determined and reported (see Section 5).

# Use of Control and Trigger levels

## 4.1 Introduction

Environmental monitoring is a crucial element of the risk-assessment process as it:

- allows for validation of the risk assessment;
- can confirm whether risk-management options are meeting their aims;
- provides a warning mechanism if adverse impacts are found.

Control and Trigger levels form the basis for assessing groundwater-monitoring data at landfill sites. Section 5 deals with the reporting requirements for Control and Trigger levels.

**Control levels** are specific assessment criteria, as defined by the Environment Agency (2002b), relating to groundwater or other relevant parameters, which are used to determine whether a landfill is performing as designed. They are intended to draw the attention of site management and the Agency to the development of adverse, or unexpected, trends in the monitoring data. Such trends may result from failure of site engineering or management, or from variations between actual conditions and those assumed within the conceptual model. Control levels should be treated primarily as an early warning system to enable appropriate investigative or corrective measures to be implemented, particularly where a Trigger level might be breached.

A well-planned method of assessment, agreed between the operator and the Environment Agency, will help to:

- protect the environment and thereby avoid breaches of Trigger levels;
- provide clarity and avoid ambiguity when Trigger level conditions are breached.

**Trigger levels** are specific compliance levels, or regulatory standards, as defined by the Environment Agency (2002b), the nature of which should be stipulated within a PPC permit. They are defined as criteria at which significant adverse environmental

effects and/or breaches of legislation have occurred. Such effects would be consistent with the groundwater having been polluted.

## 4.2 Control levels

### 4.2.1 Aims of Control levels

Control levels should:

- highlight variations between the conceptual model (that is, assumed behaviour) and observed conditions;
- identify unambiguous adverse trends that are indicative of leachate impacts;
- allow for variation in natural water quality from baseline conditions (see Figure 4.1);
- give sufficient time to take corrective or remedial action **before** Trigger levels are breached.

### 4.2.2 Deriving Control levels

Control levels must be set for all landfills. However, no one method of deriving such levels may be applicable for all landfills owing to different site circumstances (for example, historical groundwater contamination, poor natural groundwater quality, baseline trends in groundwater chemistry and the like). Consequently, levels must be set that are appropriate for each individual landfill and its local setting.

Control levels should be set for each parameter for which a Trigger level has been set (see Section 2.6), but they may be derived for additional parameters if this aids effective management and control at a site. Control levels should allow the site operator and the Agency to identify, at an early stage, if the landfill's performance is deviating from its design performance, as assumed within the conceptual model. They should give an early warning that allows action to be taken by the operator to avoid more serious pollution.

The approach taken to derive Control levels for List I and List II substances is likely to differ, and appropriate methods are described below.

The GWD prohibits the entry of List I substances into groundwater. Since the Trigger levels for List I substances will generally be very low (see Section 2.6.2), it is unlikely to be practicable to derive Control levels for these substances in groundwater that can be measured by analytical methods.

For List I substances, other parameters should be considered, such as leachate chemistry and leachate head. Appropriate parameters should be selected, having regard to the conceptual model for the site and the outcome of the risk-assessment process. In particular, the results of a sensitivity analysis on the predictive modelling of the landfill are likely to be important in identifying those parameters that are likely to have the greatest impact on the rate at which contaminant mass is released from the landfill.

Control levels should be set for relevant parameters at a point that represents a significant deviation from the assumed values incorporated within the conceptual model. For example, if leachate is assumed to have a concentration of a List I substance no greater than 250µg/l, it would be appropriate to set Control levels (applied to leachate-monitoring data) at, say, 250µg/l plus 10 per cent, 20 per cent and 50 per cent (that is, 275, 300 and 375µg/l respectively). Increasing levels of contingency action would be instigated at each point (see Table 4.1). Also, the trend in pollutant concentration over time should be reviewed to check whether concentrations are rising towards the values assumed within the conceptual model.

Similarly, if leachate head is a sensitive parameter in the risk assessment and it is assumed within the conceptual model that leachate head will not exceed, say, two metres above the base of the site, Control levels should be set that will highlight if this is breached. Such a Control level should be reflected in permit conditions relating to the leachate controls at the site. Again, reviewing trends in monitoring data is important to check whether the levels are likely to be compromised in the near future.

The GWD requires that any discharge of **List II substances** should be such that it does not cause pollution. Consequently, an increase in the concentration of List II substances in groundwater may be acceptable so long as its impact does not cause pollution. It is normally possible to detect concentrations of List II substances in groundwater before they cause pollution.

Control levels for List II substances should be set as a concentration for a substance in the groundwater. They will typically be set at a level between the predicted concentration in groundwater (that is, the risk assessment output based on the conceptual model) and the EAL (or the Trigger level), as illustrated in Figure 4.1.

For example, if, on the basis of a robust risk-assessment model, it is predicted that the maximum concentration of ammonium,  $\text{NH}_4^+$ , in groundwater at the site boundary will be 0.2mg/l and the Trigger level is set at 0.5mg/l, then Control levels at 0.25 and 0.35mg/l could be appropriate. That is, 25 per cent above predicted maximum and half-way between predicted concentration and the Trigger level. Simultaneously, the trends in pollutant concentrations in the groundwater should be reviewed to check whether there are unexpected trends, and whether Control and Trigger levels are likely to be breached in the near future.

For inert sites, Control levels should be derived based on an understanding of natural fluctuations in baseline groundwater quality.

The most basic **Control level test** is to look for trends in the data by plotting the monitoring data against time to detect adverse or unpredicted temporal variations (see Environment Agency, 2002b for more information). Trend analysis for groundwater-quality data is the subject of a separate guidance document (Environment Agency, 2002f).

Examples of other methods that could be used are as follows:

- a simple breach of the Trigger level, or a set Control level, on a single occasion;
- assessment of breach of the pre-set Control level for single determinands using rolling average or temporal trend methods such as:
  - Control chart rules (for example, a simple breach of the Control level on a specified number of occasions);
  - cusum charts;
- probabilistic assessment of breach of the Control level for single determinands using methods such as:
  - multivariate Control chart rules.

Examples of data for a single determinand interpreted using some of the above methods are illustrated in Figure 4.2.

Whatever method is adopted to analyse the data, it must be robust and clearly documented in the site's Environmental Monitoring Plan. In particular, the basis of the assessment process and for instigating contingency actions must be clearly documented.

#### **4.2.3 Intervals between control level testing**

Comparison of monitoring data with Control levels should be carried out each time monitoring data are collected. The frequency of monitoring should be derived based on an understanding of the hydrogeologic environment and likely risks posed by the landfill, as described in Environment Agency 2002b. The monitoring frequency may need to be increased when there appears to be a danger of the Trigger levels being breached, or when there is a rapidly rising trend towards this point. When an adverse trend or breach of a Control level is indicated by the monitoring results, contingency actions should be implemented, within pre-specified response times, as agreed with the Agency.

### **4.3 Trigger levels**

The derivation of Trigger levels is discussed in Section 2.6. This Section describes the use of Trigger levels.

#### **4.3.1 The intervals between Trigger level reviews**

The frequency of Trigger level reviews (that is, to determine whether a Trigger level has been breached or not) should be set out in the PPC permit. However, it should occur at least once a year. Notwithstanding this, the Control level reviews, which should be carried out each time new groundwater-monitoring data are obtained, will also constitute an informal Trigger levels review.

The regular intervals specified within the PPC permit should be viewed as minimum requirements. There may be some circumstances when more frequent testing is appropriate. For example, if groundwater monitoring has established breaches of a Control level and indicates a potential breach of a Trigger level in the near future. Accordingly, it would be beneficial for the waste operator to carry out ongoing analysis of the Trigger level conditions to provide information applicable to landfill management.

If non-compliance with Trigger levels occurs, then the operator should notify the Agency at the earliest opportunity (typically within five working days of

receipt of the monitoring data). Notification of non-compliance with a Trigger level should **not** be left until the annual reporting round.

#### **4.3.2 The period of monitoring used for the analysis**

A minimum of one year's worth of baseline monitoring data should be used to underpin the assessment of compliance, as described in Environment Agency (2002b). However, this period may need to be increased if it provides insufficient volumes of information to allow viable and robust assessment.

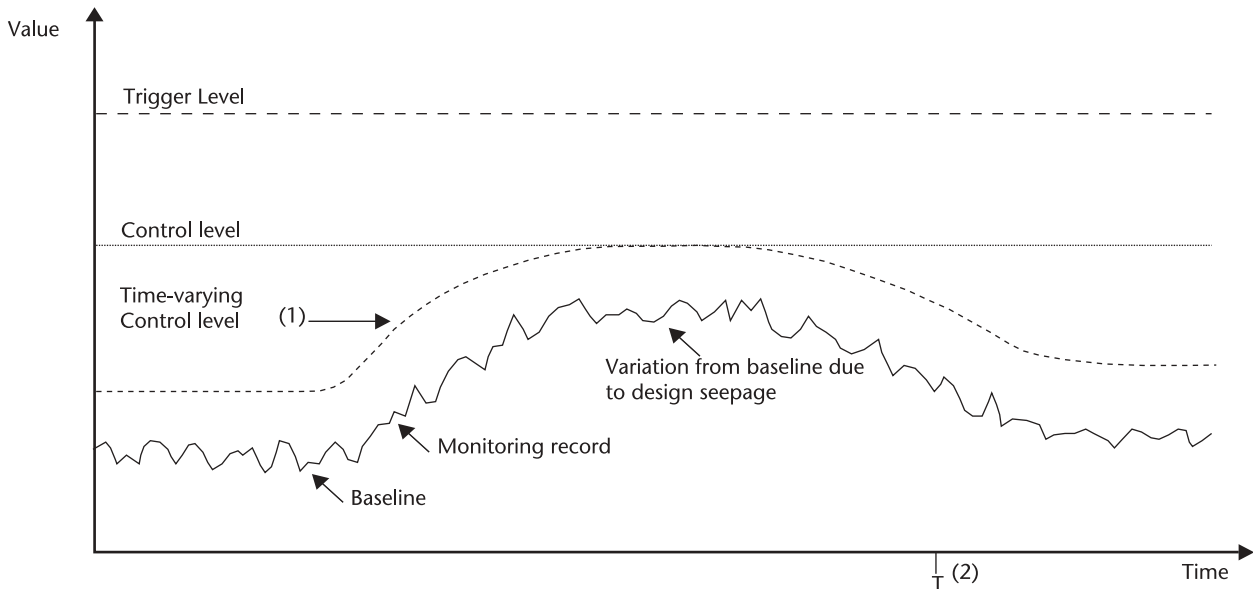
#### **4.3.3 The inclusion of Trigger levels into PPC permits**

Trigger levels need to be specified within the PPC permit. However, the permit conditions should not be drafted so as to require a permit modification each time the Trigger trigger levels are reviewed. This could occur, for example, following an alteration of the most appropriate EAL (for example, if the drinking water standard for a substance changes), a revision to the conceptual model or a significant change in baseline groundwater quality.

Accordingly, the PPC permit should refer directly to the basic methodology of Trigger level determination and the conditions under which a breach has occurred. The specific values of the Trigger levels should be limited to the monitoring plan that accompanies the permit. This, in turn, should refer to the Trigger levels as determined by the hydrogeological risk assessment.

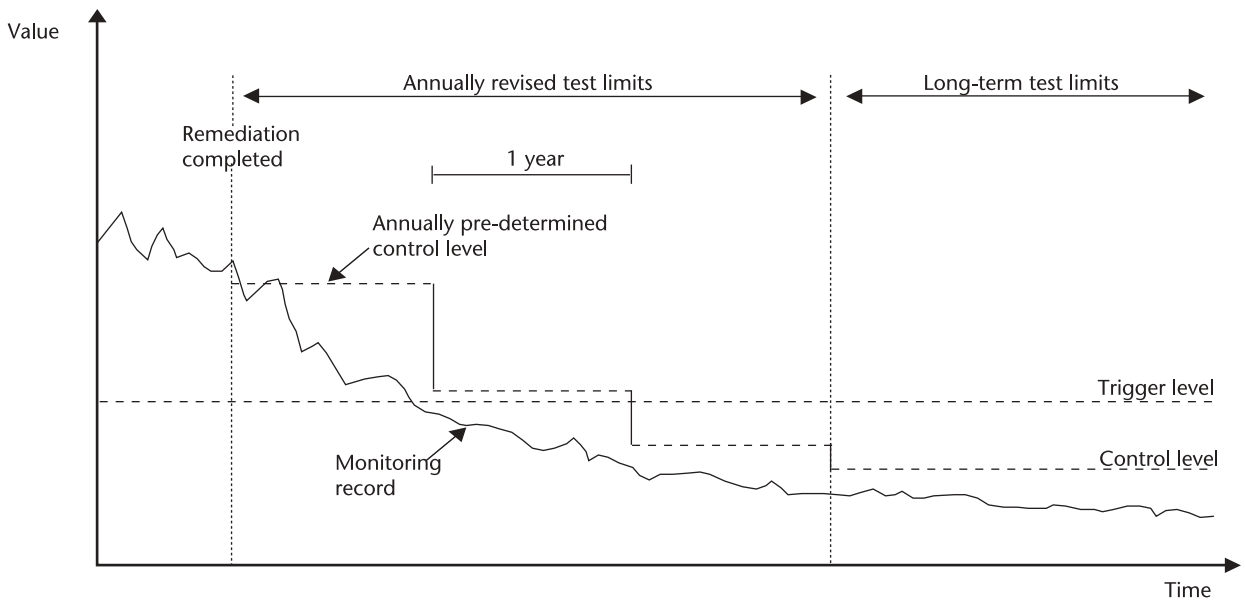
**Figure 4.1** | Illustration of general principles of control and trigger levels (after Agency, 2002b)

(a) Test limits at a previously uncontaminated site.



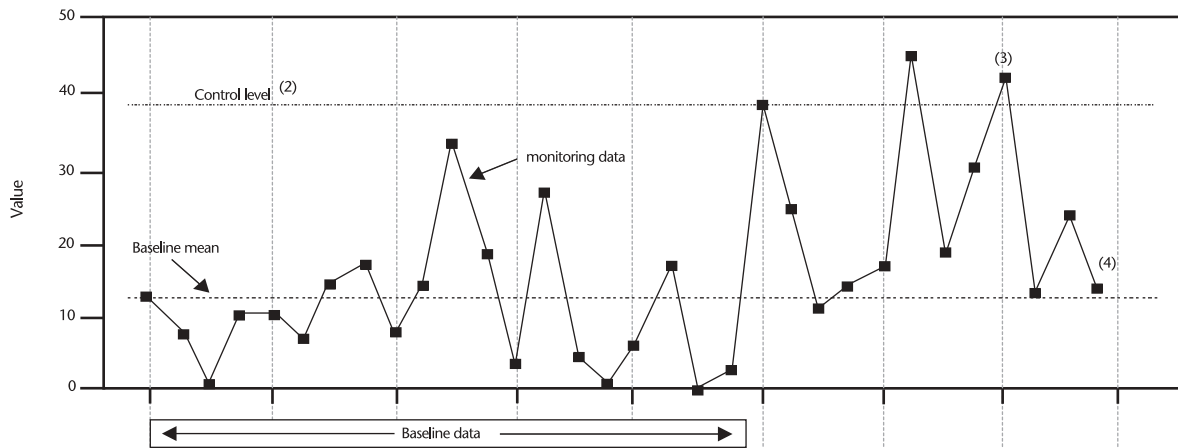
Notes: (1) In sensitive situations, time-varying assessment limits may be appropriate, see text for explanation.  
 (2) A lower assessment limit may be appropriate after Time T.

(b) Test limits at leachate uncontaminated site following remediation.

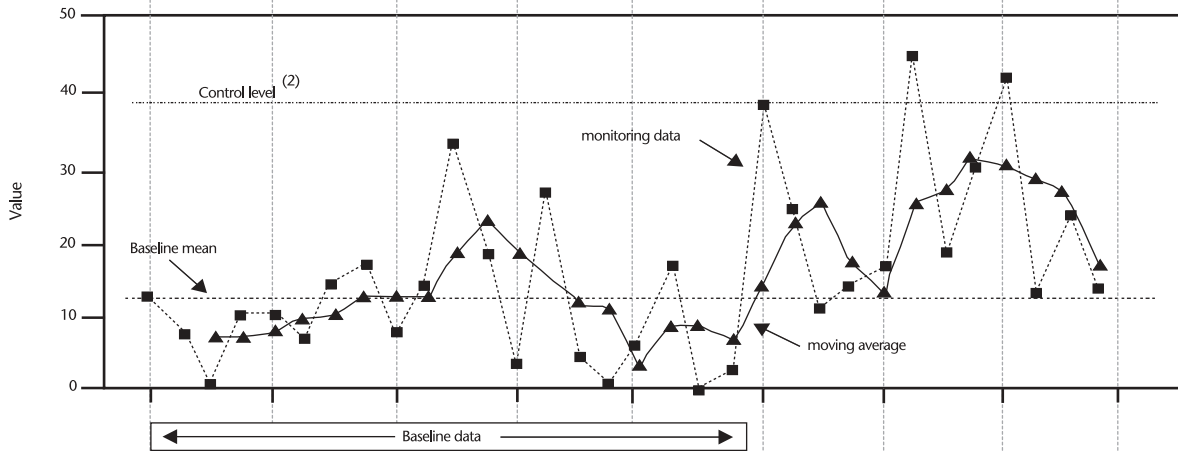


**Figure 4.2** | Examples of use of control charts to interpret trends in monitoring data (after agency 2002b)

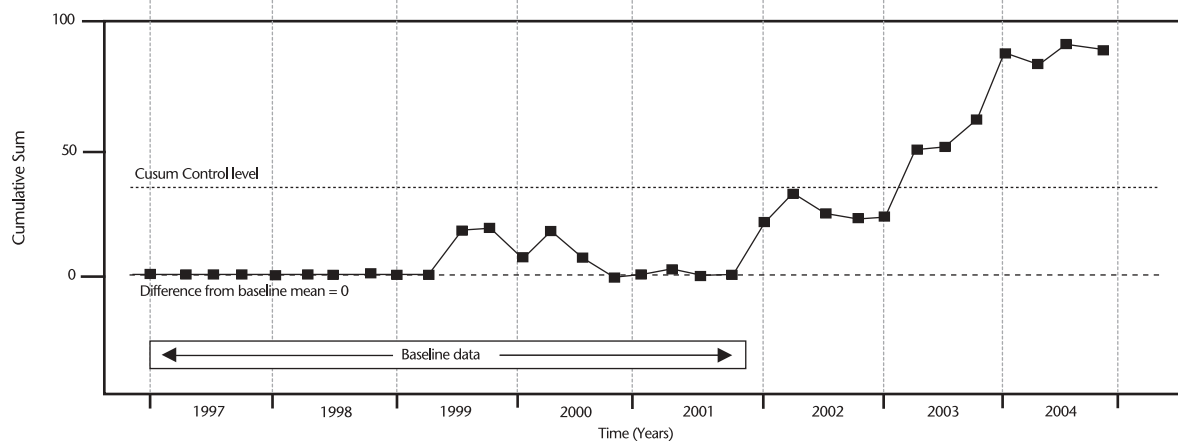
(a) Simple Control Chart (Individuals Chart) <sup>(1)</sup>



(b) Moving average Control Chart  
(Example is based on moving average of 3 data points)



(c) Upper Cusum Control Chart <sup>(5)</sup>



**Notes**

- (1) For further explanation of control charts see Oakland 1996.
- (2) A control level 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 control level or development of an adverse trend should be separately formulated. The point marked as (3) could, for example, indicate a breach in control level 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 devised 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 charts is calculated as the cumulative summation of the positive difference between the baseline mean and the actual recorded value.

## 4.4 Contingency actions (risk management)

Regulation 14 of the Landfill Regulations, regarding control and monitoring procedures in the operational phase, requires the operator of a landfill to carry out a control and monitoring programme. Regulation 15, regarding closure and aftercare procedures, requires monitoring and control to be maintained in the aftercare period for as long as the landfill could present hazards. If this monitoring programme shows that there are significant adverse environmental effects, the operator must notify the competent authority (that is, the Environment Agency). The operator must then act on the Agency's decision on the nature and timing of any corrective measures. These should be carried out at the operator's expense.

The actions to be taken following breaches of both Control and Trigger levels should be specified clearly and each action should have an agreed response time. In all cases, where breaches are confirmed as being due to leachate contamination, the assumptions within the conceptual model should be undertaken, and the risk assessment may need to be revised accordingly. Where baseline conditions are shown to have changed (for example, changes to up-gradient groundwater chemistry), and the risk is proven to be small, Control and Trigger levels may be re-evaluated in consultation between the site operator and the Agency.

Contingency actions and plans should be developed on a site-specific basis, taking into account the nature of both the landfill development and its setting. However, the general steps that could be applicable following these breaches are indicated in Table 4.1.

If a breach of a Trigger level occurs as a result of substances migrating from the landfill, this indicates non-compliance with both the LFD and the GWD, and the operator should immediately take steps to identify the source of those substances:

- (a) where it is likely that the source of the contamination is the landfill, to reduce ongoing discharges to an acceptable level;
- (b) to determine by risk assessment the potential impact of that discharge on identified sensitive receptors.

These steps should form part of an action plan, developed in consultation with the Agency. The plan should include more frequent groundwater monitoring, both in the vicinity of the site and upstream, and a review of the essential and technical precautions required by the permit. If the assessment confirms that the landfill is the likely source of contamination, then appropriate remedial action must be taken to minimise ongoing releases.

Some corrective action can be relatively simple (for example, reducing leachate heads), but others can be very costly and technically complex (for example, in-situ groundwater remediation). 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 consultation between the site operator and the Agency. Notwithstanding the above, the Agency has the power to require corrective measures.

All elements of the contingency plans should be documented within the monitoring plan. This and, therefore, the contingency plans should be kept under periodic review. These reviews should be carried out in consultation with the Agency as part of the normal review process of the PPC permit.

**Table 4.1** | Examples of appropriate contingency actions

Appropriate contingency action	Following a breach of a	
	control level	trigger level
Advise site management	✓	✓
Advise environmental manager of landfill operating company	✓	✓
Advise Environment Agency	✓	✓
Confirm by repeat sampling and analysis	✓	✓
Review existing monitoring information	✓	✓
Review site management and operations, and implement actions to prevent future failure of a trigger level	✓	
Review the assumptions incorporated into the conceptual site model	✓	✓
Review existing hydrogeological risk assessment, control and trigger levels	✓	✓
If risks are unacceptable, set in place procedures for implementing corrective measures in consultation with or required by the Agency		✓

<sup>2</sup> This should include a re-evaluation of whether the baseline conditions have changed since the last risk assessment.



# Reporting

## 5.1 Introduction

Hydrogeological risk assessment may be undertaken as part of the planning process as well as the PPC permitting process. For instance, an Environmental Impact Assessment undertaken for the purposes of planning permission may fulfil many requirements of the conceptual model and risk-screening stage. Where the PPC application and planning application are made concurrently (“twin tracking”) the applicant will wish to address the risk and impact assessment requirements together. However, there are a number of specific requirements arising from PPC, the GWD and the LFD that must be addressed at the permit stage. This Section deals specifically with the permit requirements.

This guidance is most likely to be used in preparing and supplementing Part B of the PPC application form for new and existing landfill sites. It is important, therefore, that the reporting requirements for the risk assessment fulfil all the requirements of the PPC application. There are two main stages in the PPC application process: pre-application and the submission of the application. After a permit has been issued, there are further requirements for monitoring, interpretation of those results and reviews. These must serve to validate and reassess the risk assessment and evaluate the risk-management measures in place. The following sections address the reporting requirements at these three stages.

## 5.2 PPC pre-application

As part of the pre-application stage, the conceptual model and risk-screening assessment should be submitted to the Agency. This will allow for a general agreement on the understanding of the hydrogeological setting, the sensitivity of the receptors, where the main risk-assessment effort should be directed and the level of detail required in a subsequent risk assessment.

Appendix 10 presents a hydrogeological risk assessment “checklist”, which should be used as an indicative guide to what should be considered for developing a conceptual site model.

A continued dialogue should be maintained with the Agency during the pre-application period to discuss and provisionally agree the following elements:

- the understanding of the landfill proposals and environmental setting presented in the conceptual model and the risk screening;
- the prioritisation of the risks and the possible environmental consequences;
- the appropriate accident scenarios for the landfill;
- the appropriate level of complexity for the risk assessment and the Agency/local authority requirements at each phase of the landfill development process;
- the appropriate contaminants that should be modelled within the assessment and those that should ultimately have Control and Trigger levels assigned to them;
- the models that are to be used within the risk assessment process. This should include the validation and verification of models that have not been previously submitted to the Agency;
- the input parameters and any assumptions that are to be used within the assessment;
- the appropriate EALs that are to be used and proposed Trigger levels.

These issues should be agreed with the Agency, as far as possible, before the risk assessment is finalised and the PPC application submitted.

Following the completion of any required site investigations, the conceptual site model should be reviewed and refined where necessary. The Agency should be consulted during this process to ensure that there is agreement on the appropriate outcome of the conceptual site model review. The complete site investigation results and a brief interpretative statement, which places the investigations within the

context of the initial conceptual site model, should be submitted to the Agency.

Following the written submissions to the Agency (and the planning authority), a verbal presentation with visual aids can be useful to help communicate the main points of an investigation, especially where information is extensive or issues are particularly complex.

It is important to recognise that a conceptual model will always be a simplified representation or working description of the processes operating within both the landfill and its environmental setting. These simplifications and assumptions should be clearly documented and supporting information given to justify any assumptions. It is also vital to be aware of the implications of these assumptions and to be able to justify the decisions made, as well as being aware of whether simplifications are likely to be conservative or otherwise.

## 5.3 The PPC application

With regard to landfill permitting, risk management should essentially involve deciding between three options:

- rejection of the landfill application because it poses an unacceptable environmental risk over its lifecycle;
- acceptance of the current landfill application as the risks and corrective measures are acceptable;
- reduction of the risks to an acceptable level by modifying wastes types, changing the proposed waste acceptance criteria or by incorporating improved risk- management measures (for example, upgrading the lining system or improving the leachate-management system).

For assessments that indicate the risks are unacceptable at the simple level (that is, using conservative assumptions), there is also the option of collecting additional data and undertaking a more complex risk assessment to determine whether the proposed landfill operations are acceptable, using more realistic assumptions. As stated above, the risk- assessment process should ensure that the development complies with both the GWD and the LFD.

The more sensitive the environment surrounding a landfill site and the greater the hazard presented by the waste deposited, the more stringent will be the requirements for site-specific data collection. Where a proposed site is located in a very low sensitivity

environment, literature values may be used for non-critical parameters. However, in more sensitive locations the Agency will expect comprehensive site-specific data to be collected to support a robust, long-term site-specific assessment. However, if a site is in a particularly sensitive location and poses a long-term pollution threat, the Agency may object to its development because of the lack of certainty about environmental protection measures over the long-term. The Agency's policies and guidance on groundwater protection and landfill location are particularly relevant in this context, especially where there is likely to be long-term reliance on engineering or active measures to control pollution risks.

The clear recording of the hydrogeological risk-assessment process and its findings is essential for a number of reasons:

- it allows transparency in the risk-assessment process and greatly helps the Agency's decision-making process regarding the authorisation;
- it provides a clear record of the risk-assessment process that can be reviewed by any party at any time. It also provides a clear "audit trail" to the results of the assessment;
- it encourages two-way communication between the risk assessor and the Agency and ensures that all relevant matters are discussed at the appropriate stages.

The following sections provide some recommendations on the contents of submitted risk- assessment reports. Further advice is presented in Environment Agency (2002b and 2001e).

### 5.3.1 Emissions to groundwater

Section 2 of Part B of the PPC application form for the landfill sector deals specifically with the Groundwater Regulations. The requirements of this section of the application should be met by submitting a hydrogeological risk-assessment document. It is important to remember that the prior investigation required by the Groundwater Regulations is to be met by the risk assessment.

It should be noted that the conceptual site model should be reviewed and refined as additional information becomes available or as understanding of the system is improved throughout the risk-assessment process. The refined conceptual site model should be presented within the hydrogeological risk-assessment document.

Appendix 10 provides an indication of the information that needs to be reported as part of the hydrogeological risk-assessment process. In summary, this includes the following:

- **site details**, such as location, historical development and the like;
- **the conceptual hydrogeological model**, including a consideration of all the potential source, pathway and target terms. Such source considerations need to include the contaminant concentrations within the site, the volume of leachate produced, the depth of leachate above the lining system at various key locations in the site and the like;
- **the prior investigations** that have taken place, such as the “purifying powers” of the soils and sub-soils (Appendix 9) and any mineral component of the engineered lining systems, if used within assessment (that is, the attenuation capacity of the geological barrier);
- **technical precautions**, such as engineering and operational controls, post- closure controls;
- **the risk assessment** carried out and the use of numerical models;
- **requisite surveillance**, such as the risk-based monitoring scheme;
- **the acceptability of the discharge to the environment** (that is, the impact of leachate on groundwater quality at receptor locations and its impact on the potential use of the groundwater, as well as whether the site complies with the requirements of the LFD and GWD at all stages throughout its life span. This will need to include the calculated annual mass of the emission (for the purposes of the Pollution Inventory);

It is important to note that the actual output of each landfill risk assessment, the complexity of the models and the nature of the input data should depend upon the nature of the proposed development (including waste types) and the environmental setting of the site (including the vulnerability of the groundwater). The above information should therefore be used only as a guide.

### 5.3.2 Accidents and their consequences

The PPC process requires the identification of accidents and their consequences. Accidents that are relevant to the hydrogeological risk assessment can be reported either within the assessment itself or in a separate document that considers all appropriate

accidents that are relevant to the site and the potential hazards they present. However it is reported, the relevant section should cover the assessment and analysis of the consequences of accidents (see Section 3.5). A permit may be issued only where the landfill site does not pose an unacceptable risk to the environment or human health. The likelihood and consequences of accidents and failures will form part of this consideration.

Where the risk-management measures are inadequate, a permit may not be issued. The impacts of accidents should be considered in the contingency plans for the landfill (see Section 4.5).

It is recommended that reporting of potential accidents and their associated preventative measures (that is, incidents that can be prevented with adequate design and control) is separated from the assessment and reporting of (inevitable) engineering system degradation.

### 5.3.3 Completion

Site closure, after-care and completion need to be considered as part of the PPC application process. A landfill should not be permitted unless the risks have been considered for the whole life of the site up to the point where it no longer poses an unacceptable risk to the environment. The hydrogeological risk assessment should contribute a section to the Site Closure and Aftercare Plan and provide the following:

- proposed completion criteria based on predictions of leachate quality and quantity;
- a calculated time period for achieving the predicted hydrogeological surrender conditions;
- a series of performance criteria throughout the life of the landfill that can be used to validate issues such as the declining source term (see Section 5.4 on the review of the risk assessment).

## 5.4 Monitoring, validation and review

### 5.4.1 Review of the risk assessment

The Groundwater Regulations require a review of each authorisation every four years and Regulation 14 of the Landfill Regulations requires the reporting of aggregated monitoring data at a frequency specified by the Agency. An annual review of the risk assessment (in particular, a review of the conceptual

model in the light of new observations and monitoring data), and associated risk-management provisions, will be required through the PPC landfill permit. This is a vital part of the iterative risk-assessment process and should be built into the risk assessment produced at the permitting stage. Part of the risk-assessment process should therefore be to produce a plan to validate the predictions and assumptions of the risk assessment as the site is developed.

The hydrogeological risk assessment should not be an abstract exercise divorced from the reality of the landfill facility. This link is made explicit by the reliance of the risk assessment on the essential and technical precautions at the landfill. With regard to the construction of the landfill lining systems, fundamental assumptions are made in the risk assessment about its performance in terms of permeability and defect rates. Similarly, the permeability of drainage systems is likely to have been an assumption in the assessment. To reflect the iterative nature of risk assessment, the “as built” details of the engineering systems should be compared to the risk-assessment assumptions as part of the annual review. In the medium- and longer-term, any instrumentation installed to evaluate liner performance must be used to compare the observed situation with the predicted performance.

Operational issues will also impact directly on the risk assessment and must be adequately recorded and assessed. Examples of issues that must be considered are leachate management, specifically volumes generated and removed or re-circulated. Waste types and inputs rates, phasing, intermediate capping and the like are all relevant. Any failures of systems, such as drainage pipe-work collapses or leachate extraction point failures, are directly relevant to assumptions made. It is important to remember that there are numerous aspects of the site’s operation that can affect the risk assessment.

Landfill monitoring is dealt with in separate guidance (Environment Agency 2002b) and has a clear relationship to comparing performance with risk-assessment assumptions. For instance, assumptions will have been made about leachate quality that only monitoring can validate. In particular, the concentrations of specific List I substances are difficult to predict with any confidence. Leachate heads are another obvious example where monitoring results can be related to risk-assessment assumptions. Meteorological monitoring will also be relevant. The overall review plan must link the initial assumptions made with the sensitivity and importance of those assumptions in the model

output. This review plan must essentially identify the critical assumptions and ensure that validation of these is part of the formalised review process.

The following is a checklist of issues that should be reviewed:

- **the conceptual site model** (for example, groundwater level monitoring may indicate a possible change in the hydrogeological regime);
- **essential and technical precautions** (for example, are the risk management measures, such as leachate-management systems, performing as predicted?);
- **risk assessment inputs and assumptions** (for example, is the leachate quality as predicted?);
- **sampling and analysis plan and data quality** (for example, are monitoring points correctly located and designed to provide the information required? Are enough samples being taken and are the appropriate determinands being analysed? Are the objectives of the monitoring plan being met?);
- **laboratory analysis quality assurance and quality control** (for example, are the laboratory analyses reported with sufficient accuracy and precision? Are the reporting limits adequate to assess compliance against control and trigger levels?);
- **baseline groundwater quality** (for example, could the groundwater that is flowing below the site have naturally elevated concentrations of contaminants that could influence the results of the monitoring on the down-gradient side of the site?);
- **landfill operations and destruction of monitoring installations** (for example, during routine operations a groundwater monitoring well may be destroyed. In this situation, a replacement well will normally have to be installed. However, there could be implications for the compliance monitoring results);
- **standard operating procedures to monitor wells and take samples** (for example, unless a good training programme is in place, different operatives may have slightly different practices in the field that could account for differences in monitoring results);
- **the requirements for additional boreholes;**
- **the requirements for increased frequency of monitoring.**

### 5.4.2 Monitoring reporting

The monitoring reporting forms will be specified in the PPC permit (Schedule 3) and the following is an indication of the appropriate information.

- **Routine survey documentation** is primarily concerned with conveying the details of works undertaken, results obtained and the implications of these to site management. This information does not need to be compiled into a formal report, although it should be available for inspection by the Agency on request. This documentation should be updated following each monitoring event and should conclude with statements regarding:
  - whether any breaches in Control or Trigger levels have been noted;
  - whether any adverse trends are apparent;
  - any significant changes in the rate of change of concentrations of constituents;
  - proposals for varying the frequency and range of monitoring.
- **Notification reports** should be seen as the prime means of disseminating information that requires action by site management and/or the Agency. Notification reports should be issued when breaches in Control or Trigger levels have occurred. They should provide clear, concise information and recommend action (or advice of action taken). The time scales for issuing reports will be specified by the permit conditions (section 5 of the PPC permit will specify the notification requirements).

In instances where Control and Trigger levels are regularly being breached and action is being implemented by the site operator, alternative ongoing reporting procedures should be agreed between the site operator and the Agency to avoid unnecessary duplication of notification reports.

- **Review or compliance reports** should be prepared at least annually as required by the LFD and the PPC permit. They should summarise the monitoring data collected with regard to compliance with the Control and Trigger values set for the site. The main purpose of this report is to inform site management and the Agency about the environmental performance of the landfill site, as well as the performance of the monitoring programme. Recommendations for improving the monitoring plan should be made and discussed with the Agency.

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# Glossary of terms and abbreviations

**This glossary defines terms as they are used in this document. Some terms may have broader meanings outside this guidance. Within definitions, words in *italics* are themselves defined elsewhere in the glossary.**

**Absorption** The incorporation of a chemical within a solid or liquid.

**Adsorption** The attachment of a chemical to the surface of a solid.

**Abstraction** Removal of water from surface water or groundwater, usually by pumping.

**Advection** Mass transport in response to a pressure gradient caused by the bulk movement of flowing groundwater.

**Aquifer** A subsurface layer of layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater [Water Framework Directive (2000/60/EC)]. See also *Groundwater system*.

**Aquifer classification** Classification given to water-bearing strata by the Environment Agency and published in groundwater protection policy documents (for example, major aquifer, minor aquifer, non-aquifer).

**Aquitard** A geologic stratum or formation of low permeability that impedes the flow of water.

**Artesian Flow** Overflow of groundwater where water rises under pressure above the top of the aquifer.

**Attenuation** A decrease in contaminant concentration or flux through biological, chemical and physical processes, individually or in combination (for example, dispersion, precipitation, ion exchange, biodegradation, oxidation, reduction). See also *natural attenuation*.

**Background** See *baseline*.

**Baseflow** That part of the flow in a watercourse made up of groundwater discharges. It sustains the watercourse in dry weather.

**Baseline** In the context of a permit, the measurements that characterise the pre-permit physical, chemical or other distinctive properties of groundwater and surface water beneath/around a site.

**Biodegradation** The breakdown of a substance or chemical by biological organisms, usually bacteria.

**Compliance** The process of achieving, and the achievement of, conformity with a regulatory standard.

**Conceptual model** A simplified representation or working description of how the real (hydrogeological) system is believed to behave, based on qualitative analysis of field data. A quantitative conceptual model includes preliminary calculations for the key processes.

**Consented discharge** A *discharge* of effluent controlled by a discharge consent or groundwater regulations authorisation issued by the Agency.

**Conservative contaminants** *Contaminants* that can move readily through a permeable medium with little or no reaction and that are unaffected by biodegradation (for example, chloride).

**Contamination / contaminant** The introduction of any substance to water at a concentration exceeding the *baseline* concentration. A contaminant is any such substance.

**Contingency action** A predetermined plan of action to respond to a breach of a *Control* and/or a *Trigger level*.

**Control (Assessment)** The process of evaluating the significance of a departure from baseline groundwater quality conditions by reference to an adverse trend in data, the breach of a specified limit or some other *Control level*. Control is directly comparable to assessment (Environment Agency 2001b).

**Control chart** A graphical statistical method for evaluating changes in monitoring data.

**Control level** A test of the significance of a deviation from baseline groundwater conditions, which is used to determine whether a landfill is performing as designed and should be regarded as an early warning system to enable appropriate investigation or corrective measures to be implemented (*see contingency action*). Control level specifically relates to groundwater and is directly comparable to assessment criterion (Environment Agency 2001b).

**Controlled waters** Defined by the Water Resources Act 1991, Part III, Section 104. All rivers, canals, lakes, ground waters, estuaries and coastal waters to three nautical miles from the shore.

**Cusum chart** A type of *control chart* that exaggerates small, permanent shifts from a baseline mean value.

**Detection limit** The lowest concentration of a substance that can be reliably measured to be different from zero concentration.

**Diffusion** Migration of substances in response to a concentration gradient within a fluid due to random movement of particles.

**Dilution** Reduction in concentration brought about by mixing (typically with water).

**Discharge** A release of leachate or water into another water body.

**Dispersion Groundwater** – irregular spreading of solutes due to heterogeneities in groundwater systems at pore-grain scale (microscopic dispersion) or at field scale (macroscopic dispersion).

**Surface water** spreading of substances through the receiving water by means of differential flow rates and turbulence.

**Down-gradient** In the direction of decreasing water level (in groundwater this is following the *hydraulic gradient*).

**Environmental Assessment Level (EAL)** A water-quality standard that is defined by either UK Regulations (for example, Water Supply (Water Quality) Regulations 1989), EU Directives (for example, Drinking Water Directive (80/778/EEC) or another relevant source (for example, non-statutory *Environmental Quality Standards*)

**Environmental Quality Standard (EQS)** A water quality and biological standard for a surface watercourse.

**Ground waters** Any water contained in underground strata (in both the saturated and unsaturated zones). Defined in s104, Water Resources Act 1991.

**Groundwater** The definition used is that given in the EC Groundwater Directive (80/68/EEC) and Water Framework Directive (2000/60/EC): "all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil".

**Groundwater system** A saturated groundwater-bearing formation, or group of formations, which form a hydraulically continuous unit.

**Hazard** A property or situation that, in particular circumstances, could lead to harm or pollution.

**Head (hydraulic head)** The sum of the elevation head, the pressure head and the velocity head at a given point in a water system. In practical terms, this is the height of the surface of a column of water above a specified datum elevation.

**Hydraulic conductivity** A coefficient of proportionality describing the rate at which a fluid can move through a medium. The density and kinematic viscosity of the fluid affect the hydraulic conductivity, so that this parameter is dependent on the fluid as well as the medium. Hydraulic conductivity is an expression of the rate of flow of a given fluid through unit area and thickness of the medium, under unit differential pressure at a given temperature. (See also *permeability*).

**Hydraulic gradient** The change in total *head* (of water) with distance in a given direction. The direction is that which yields a maximum rate of decrease in head.

**Landfill** Site used for waste disposal into or onto land.

**Leachate** Liquor formed by the interaction of water with wastes.

**List I and II substances** As defined by EC Groundwater Directive (80/68/EC).

**Major** Highly permeable formations usually with the known or probable presence of significant fracturing. Highly productive strata of regional importance, often used for large potable abstractions.

**Minimum Reporting Value (MRV)** The lowest concentration of a substance that is reported in the results of an analysis. It is not necessarily the *detection limit*.

**Minor Aquifer** Either:

- variably porous/permeable but without significant fracturing. Generally support only locally important abstractions; or
- fractured or potentially fractured but with high intergranular permeability. Generally support only locally important abstractions.

**Monitoring point** An individual point or structure from which unique sets of monitoring measurements can be obtained.

**Monitoring programme** A series of similar monitoring tasks with a common function.

**Natural attenuation** Natural processes that, without human intervention, reduce the concentration, mass, flux or toxicity of *contaminants* in *groundwater* and surface water.

**Non-Aquifer** Formations with negligible *permeability*. Support only very minor abstractions, if any.

**Pathway** The route along which a particle of water, substance or contaminant moves through the environment (for example, the route contaminants are transported between the source of landfill leachate and a water *receptor*).

**Perched water** This is a layer of saturated soil formed above the main water table due to a layer of low-permeability material intercepting water moving downwards through the unsaturated zone.

**Permeability** A measure of the rate at which a fluid will move through a medium. The permeability of a medium is independent of the properties of the fluid. See also *hydraulic conductivity*.

**Pollutant** Water Framework Directive: “any substance liable to cause *pollution*, in particular those listed in Annex VIII [of the WFD]”. The list of main pollutants referred to in Appendix 2.

**Pollution** Defined in PPC Regulations as: “emissions as a result of human activity which may be harmful to human health or the quality of the environment, cause offence to any human senses, result in damage to material property, or impair or interfere with amenities and other legitimate uses of the environment”; and “pollutant” means “any substance, vibration, heat or noise, released as a result of such emission which may have such an effect”.

Also defined in the EC Groundwater Directive (80/68/EC) in relation to groundwater as: “the discharge by man, directly or indirectly, of substances or energy into groundwater, the results of which are such as to endanger human health or water supplies, harm living resources and the aquatic ecosystem or interface with other legitimate uses of water”.

Also defined in Water Framework Directive as: “the direct or indirect introduction, as a result of human activity, of substances or heat into the air, water or land which may be harmful to human health or the quality of aquatic ecosystems or terrestrial ecosystems directly depending on aquatic ecosystems, which result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the environment”.

**Pollution Prevention and Control (PPC)** Refers to the provisions of the Landfill Regulations (England and Wales) 2001 and minor modifications to the Pollution Prevention and Control Regulations 2000, both made under the PPC Act 1999. These implement the EU Integrated Pollution Prevention and Control Directive in England and Wales.

**Pore water** Any free water contained within the primary pore space or within fissures in either the unsaturated or the saturated zone.

**Porosity** The ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment.

**Potable water** Water of suitable quality for drinking.

**Receptor** An entity/organism or a controlled water that is being or could be harmed by a potential pollutant, such as groundwater or surface water resource, amenity or abstraction point.

**Recharge** The amount of water added to the groundwater system by natural or artificial processes.

**Remediation** The process of improving the quality of a polluted body of water or an area of land, either by carrying out works on the pollutant source or by treating the affected water or land.

**Retardation** A measure of the reduction in solute velocity relative to the velocity of the flowing groundwater caused by processes such as adsorption.

**Risk** A quantitative or qualitative combination of the probability of a defined *hazard* causing an adverse consequence at a *receptor*, and the magnitude of that consequence.

**Risk assessment** The process of identifying and quantifying a risk, and assessing its significance in relation to other risks.

**Saturated zone** The zone in which the voids of the rock or soil are filled with water at a pressure greater than atmospheric. The water table is the top of the saturated zone in an unconfined groundwater system. In general, flow on a macro scale is horizontal and typically faster than for unsaturated zone flow. Flow rates between different types of strata vary over several orders of magnitude.

**Sorption** *Absorption* and *adsorption* considered jointly

**Time-series** A graphical representation of data arranged sequentially by time or date.

**Trigger level** Defined as levels at which significant (adverse) environmental effects have occurred. For List II substances, such effects would be consistent with the most stringent *Environmental Assessment Limit (EAL)* for a groundwater *receptor* being breached, while for List I substances concentrations would need to be discernible. A Trigger level specifically relates to groundwater and is directly comparable to a compliance level (Environment Agency 2001b).

**Unsaturated zone** The zone between the land surface and the water table. The pore space contains water at less than atmospheric pressure, as well as air and other gases. Saturated bodies, such as perched groundwater, may exist in the unsaturated zone. Also called the vadose zone.

Overall flow, on a macro scale, is downward (gravity driven); moisture content is low and water normally flows slowly in close contact with the rock matrix.

**Up-gradient** In the direction of increasing *hydraulic head* (in groundwater this is moving up the *hydraulic gradient*).

**Water balance** An evaluation of all the sources of supply, storage and corresponding discharges of water – (for example, within a landfill site or an entire surface water catchment area).

## Appendix 1:

# List I and list II of the Groundwater Directive

### List I of families and groups of substances

List I contains the individual substances that belong to the families and groups of substances enumerated below, with the exception of those considered inappropriate to List I on the basis of a low risk of toxicity, persistence and bio-accumulation.

Such substances, which with regard to toxicity, persistence and bio-accumulation are appropriate to List II, are to be classed in List II.

- 1 Organohalogen compounds and substances that may form such compounds in the aquatic environment.
- 2 Organophosphorus compounds.
- 3 Organotin compounds.
- 4 Substances that possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment.<sup>3</sup>
- 5 Mercury and its compounds.
- 6 Cadmium and its compounds.
- 7 Mineral oils and hydrocarbons.
- 8 Cyanides.

### List II of families and groups of substances

List II contains the individual substances and the categories of substances belonging to the families and groups of substances listed below that could have a harmful effect on groundwater.

- 1 The following metalloids and metals and their compounds:
 

1 Zinc	11 Tin
2 Copper	12 Barium
3 Nickel	13 Beryllium
4 Chrome	14 Boron
5 Lead	15 Uranium
6 Selenium	16 Vanadium

- |              |              |
|--------------|--------------|
| 7 Arsenic    | 17 Cobalt    |
| 8 Antimony   | 18 Thallium  |
| 9 Molybdenum | 19 Tellurium |
| 10 Titanium  | 20 Silver.   |

- 2 Biocides and their derivatives not appearing on List I.
- 3 Substances that have a deleterious effect on the taste and/or odour of groundwater, and compounds liable to cause formation of such substances in such water and to render it unfit for human consumption.
- 4 Toxic or persistent organic compounds of silicon, and substances that may cause the formation of such compounds in water, excluding those that are biologically harmless or are rapidly converted in water into harmless substances.
- 5 Inorganic compounds of phosphorus and elemental phosphorus.
- 6 Fluorides.
- 7 Ammonia and nitrites.

List I substances are defined in terms of broad groups and there is no definitive list of individual species in the Directive. The National Scheme for the Classification of Listed Substances has confirmed 79 substances as belonging to List I, and these are reproduced in the *Statutory Guidance to the Groundwater Regulations* (DETR, 2001). However, many more compounds are likely to meet the List I criteria and the list of 79 should not be considered as an exhaustive list. The Joint Agency Groundwater Directive Advisory Group (JAGDAG) continues to consider additional substances that may fall within the definition of List I and II substances. If there is evidence to indicate that a site contains additional substances that may fulfil the List I criteria, but there is uncertainty over their status, then specialist advice should be sought. Where the uncertainty cannot be

<sup>3</sup> Where certain substances in List II are carcinogenic, mutagenic or teratogenic, they are to be included in category 4 of this list.

resolved, judgement should err on the side of caution and those substances should be included in the groundwater risk assessment and assumed to be List I substances in the first instance.

To date, JAGDAG has considered around a further 540 substances and products, and proposed classification as List I, II, or not-listed. Consultation documents (JAGDAG, 2001 & 2002) contain the detailed lists and can be viewed on the Agency's website.

There is little published data on the likely presence of List I substances in leachate. The best sources of information at present are the DoE research report No CWM/072/95, *A Review of the Composition of Leachate from Domestic Wastes in Landfill Sites* and Knox K *et al*, 2000, *The occurrence of trace organics components in landfill leachates and their removal during on-site treatment*.<sup>4</sup> Both indicate that such leachates may contain a number of List I substances at relatively low concentrations.

As a consequence of the requirements of the LFD (for example, to reduce the biodegradable content of landfilled wastes), the chemistry of leachate is likely to change significantly in the future.

<sup>4</sup> Presented at Proceedings of the Waste 2000 Conference. 2-4th October 2000. Pp263-272.

## Appendix 2:

# Main pollutants for the Water Framework Directive

The Water Framework Directive presents an “indicative list of the main pollutants”, in Annex VIII of the directive. The list is reproduced below. It is important to note, however, that under the WFD a pollutant is defined as “any substance liable to cause pollution”, and assessment for the purposes of the WFD may need to consider additional, potentially polluting substances.

- 1 Organohalogen compounds and substances that may form such compounds in the aquatic environment.
- 2 Organophosphorus compounds.
- 3 Organotin compounds.
- 4 Substances and preparations, or the breakdown products of such, that have been proved to possess carcinogenic or mutagenic properties or properties that may affect steroidogenic, thyroid, reproduction or other endocrine-related functions in or via the aquatic environment.
- 5 Persistent hydrocarbons and persistent and bioaccumulative organic toxic substances.
- 6 Cyanides.
- 7 Metals and their compounds.
- 8 Arsenic and its compounds.
- 9 Biocides and plant-protection products.
- 10 Materials in suspension.
- 11 Substances that contribute to eutrophication (in particular, nitrates and phosphates).
- 12 Substances that have an unfavourable influence on the oxygen balance (and can be measured using parameters such as BOD, COD and the like.).



## Appendix 3:

# Potential sources of information on leachate quality

Development scenarios	Information sources	Additional comments
<p><b>New landfill</b> where the assessment is required as part of a PPC permit (no current information)</p>	<ul style="list-style-type: none"> <li>• No existing leachate information is available. Consequently, leachate quality has to be determined from:               <ul style="list-style-type: none"> <li>• literature;<sup>5</sup></li> <li>• similar landfills that the operator may own;</li> <li>• information on landfills taking similar waste streams that are operated by a third party. This information is available from the public register.</li> </ul> </li> <li>• As well as the above, for some waste types, such as soils and inert materials, it may be appropriate to carry out leaching tests.</li> </ul>	<ul style="list-style-type: none"> <li>• This scenario demands complete reliance on information gathered from other sources. Consequently, the comparability of the information must be assured. To do this, the following procedure should be adhered to:               <ul style="list-style-type: none"> <li>• obtain information about waste stream and potential leachate quality;</li> <li>• review data usability (completeness, comparability, representativeness, precision, accuracy);<sup>6</sup></li> <li>• data review and identify chemicals of concern;</li> <li>• calculate the source term.</li> </ul> </li> <li>• Note that Landfill Classification, following implementation of the LFD, may alter the nature of leachate produced within landfills. Existing leachate information and literature may therefore be inappropriate. The potential impacts of the LFD on leachate chemistry are addressed in Environment Agency (2002e).</li> <li>• Leaching tests should be undertaken using an appropriate test method,<sup>7</sup> which essentially consists of agitating a mass of waste with a volume of water for a set time and measuring the concentration of contaminants in the eluant.</li> <li>• Extreme care should be exercised when interpreting leaching test results because of the potential heterogeneous nature of some waste materials and their potential inability to replicate the leaching process fully under landfill conditions.</li> <li>• The determinands to be tested should have been identified in the conceptual site model (see Section 3). They will depend on the properties of the wastes being analysed. The basic monitoring suite should, however, comply with <i>Guidance on the Monitoring of Landfill Leachate, Groundwater and Surface Water</i>.</li> </ul>

Development scenarios	Information sources	Additional comments
<p><b>New landfill</b> (cont.)</p>		<ul style="list-style-type: none"> <li>The Environment Agency strongly recommends operators to consult with them during the specification of the leaching test methodology and determinands to ensure that valid and relevant information is collected.</li> </ul>
<p><b>Existing landfill</b> Either to:</p> <ul style="list-style-type: none"> <li>evaluate a waste stream to determine suitability for disposal (in compliance with permitted conditions).</li> </ul> <p>Or for the:</p> <ul style="list-style-type: none"> <li>permitting of an extension or modification to an existing landfill.</li> </ul>	<ul style="list-style-type: none"> <li>Existing leachate quality data may exist from a currently operating landfill site. These data should derive from routine monitoring of leachate, groundwater and possible leaching tests from waste accepted at the landfill.</li> <li>This information may need to be supplemented by the following: <ul style="list-style-type: none"> <li>additional leachate sampling and analysis for specific List I and List II substances of interest (Annex 6);</li> <li>literature;</li> <li>similar landfills that the operator may own;</li> <li>information on landfills taking similar waste streams that are operated by a third party. This information is available from the public register.</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>Even though existing information is being used within this scenario, the applicability of the data for the future development of the landfill should be determined using the process outlined above. Potential factors that need to be taken into account are potential changes of waste type and the alteration of leachate quality with time.</li> <li>As with the above scenario, note that Landfill Classification, as a result of implementing the LFD, could alter the nature of leachate produced within landfills. Existing leachate information and literature may therefore not be appropriate. The potential impacts of classification are addressed within Environment Agency (in prep) <i>Improved Definition of Leachate Source Term from Landfill</i>, R&amp;D Project P2-236.</li> </ul>

5 Potential sources of information include:

- Department of the Environment, 1995. *A Review of the Composition of Leachate from Domestic Wastes in Landfill Sites*, CWM/072/95.
- Knox K et al, 2000. *The occurrence of trace organic components in landfill leachates and their removal during on-site treatment*. In Proceedings of the Waste 2000 Conference. 2-4th October 2000, pp263-272.
- Environment Agency (in prep). *Improved Definition of Leachate Source Term from Landfill*, R&D Project P2-236.

6 United States E.P.A. 1992. Guidance for Data Useability in Risk Assessment (Part A) Final Publication 9285.7-09A. Office of Emergency and Remedial Response.

7 The most appropriate of the three CEN Batch tests prEN 12457-1 (one-stage batch test performed at L/S = 2l/kg); prEN 12457-2 (one-stage batch test performed at L/S = 10l/kg); or prEN 12457-3 (two-stage batch test performed at L/S = 0-2l/kg and 2-10l/kg) should be used.



## Appendix 4:

# Geological and hydrogeological information requirements

This Appendix considers the iterative development of the site's conceptual model.

The list below is presented for information only and should not be viewed as exhaustive. Nevertheless, the information requirements should include the following:

### 1. Geology

It will be necessary to identify the detailed geological sequence and relationships to an appropriate depth, both at the site under investigation and within the surrounding area that may potentially be affected by the site.

- (a) **solid geology** – this should include assessment of the rock type(s), thickness(es) and depth(s) and the angle, direction of dip and magnitude of discontinuities such as bedding planes, joints, cleavage, faults and other fracturing, where they may affect fluid migration.
- (b) **drift geology** – this should include the nature and depth of the deposit(s) (including degree of homogeneity), the lateral extent and the relationship with adjoining deposits.
- (c) **mineral workings and made ground** – this should include mining, quarrying and other extraction (including solution mining). Where appropriate, the detail should include the location and depth of shafts, the depth of excavation, the subsidence/stability history of the site, the location of made ground and the location of old settlement lagoons.

### 2. Hydrogeology

The hydrogeological characteristics and hydraulic properties of the soils and rocks should be identified together with the hydraulic relationships between different strata. This should lead to confirming the location of the site with regard to the sensitive areas outlined in the Agency's guidance on the location and impact assessment of landfills (Environment Agency, 2002d).

#### (a) *Saturated zones*

The following are required:

- details of all relevant strata whether major or minor aquifers, aquitards or aquicludes;
- details of the hydraulic properties of the saturated zones, that is:
  - hydraulic conductivity/effective porosity/storage characteristics;
  - predominant type of flow (fissure, intergranular or dual);
  - fissure characteristics and orientation;
  - flow patterns (vertical and horizontal hydraulic gradients and likely flow regimes and directions);
- identification of probable discharges (natural or artificially induced) such as river base-flow, spring discharge, wetland, pumped abstraction, artesian discharge, drains/soughs/adits, mine systems;
  - phreatic and piezometric levels, including any variations (for example, seasonal);
  - influence of former, current or proposed developments (for example, local dewatering or diversion of groundwater flow due to quarrying, tunnelling, and the like, predicted rebound due to decline in local rates of abstraction, changes in rates of recharge due to changes in landform);
  - groundwater chemistry;
  - identification of local pollution caused by former

contaminative land uses (where appropriatedetails of the rate of decline of the pollution source should be included);

- basic mineralogy (for example, carbonate content, clay content, CEC and foc values and the like).

### **(b) Unsaturated zones**

This should include assessing the following:

- nature and thickness (including seasonal variability);
- hydraulic properties (porosity, hydraulic conductivity, type and rate of flow, preferential pathways such as the likely presence of sand or gravel lenses in clays and the like.);
- basic mineralogy (for example, carbonate content, clay content, CEC and foc values and the like).

Where the “purifying powers of the soils and sub-soils” (that is, attenuation properties) are being considered, these must be fully justified and based upon actual test results of the soils and sub-soils (as appropriate) collected from the site. Site-specific testing must be carried out if attenuation (such as cation exchange capacity) is relied upon within the groundwater risk assessment. Although theoretical assumptions or literature data<sup>8</sup> could prove useful for screening purposes, it is unlikely to relate to the specific site and testing should be carried out using recognised good-practice and quality-assurance procedures<sup>9</sup> for the key parameters. Appendix 9 provides further comment on considering the purifying powers of soils and sub-soils.

### **(c) Potential receptors**

It will be necessary to identify the potential receptors near the site, including:

- current licensed/exempt abstractions of water and the nature of its use (for example, domestic, agricultural, industrial or other);
- existing natural/induced discharges (for example, springs, wetlands);
- unused groundwaters below or adjacent to the site, including its potential as a resource;
- surface water likely to be affected;
- sites of ecological or nature conservation significance.

8 Environment Agency, 2001. *Determination of cation exchange capacity in selected lithologies from England, Wales and Scotland*. R&D Technical Report P435.

9 Environment Agency, 2000. *CEC and Kd Determination in Landfill Performance. Evaluation: A Review of methodologies and preparation of standard materials for laboratory analysis*. R&D Technical Report P340.



## Appendix 5:

# Potential site investigations

Conceptual site model issue	Potential site investigations	Additional comments
<b>Identifying the potential hazards</b>	Field observations of the land fill development.	<ul style="list-style-type: none"> <li>• Can provide invaluable information about potential pathways at the site (for example, observing perched leachate escaping over outer bunds, the surface run-off of recirculated leachate that has failed in infiltrate into the waste mass).</li> </ul>
	Installation and logging of leachate wells.	<ul style="list-style-type: none"> <li>• May be required to investigate leachate levels and quality within a specific area of the landfill.</li> <li>• It is important to note that:               <ul style="list-style-type: none"> <li>– an experienced geotechnical engineer or geologist should supervise the installation of the wells, log them and provide detailed descriptions of the finished structures. This is an essential element of the CQA (Construction Quality Assurance) process;</li> <li>– particular attention should be paid to the observation and recording of leachate strikes and entries, their relative rates of flow and temporary standing leachate;</li> <li>– it is critical that the drilling of leachate wells should not puncture the landfill's lining system. Extremely careful design and supervision is therefore required with appropriate action plans in place should this occur.</li> </ul> </li> </ul>
	Laboratory testing of soils and rocks.	<ul style="list-style-type: none"> <li>• This may include:               <ul style="list-style-type: none"> <li>– partition coefficients (Kd) – to determine the degree to which specific contaminants are retarded within the lining materials;<sup>10</sup></li> <li>– remoulded permeability of clays – to determine the likely performance of a clay lining material;</li> <li>– cation exchange capacity (CEC) – to characterise the ability of the potential lining materials to attenuate cationic contaminants such as ammonium;<sup>10</sup></li> <li>– Fraction of Organic Carbon (foc) – to characterise the general ability of the lining materials to retard organic contaminants.</li> </ul> </li> </ul>
	Leachate monitoring	<ul style="list-style-type: none"> <li>• The existing monitoring may need to be augmented to provide information on:               <ul style="list-style-type: none"> <li>– the movement of leachate within the landfill and its inter-relationship with the outside groundwater;</li> <li>– the potential contaminative sources that are present within the leachate.</li> </ul> </li> </ul>

Conceptual site model issue	Potential site investigations	Additional comments
<p><i>Defining the source, pathway and receptor terms and establishing the baseline conditions</i></p>	<p>Field observations of geological exposures and hydrogeological features such as springs.</p>	<ul style="list-style-type: none"> <li>• Can provide invaluable information about the geology and hydrogeology of an area.</li> </ul>
	<p>Installation and logging of geological boreholes and groundwater wells.</p>	<ul style="list-style-type: none"> <li>• To investigate geological stratigraphy and structure.</li> <li>• To determine water table and piezometric levels.</li> <li>• It is important to note that: <ul style="list-style-type: none"> <li>– an experienced geotechnical engineer or geologist should supervise the installation of the boreholes, log them and provide detailed descriptions of the finished structures. This is an essential element of the CQA process;</li> <li>– particular attention should be paid to the observation and recording of water strikes and entries, their relative rates of flow and temporary standing water levels;</li> <li>– boreholes used for groundwater monitoring should be specifically designed to provide representative samples from each of the horizons of interest without allowing cross-contamination from other water-bearing strata. Multiple piezometers in one borehole should be avoided where possible. Separate shallow and deep boreholes are preferred;</li> <li>– the drilling of boreholes should not create new pathways for ground water contamination through the interconnection of layers (strata) that would otherwise be isolated. Careful design and supervision is therefore required.</li> <li>– Where appropriate, boreholes should be cored sufficiently (though not necessarily throughout) to provide information on porosity, permeability, moisture content and the openness, frequency and orientation of fracturing. Jar, bulk undisturbed or other special samples should be provided from boreholes advanced using shell and auger techniques.</li> </ul> </li> </ul>
	<p>Non-intrusive surface geophysics.</p>	<ul style="list-style-type: none"> <li>• A range of tests is available to augment borehole information to help characterise ground conditions.</li> <li>• These investigations are likely to be undertaken by a specialist contractor and should be designed, supervised and interpreted by a suitably qualified and experienced geophysicist.</li> <li>• The surveys should be integrated with the intrusive investigation and sufficient borehole control provided to enable calibration and validation of the geophysical results.</li> </ul>
	<p>Down-hole borehole geophysics.</p>	<ul style="list-style-type: none"> <li>• Carried out before installing the well lining to obtain information about the geological and hydrogeological structure of the borehole.</li> </ul>
	<p>In-situ testing to determine bulk formation properties.</p>	<ul style="list-style-type: none"> <li>• Includes tests such as falling-head tests and pumping tests that will provide information on parameters such as permeability and specific yield.</li> </ul>

Conceptual site model issue	Potential site investigations	Additional comments
<p><i>Defining the source, pathway and receptor terms and establishing the baseline conditions (cont.)</i></p>	<p>Laboratory testing of soil and rock materials.</p>	<ul style="list-style-type: none"> <li>• Potentially to include properties such as:               <ul style="list-style-type: none"> <li>– partition coefficients (<math>K_d</math>) – to determine the degree to which specific contaminants are retarded within the tested materials;<sup>10</sup></li> <li>– particle size analysis – to characterise the materials and provide estimations of permeability for certain materials;</li> <li>– undisturbed permeability of clays;</li> <li>– cation exchange capacity (CEC) – to characterise the ability of the materials to attenuate cationic contaminants such as ammonium;<sup>10</sup></li> <li>– Fraction of Organic Carbon (foc – to characterise the general ability of the material to retard organic contaminants.</li> </ul> </li> </ul>
	<p>Detailed environmental monitoring over time.</p>	<ul style="list-style-type: none"> <li>• To include both groundwater and surface water to establish baseline conditions.</li> <li>• Information could include both water levels and flow rates as well as water quality.</li> <li>• Note that any monitoring should normally be carried out over at least 12 months to take account of seasonal variations and to establish a reasonably reliable database of baseline conditions.</li> </ul>
	<p>Tracer tests.</p>	<ul style="list-style-type: none"> <li>• To determine actual groundwater flow directions and rates.</li> <li>• It is important to note that:               <ul style="list-style-type: none"> <li>– the tracer material must be suitable for the site setting and the environmental conditions;</li> <li>– these investigations are likely to be undertaken by a specialist contractor and should be designed, supervised and interpreted by a suitably qualified and experienced hydrogeologist in co-operation with the Agency;</li> <li>– all tracer tests should only be carried out following agreement with the Agency.<sup>11</sup></li> </ul> </li> </ul>

<sup>10</sup> Environment Agency, 2000., *CEC and Kd Determination in Landfill Performance. Evaluation: A Review of methodologies and preparation of standard materials for laboratory analysis.* R&D Technical Report P340, prepared by British Geological Survey.

<sup>11</sup> Environment Agency, 1998. *Groundwater Tracer Tests: A Review and Guidelines for their use in British Aquifers.* R&D Technical Report P139.

## Appendix 6:

# Analytical framework for screening landfill leachates

The basic monitoring regime for all leachate at landfills should comply with the Agency's current guidance.<sup>12</sup> Sampling procedures, including the types of sample bottle, the use of reagents and the storage of samples, should be in accordance with this guidance and the advice of the laboratories undertaking the analysis.

The determinands within a monitoring programme should be sufficient to establish a site's potential to discharge List II substances. For sites that take wastes containing List I substances, or which have the potential to generate List I substances in their leachate, appropriate additional determinands will be required.

Where the waste types allowed by the permit are specific enough to provide an accurate prediction of all List I substances that could be discharged from the site, then those substances should be added to the list of determinands for leachate. For many wastes, however, it will not be feasible to specify such a list.

If there is any doubt about the possible range of List I substances that might be discharged from a site, then the analytical framework for screening **landfill leachates only** proposed in Tables 6.1 to 6.7 of this Appendix should be adopted. No single analytical technique can identify the entire range of List I substances. To provide an adequate definition, a combination of six different analytical methods is required:

- GCMS scan for volatiles;
- GCMS scan for semi-volatiles;
- derivitised GCMS scan for semi-volatiles;
- extraction of organotin compounds;

- reduction of mercury compounds;
- solution of cadmium compounds.

Tables 6.1 to 6.7 set out the basis for the different methods. Each table contains sufficient information to specify to the analytical laboratories the types of test and the limits of performance that are required. Laboratories may elect to use alternative techniques. However, if they do so, they must specify the methods used and demonstrate to the Agency's satisfaction that these will provide results comparable with those specified in the framework, particularly with regard to the lower reporting levels and core determinands. Where there is any doubt about the equivalence of tests, the operator should seek advice from the Agency's National Laboratory Service.

The report of the analyses submitted to the Agency should include the name of the laboratory, details of the analytical methods used and details of all substances detected that have the potential to be List I. For the GCMS results, the report should detail **all** peaks identified with a confidence level greater than 80 per cent. This will provide a list of compounds that the site has the potential to discharge. Only a very broad indication of compound concentrations is possible by referencing compound responses to those of added internal standards.

All results should be available for audit for at least four years from the date of the analysis or other such period specified in the PPC permit.

The requirement to screen the leachate for List I substances should be included in the PPC permit. The number of samples collected should be sufficient to provide an adequate characterisation of the site's leachate. In most cases, annual monitoring should be adequate unless there are site-specific circumstances that require a higher frequency. For further details,

<sup>12</sup> Environment Agency, 2002b, *The Monitoring of Landfill Leachate, Groundwater and Surface Water*

refer to the Agency's guidance on the monitoring of landfill sites.<sup>12</sup> If the analytical framework set out in tables 6.1 to 6.7 is adopted, the cost of the analysis is likely to be about £350 per sample (at 2001 prices).

**Table A6.1** | Volatiles

<b>Basis of test</b>	Purge and Trap or Headspace GCMS, full scan EI mode (for example, EPA 8260)
<b>Mass scan range</b>	35 to 300
<b>Lower reporting level for core determinands</b>	<10 µg/l
<b>Core determinands (C.D.)</b>	chlorobenzene, trichloroethene, tetrachloroethene, 1,2 dichlorobenzene
<b>Precision % (on C.D.)</b>	25 @ 100 µg/l
<b>Bias % (on C.D.)</b>	20
<b>Spiking recovery % (on C.D.)</b>	>50
<b>Internal standards (I.S.)</b>	For example, pentafluorobenzene, difluorobenzene, chlorobenzene-d5, 1,4-dichlorobenzene-d4 (required to overlap with semi-volatile analysis). Surrogates such as BCTFE fluorobenzene, p-bromofluorobenzene (BFB), dibromofluorometane, toluene-d8. Use a minimum of 3 surrogates.
<b>Calibration</b>	Normal MS tune/sensitivity checks. Calibrate using C.D./I.S.
<b>Minimum QC requirements</b>	1 AQC sample (C.D. @ ~ 100 µg/l plus I.S.) with every 10 samples, taken throughout the entire procedure
<b>Reporting</b>	Report all peaks with a library match confidence of >80%
<b>Libraries</b>	NIST, Wiley

The method performance is to be established using normal procedures where applicable (for example, WRc NS 30) and the raw test data should be available for inspection. Routine controls should be maintained, using the core determinands QC data, to demonstrate continued achievement.

External proficiency testing is to be utilised (for example, Aquacheck, CONTEST) where available and appropriate.

Table A6.2 | Semi-volatiles

<b>Basis of test</b>	Liquid/liquid extraction (for example, DCM, iso-hexane, hexane) at pH ~7 and pH>11, followed by GCMS full scan E1 mode
<b>Mass scan range</b>	35 to 650
<b>Lower reporting level for core determinands</b>	<10 µg/l
<b>Core determinands (C.D.)</b>	Aldrin, pentachlorobenzene, malathion, trifluralin, atrazine
<b>Precision % (on C.D.)</b>	25 @ 100 µg/l
<b>Bias % (on C.D.)</b>	20
<b>Spiking recovery % (on C.D.)</b>	>50
<b>Internal standards (I.S.)</b>	For example, 1,4-dichlorobenzene-d4 (required to overlap with semi-volatile analysis), naphthalene-d8, phenanthrene-d10, perylene-d12. Surrogates such as decafluorobiphenyl, 4-fluoroaniline, 2-fluoronaphthalene. Use a minimum of 3 surrogates
<b>Calibration</b>	Normal MS tune/sensitivity checks. Calibrate using C.D./I.S.
<b>Minimum QC requirements</b>	1 AQC sample (C.D. @ ~ 100 µg/l plus I.S.) with every 10 samples, taken throughout the entire procedure
<b>Reporting</b>	Report all peaks with a library match confidence of >80%
<b>Libraries</b>	NIST, Wiley

The method performance is to be established using normal procedures where applicable (for example, WRc NS 30) and the raw test data should be available for inspection. Routine controls should be maintained, using the core determinands QC data, to demonstrate continued achievement.

External proficiency testing is to be utilised (for example, Aquacheck, CONTEST) where available and appropriate.

**Table A6.3** | Semi-volatiles derivatised

<b>Basis of test</b>	Liquid/liquid extraction (for example, DCM, iso-hexane, hexane) at pH<2, then esterification (for example, diazomethane#, TMAH) followed by GCMS full scan EI mode
<b>Mass scan range</b>	35 to 650
<b>Lower reporting level for core determinands</b>	<10 µg/l
<b>Core determinands (C.D.)</b>	2-chlorophenol, dichlorprop, PCP, bromoxynil, 2,4,6-trichlorophenol, ioxynil
<b>Precision % (on C.D.)</b>	25 @ 100 µg/l
<b>Bias % (on C.D.)</b>	20
<b>Spiking recovery % (on C.D.)</b>	<50
<b>Internal standards (I.S.)</b>	1,4-dichlorobenzene-d4, naphthalene-d8, phenanthrene-d10, chrysene-d12, perylene-d12. Surrogates e.g. 2,3,5,6- tetrafluorobenzoic acid, 1,2,3-trichloropropane, 4,4-dibromooctafluorobiphenyl, 2,4,5,6-tetrachloro-m-xylene. Use a minimum of 2surrogates
<b>Calibration</b>	Normal MS tune/sensitivity checks. Calibrate using C.D./I.S.
<b>Minimum QC requirements</b>	1 AQC sample (C.D. @ ~ 100 µg/l plus I.S.) with every 10 samples, taken throughout the entire procedure
<b>Reporting</b>	Report all peaks with a library match confidence of >80%
<b>Libraries</b>	NIST, Wiley

The method performance is to be established using normal procedures where applicable (for example, WRc NS 30) and the raw test data should be available for inspection. Routine controls should be maintained, using the core determinands QC data, to demonstrate continued achievement.

External proficiency testing is to be utilised (for example, Aquacheck, CONTEST) where available and appropriate.

# Laboratories using **diazomethane** should be aware of the extreme health and safety hazards associated with this reagent, and have effective risk-management measures in place. Tetramethyl anilinium hydroxide (TMAH) has proved to be an effective alternative methylating agent with less significant health and safety hazards, which are more easily controlled.

Table A6.4 | Organotin compounds

<b>Basis of test</b>	Liquid/liquid extraction (for example, toluene, hexane/tropolone and the like) followed by EAAS (for example, SCA 1992 method, ISBN 9 780117 523609) or GC-MS/FPD/AED
<b>Lower reporting level for core determinands</b>	<1 µg/l
<b>Core determinands (C.D.)</b>	bis(tributyltin) oxide or tributyltin chloride, triphenyltin chloride
<b>Precision % (on C.D.)</b>	10 @ 10 µg/l or 25 @ 0.1 mg/l
<b>Bias % (on C.D.)</b>	10
<b>Spiking recovery % (on C.D.)</b>	>85
<b>Calibration</b>	Normal instrument tune/sensitivity checks. Calibrate using C.D. standard with I.S. standard when undertaking GC procedures
<b>Minimum QC requirements</b>	1 AQC sample (C.D. @ ~ 10 µg/l, or lower for GC procedure, for example, 0.1µg/l) with every 10 samples, taken throughout the entire procedure
<b>Reporting</b>	Report as total organotin (EAAS) or as individual compounds for GC procedure

The method performance is to be established using normal procedures where applicable (for example, WRc NS 30) and the raw test data should be available for inspection. Routine controls should be maintained, using the core determinands QC data, to demonstrate continued achievement. External proficiency testing is to be utilised (for example, Aquacheck, CONTEST) where available and appropriate.

Table A6.5 | Mercury

<b>Basis of test</b>	Mercury compounds reduced to elemental mercury (for example, using stannous chloride) then measured by AFS or Cold Vapour AAS
<b>Lower reporting level for core determinands</b>	<1 µg/l
<b>Core determinands (C.D.)</b>	Mercury (II) nitrate
<b>Precision % (on C.D.)</b>	10 @ 10 µg/l
<b>Bias % (on C.D.)</b>	10
<b>Spiking recovery % (on C.D.)</b>	>75
<b>Calibration</b>	Normal instrument tune/sensitivity checks. Calibrate using C.D.
<b>Minimum QC requirements</b>	1 AQC sample (C.D. @ ~ 10 µg/l) with every 10 samples, plus spiking recovery for each sample
<b>Reporting</b>	Report as total organotin (EAAS) or as individual compounds for GC procedure

The method performance is to be established using normal procedures where applicable (for example, WRc NS 30) and the raw test data should be available for inspection. Routine controls should be maintained, using the core determinands QC data, to demonstrate continued achievement.

External proficiency testing is to be utilised (for example, Aquacheck, CONTEST) where available and appropriate.

Table A6.6 | Cadmium

<b>Basis of test</b>	Cadmium compounds are brought into solution by acid digestion (for example, HNO <sub>3</sub> ) then measured by ICP or EAAS
<b>Lower reporting level for core determinands</b>	<1 µg/l
<b>Core determinands (C.D.)</b>	Cadmium chloride
<b>Precision % (on C.D.)</b>	10 @ 10 µg/l
<b>Bias % (on C.D.)</b>	10
<b>Spiking recovery % (on C.D.)</b>	>75
<b>Calibration</b>	Normal instrument tune/sensitivity checks. Calibrate using C.D.
<b>Minimum QC requirements</b>	1 AQC sample (C.D. @ ~ 10 µg/l) with every 10 samples, plus spiking recovery for each sample matrix
<b>Reporting</b>	Report as total organotin (EAAS) or as individual compounds for GC procedure

The method performance is to be established using normal procedures (for example, WRc NS 30) and the raw test data should be available for inspection. Routine controls should be maintained, using the core determinands QC data, to demonstrate continued achievement.

External proficiency testing is to be utilised (for example, Aquacheck, CONTEST) where available and appropriate.

## Appendix 7:

# Assessing discharges of List I substances to groundwater: Minimum Reporting Values for selected substances in clean water

The table below presents typical Minimum Reporting Values (MRVs) for selected List I substances in clean groundwater (as required by Environment Agency National Laboratory Service). These values will probably be used in assessing whether a predicted discharge of the List I substance to groundwater is discernible, and consequently whether the discharge complies with the Groundwater Directive.

In practice, it is likely that the *predicted* concentration of List I substances immediately before they enter the water table will be compared with the relevant values presented below to assess whether the discharge would be below a discernible concentration.

Substance	MRV ( $\mu\text{g/l}$ )	Comment
1,1,1-trichloroethane	0.1	
1,1,2-trichloroethane	0.1	
1,2-dichloroethane	1	
2,4 D ester	0.1	methyl, ethyl, isopropyl, isobutyl and butyl each to 0.1
2,4-dichlorophenol	0.1	
2-chlorophenol	0.1	
4-chloro-3-methylphenol	0.1	
aldrin	0.003	
atrazine	0.03	
azinphos-ethyl	0.02	
azinphos-methyl	0.001	
benzene	1	
cadmium	0.1	
carbon tetrachloride	0.1	
chlorfenvinphos	0.001	

Substance	MRV ( $\mu\text{g/l}$ )	Comment
chloroform	0.1	
chloronitrotoluenes	1	2,6-CNT; 4,2-CNT; 4,3-CNT; 2,4-CNT; 2,5-CNT each to $1\mu\text{g/l}$
PCB (individual congeners)	0.001	
demeton	0.05	demeton-s-methyl only
diazinon	0.001	
dieldrin	0.003	
dimethoate	0.01	
endosulfan	0.005	endosulphan a and endosulphan b, each to $0.005\mu\text{g/l}$
endrin	0.003	
fenitrothion	0.001	
fenthion	0.01	
hexachlorobenzene	0.001	
hexachlorobutadiene	0.005	
hexachlorocyclohexanes	0.001	$\alpha$ -HCH, $\gamma$ -HCH and $\delta$ -HCH each to $0.001\text{mg/l}$ $\beta$ -HCH to $0.005\mu\text{g/l}$
isodrin	0.003	
malathion	0.001	
mecoprop	0.04	
mercury	0.01	
mevinphos	0.005	
op DDT	0.002	o = ortho; p = para
pp DDT	0.002	
op DDE	0.002	
pp DDE	0.002	
op TDE	0.002	
pp TDE	0.002	
parathion	0.01	
parathion methyl	0.015	
pentachlorophenol	0.1	
permethrin	0.001	cis and trans-permethrin both to $0.001\mu\text{g/l}$
simazine	0.03	
tetrachloroethylene	0.1	
toluene	4	
tributyltin compounds	0.001	
trichlorobenzene	0.01	135 tcb; 124 tcb; 123 tcb each to 0.01
trichloroethylene	0.1	
trifluralin	0.01	
triphenyltin compounds	0.001	
xylenes	3	o-xylene and m/p-xylene each to $3\mu\text{g/l}$ May not be possible to separate m- and p-xylene

## Appendix 8:

# Selected water quality standards

The following selected water-quality standards are to be used in assessing the presence of pollution in controlled waters. It is important to note that the tables are for general guidance only and care should be exercised when applying these for specific purposes. This information is necessarily summarised. It may be necessary to refer back to the original source of the data for qualifying/clarifying information.

Water-quality standards should be used only where they are relevant to the site being assessed.

### *Key to standards referenced*

1 Figures for Environmental Quality Standards (EQS) are Annual Average Concentrations with Maximum Allowable Concentrations in brackets.

Where a range of EQS for freshwater is given, it depends on the hardness of the water. Seek further advice from the Agency.

2 World Health Organisation (WHO) *Guidelines for Drinking Water Quality*, 1984.

The health value is a guideline value representing the concentration of a constituent that does not result in any significant risk to the consumer over a lifetime of exposure.

The ATO is the concentration of the substance, at or below the health-based guideline value, which may affect the appearance, taste or odour of the water. The concentrations given are those likely to give rise to consumer complaints.

3 Council Directive 98/83/EC on the quality of water intended for human consumption.

4 UK Drinking Water Standards taken from:

- Water Supply (Water Quality) Regulations 1989 (SI 1989/1147) (as amended);
- Water Supply (Water Quality) Regulations 2000 (SI 2000/3184) (as amended).

Contaminant	units	EQS freshwater (1)	EQS saltwater (1)	WHO Health (2)	WHO ATO (2)	EU Drinking Water Standards (3)	UK Drinking Water Standards (4)
Acrylamide	ug/l			0.5		0.1	0.1
Alachlor	ug/l			20		0.1	0.1
Aldicarb	ug/l			10		0.1	0.1
Aldrin	ug/l	0.01	0.01	0.03		0.03	0.03
Aluminium	ug/l				200	200	200
Ammonia (NH <sub>3</sub> as N)	mg/l	0.015	0.021		1.5		
Ammonium (as NH <sub>4</sub> <sup>+</sup> )	mg/l					0.5	0.5
Antimony	ug/l			5		5	5
Arsenic	ug/l	50	25	10		10	10
Atrazine	ug/l	2	2	2		0.1	0.1
Azinphos-methyl	ng/l	10 (40)	10 (40)			100	100
Barium	mg/l			0.7			1
Bentazone	mg/l	0.5	0.5	0.03		0.1	0.1
Benzene	ug/l	30 (300)	30 (300)	10		1	1
Benzo [a] pyrene	ug/l			0.7		0.01	0.01
Biphenyl	ug/l	25	25				
Boron	mg/l	2	7	0.3		1	1
Bromate	ug/l					10	10
Bromoxynil	ug/l	100 (1000)	100 (1000)			0.1	0.1
Cadmium	ug/l	5	2.5	3		5	5
Calcium	mg/l						250
Carbofuran	ug/l			5		0.1	0.1
Chlordane (all isomers)	ug/l			0.2		0.1	0.1
Chlorfenvinphos	ug/l	0.01 (0.1)	0.01 (0.1)			0.1	0.1
Chloride	mg/l	250			250	250	250
Chlorine	ug/l	2	10				
Chloroform	ug/l	12	12	200			
Chloroform extractable substances	ug/l						1000
Chlorophenylid	ug/l	0.05	0.05			0.1	0.1
Chloronitrotoluenes	ug/l	10	10				
Chlorothalonil	ug/l	0.1	0.1			0.1	0.1
Chlorpropham	ug/l	10	10			0.1	0.1
Chlorotoluron	ug/l	2	2	30		0.1	0.1
Chromium	ug/l	5 - 250	15	50		50	50
Copper	ug/l	1 - 28	5	2000	1000	2000	2000
Coumaphos	ug/l	0.01 (0.1)	0.04 (0.4)			0.1	0.1
Cyanide	ug/l			70		50	50
Cyfluthrin	ug/l	0.001	0.001			0.1	0.1

Contaminant	units	EQS freshwater (1)	EQS saltwater (1)	WHO Health (2)	WHO ATO (2)	EU Drinking Water Standards (3)	UK Drinking Water Standards (4)
2,4-dichlorophenoxyacetic acid (2,4-D), (ester form)	ug/l	1	1	30		0.1	0.1
Demetons	ug/l	0.5	0.5			0.1	0.1
Diazinon	ug/l	0.01 (0.1)	0.015 (0.15)			0.1	0.1
Dichlorodiphenyltrichloroethane (all isomers)	ug/l	0.025	0.025				
Para, para-DDT	ug/l	0.01	0.01	2		0.1	0.1
1,2-Dichloroethane (1,2-DCA)	ug/l	10	10	30		3	3
1,1-Dichloroethene (1,1-DCE)	ug/l			30			
1,2-Dichloroethene (1,2-DCE)	ug/l			50			
1,2-dibromo-3-chloropropane	ug/l			1		0.1	0.1
1,2-Dichlorobenzene	ug/l			1000	1 to 10		
1,2-Dichloropropane	ug/l			20		0.1	0.1
1,3-Dichloropropene	ug/l			20		0.1	0.1
1,4-Dichlorobenzene	ug/l			300	0.3 to 30		
Di(2-ethylhexyl)adipate	ug/l			80			
Di(2-ethylhexyl)phthalate	ug/l			8			
Dichloromethane	ug/l			20			
Dichlorprop (DCPP)	ug/l			100		0.1	0.1
Dichlorvos	ng/l	1	40			100	100
Dieldrin	ug/l	0.01	0.01	0.03		0.03	0.03
Dimethoate	ug/l	1	1			0.1	0.1
Drins (total)	ug/l	0.03	0.03			0.1	0.1
Edetic Acid (EDTA)	ug/l			200			
Endosulfan	ng/l	3	3			100	100
Endrin	ug/l	0.005	0.005			0.1	0.1
Epichlorohydrin	ug/l			0.4		0.1	0.1
Ethylbenzene	ug/l			300	2 to 200		
Fenchlorphos	ug/l	0.01 (0.1)	0.01 (0.1)			0.1	0.1
Fenoprop	ug/l			9		0.1	0.1
Fenitrothion	ng/l	10 (250)	10 (250)			100	100
Fluocofuron	ug/l	1				0.1	0.1
Fluoride	ug/l			1500		1500	1500
Formaldehyde	ug/l	5 (50)	n/a	900		0.1	0.1
Heptachlor	ug/l			0.03		0.03	0.03
Hexachlorobenzene	ug/l	0.03	0.03	1		0.1	0.1
Hexachlorobutadiene	ug/l	0.1	0.1	0.6			
Hexachlorocyclohexane (lindane)	ug/l	0.1	0.02	2		0.1	0.1
Hydrocarbons (dissolved/emulsions)	ug/l						10
Hydrogen sulphide (H2S as S)	ug/l	0.25 to 1.0	10				

Contaminant	units	EQS freshwater (1)	EQS saltwater (1)	WHO Health (2)	WHO ATO (2)	EU Drinking Water Standards (3)	UK Drinking Water Standards (4)
loxylin	ug/l	10 (100)	10 (100)			0.1	0.1
Iron	mg/l	1	1		0.3	0.2	0.2
Isodrin	ug/l	0.005	0.005			0.1	0.1
Isoproturon	ug/l	2 to 20		9		0.1	0.1
Lead (inorganic - dissolved)	ug/l	4 - 250	25	10		10	25 (reducing to 10)
Linuron	ug/l	2	2			0.1	0.1
Magnesium	mg/l						50
Malachite green	ug/l	0.5 (100)					
Malathion	ng/l	10 (500)	20 (500)			100	100
Manganese	ug/l			500	100	50	50
MCPA	ug/l	2	2	2		0.1	0.1
Mecoprop (MCP)	ug/l	20 (200)	20 (200)	10		0.1	0.1
Mercury	ug/l	1	0.3	1		1	1
Methylbenzene	ug/l	50 (500)	40				
Methoxychlor	ug/l			20		0.1	0.1
Metolachlor	ug/l			10		0.1	0.1
Molinate	ug/l			6		0.1	0.1
Molybdenum	ug/l			70			
Monochlorobenzene	ug/l			300	10 to 120		
Naphthalene	ug/l	10 (100)	5 (80)				
Nickel	ug/l	50 - 200	30	20		20	20
Nitrate (as NO <sub>3</sub> )	mg/l			50		50	50
Nitrite (as NO <sub>2</sub> )	ug/l			3		500	100
Nitriloacetic acid	ug/l			200			
Oils/hydrocarbons (by Pet Ether extract)	ug/l						10
Omethoate	ug/l	0.01				0.1	0.1
Polycyclic Aromatic (PAH) Hydrocarbons	ug/l					0.1	0.1
Pendimethalin	ug/l			20		0.1	0.1
Pentachlorophenol	ug/l	2	2	9		0.1	0.1
Permethrin	ug/l	0.01		20		0.1	0.1
Pesticides (individual species, unless specified)	ug/l					0.1	0.1
Pesticides (total)	ug/l					0.5	0.5
Phenol	ug/l	30 (300)	30 (300)			0.5	0.5
Pirimicarb	ug/l	1	1			0.1	0.1
Phosphorous	ug/l					400 (5000)	2200
Potassium	mg/l					10 (12)	12

Contaminant	units	EQS freshwater (1)	EQS saltwater (1)	WHO Health (2)	WHO ATO (2)	EU Drinking Water Standards (3)	UK Drinking Water Standards (4)
Propanil	ug/l			20		0.1	0.1
Propetamphos	ug/l	0.01 (0.1)	0.01 (0.1)			0.1	0.1
Pryridate	ug/l			100		0.1	0.1
Selenium	ug/l			10		10	10
Silver	ug/l	0.05 (0.1)	0.5 (1)				10
Simazine	ug/l	2 (10)	2 (10)	2		0.1	0.1
Sodium	mg/l	170			200	200	200
Styrene	ug/l	50 (500)	50 (500)	20	4 to 2600		
Sulcofurone	ug/l	25	25			0.1	0.1
Sulphate	mg/l	400	250		250	250	250
Sulphide	ug/l	0.25	n/a				
Surfactants	ug/l						200
2,4,5-trichlorophenoxyacetic acid (2,4,5-T)	ug/l			9		0.1	0.1
Tecnazene	ug/l	1 (10)	1				
Tetrachloroethene (PCE)	ug/l	10	10	40		10 (with TCE)	10 (with TCE)
Tetrachloromethane (PCM, carbon tetrachloride)	ug/l	12	12	2			3
Thiabendazole	ug/l	5	5			0.1	0.1
Tin (inorganic)	ug/l	25	10				
Toluene	ug/l	50 (500)	40 (400)	700	24 to 170		
Triazophos	ng/l	5 (50)	5 (50)			100	100
Tributyltin (oxide)	ug/l	0.02	0.02	0.02			
1,1,1-Trichloroethane (1,1,1-TCA)	ug/l	100 (1000)	100 (1000)				
1,1,2-Trichloroethane (1,1,2-TCA)	ug/l	400 (4000)	300 (3000)				
Trichloroethene (TCE)	ug/l	10	10	70		10 (with PCE)	10 (with PCE)
Trichlorobenzenes (total)	ug/l	0.4	0.4	20	5 to 50		
2,4,6-Trichlorophenol	ug/l			200		2-300	
Trihalomethanes (total)	ug/l					150 reducing to 100 by 2008	100
Trifluralin	ug/l	0.1 (1)	0.1 (1)	20		0.1	0.1
Triphenyltin	ug/l	0.02	0.008				
Vanadium	ug/l	20 - 60	100				
Vinyl chloride (chloroethene)	ug/l			5		0.5	0.5
Xylene	ug/l	30	30	500	20 to 1800		
Zinc	ug/l	8 - 500			3000		5000

Note: A range of values may be given for the Environmental Quality Standard (EQS) for an individual substance in the table above.

Typically, a range for metals (for example, vanadium: 20 – 60 µg/l) relates to an acceptable concentration in waters of different hardness. Where the hardness of the receiving waters is not known, it will be appropriate to use the lowest (most stringent value).

Some organic contaminants are given two values (for example, toluene: 50 (500) µg/l). These values normally relate to an acceptable annual average concentration, followed in brackets by a maximum admissible peak concentration. It is appropriate to consider the annual average (that is, the first and lower value) in assessing the pollution potential over a period of time.

## Appendix 9:

# The purifying powers of soils and sub-soils

The term “purifying powers of the soils and sub-soils”, although used in the Groundwater Directive, is not defined there.

Several documented processes can take place in the soil and the unsaturated zone that may, to some extent, attenuate the passage of contaminants present in leachate through to the saturated zone. These processes may be used to explain observed phenomena such as lower-than-predicted concentrations of specified determinands in groundwater affected by landfill sites.

However, such processes often depend on a complex balance of a whole range of variables. These include the mineralogical composition of the soil, a range of chemical properties associated with the ions contained in the leachate (ionic radius, electronegativity and charge and the like) and the pH and redox potential of both the soil and any fluids percolating through it.

Conditions will alter with both time and distance from the landfill and the extent to which attenuation occurs is often sensitive to minor changes in any one of the variables. In some circumstances, the processes may even be reversible. It is therefore difficult to predict with any confidence the extent to which attenuation will occur and any estimate of attenuation capacity used in a risk assessment should be treated with caution. **However, this should not rule out the proper consideration of attenuation processes in soils and sub-soils, but the above difficulties should be recognised and reliance on such mechanisms should be tempered accordingly.**

A simple, steady-state estimate of the purifying powers of soils can be obtained by using LandSim2 in the “retarded” mode. The calculation is based on the partition coefficients ( $K_d$ ) of the contaminants in the strata underlying the site with respect to specific substances. The model can be run using literature-based values. However, although these values are acceptable for screening purposes, they should not be used (for the key variables) for either simple or complex risk assessments.

For a groundwater risk assessment, the CEC and  $K_d$  values used should be derived from laboratory testing of samples obtained from the site being modelled. The species that are the subjects of the tests (for example,  $\text{NH}_4^+$ ,  $\text{Cd}^{2+}$  and the like), the test methods and manner in which the values are used, should be agreed in advance with the Agency. Further technical guidance on this matter has been prepared.<sup>13</sup>

<sup>13</sup> Including:

- Environment Agency, 2000. *CEC and  $K_d$  Determination in Landfill Performance. Evaluation: A Review of methodologies and preparation of standard materials for laboratory analysis.* R&D Technical Report P340; and
- Environment Agency, 2001., *Guidance on the Assessment and Monitoring of Natural Attenuation of Contaminants in Groundwater.* R&D Publication 95.



## Appendix 10:

# Groundwater risk-assessment checklist

Site: \_\_\_\_\_

Sheet 1 of 4

This checklist is intended only as an aid to appraisal of a groundwater risk assessment internally within the EA and the formulation of an Agency response. Its purpose is to help us focus on the key issues. Other factors may be relevant to a particular site or study to which reference is not made in this table and reference should be made to all relevant sections of this guidance. Part B of the PPC application form for the landfill sector contains additional requirements, which should also be considered.

Does the report adequately address the following aspects? Please tick columns (Yes/No/See note)			Y	N	S
<b>Installation details</b>	Location	Grid references. Site plans and the like.			
	Operation	General aspects of phasing and operational control concepts.			
	Historical	Relevant historical influences and waste-disposal activities.			
	Input	Landfill classification/Nature of wastes as relevant to characterisation of source term.			
<b>Conceptual model</b>	Source- term characteristics	Leachate heads. Chemical characteristics. Likely List I and II presence and short- and long-term changes in quality with time. Screening for the actual or potential presence of Listed substances.			
		Water balance considerations.			
		Consideration of whether the Groundwater Regulations 1998 apply.			
		Consideration of whether arrangements need to be made to collect contaminated water and leachate.			
	Wider geological and geographical setting	General site context with regard to geology, hydrology, climate, topography.			
Hydrogeological mechanisms and controls	Conceptual understanding of groundwater flow regime at local and regional scale. Status of aquifers, location of Source Protection Zones, vulnerability.				

Does the report adequately address the following aspects? Please tick columns (Yes/No/See note)			Y	N	S
<b>Conceptual model (cont.)</b>	Long-term change	Potential or known long-term influences on hydraulic balance arising from future minewater rebound or changes in abstraction regime.			
	Likely pathways	Presence of geological barrier. Stratigraphic, structural and topographic controls, influence of preferential flow via fissures, drainage systems, man-made structures, old mines, boreholes and the like. Geochemical controls on contaminant migration.			
	Receptors	Groundwater below or adjacent to site. Existing and potential users of groundwater, river base-flows, springs within plausible range of impact. Relevant EALs.			
<b>Prior investigation</b>	Soil/rock characterisation	Lithology and its vertical and lateral variability. Relevant hydrogeological parameters (for example, permeability, porosity) and consideration of lab/field scales. Fracture significance.			
	Groundwater direction and flux	Groundwater levels, hydraulic gradients in all relevant deep, shallow or perched groundwaters and estimates of flow taking account of structural, stratigraphic or abstraction influences.			
	Purifying powers of subsoil	Attenuation characteristics of site liners and underlying saturated and unsaturated geology, supported as relevant by experimental data.			
	Baseline quality and suitability for use	Historical and baseline groundwater analyses to establish natural quality and current pollution impacts. Assessment in context of suitability for use and potential for impact on other aquatic environments.			
<b>Technical precautions</b>	Engineering and operational controls	Design meets requirements of the LFD and GWD, geological barrier, artificial sealing lining design rationale, drainage systems, leachate management systems and head control. Groundwater management systems and the control of external groundwater pressures (if appropriate). CQA, leak detection systems (if appropriate).  Consideration of maximum acceptable leachate head and contaminant concentrations in leachate.			
	Post-closure controls	Design meets requirements of the LFD and GWD, capping proposals and long-term leachate management. Estimation of hydrogeological completion criteria and potential timing.			
	Short- and longterm failure scenarios	Potential for future degradation or failure of pumped systems, drains, linings to occur. Likelihood of mining-related subsidence, differential settlement, structural failure.			
<b>Risk assessment</b>	Nature of risk assessment	Full justification for the risk assessment methodology used (risk screen, simple or complex).			
	Likely/plausible worst-case impacts	Quantified likely or plausible worst-case impacts on all existing and potential receptors, including groundwater under or adjacent to the site, as measured against agreed environmental standards or quality criteria.			
	Future risks	Quantified impact of long-term failure scenarios (for example, engineering and management systems) and/or groundwater rise or other future environmental changes.			
	Safety factors, uncertainties and sensitivity analysis	Consideration of the limitations of the risk assessment, including uncertainties and assumptions, the need for safety factors and sensitivity analysis.			

Does the report adequately address the following aspects? Please tick columns (Yes/No/See note)			Y	N	S
<b>Use of numerical models</b>	Rationale	Adequate prior discussion/agreement with EA (internal consultation with Agency specialists).			
		Justification for using particular computer models.			
		Model selection and suitability to represent conceptual model including hydrogeological conditions (for example, below WT) and engineering design.			
		Identification of receptors, compliance criteria and calibration.			
	Application	Realistic use of conservative parameters and plausible worst case, adequate calibration.			
		Schematic diagrams showing relationship of conceptual model to computer model inputs.			
		Use of multiple model runs to simulate different phases (time) and justified range of input parameter values.			
		Justification for field measurement and model defaults.			
	Output	Numbers consistent with conceptual model, for example: <ul style="list-style-type: none"> <li>modelled head above liner v field constraints;</li> <li>hydraulic gradients compatible with permeability.</li> </ul> Reporting of maximum acceptable leachate head and contaminant concentrations.			
	Supply of models to Agency	All models that are relied upon should be supplied to the Agency in an electronic format. Where third-party models or codes are developed or used, adequate verification that they are accurate and robust will be expected. All relevant equations and supporting documentation should be supplied.			
<b>Requisite surveillance (see Environment Agency, 2002b)</b>	Risk-based monitoring scheme	<ul style="list-style-type: none"> <li>Minimum requirements of the LFD need to be considered.</li> <li>Location for compliance monitoring.</li> <li>Critical appraisal of the adequacy of any existing monitoring.</li> <li>Risk-based leachate, groundwater and surface water monitoring scheme needs to be developed, recommended and implemented.</li> </ul>			
	Groundwater control and trigger levels	Groundwater control and trigger levels have been determined for appropriate contaminants at appropriate locations. Consideration of methods used and associated uncertainties.			
<b>Acceptability of discharge to the environment</b>	Applicable quality criteria	Assessment of applicable criteria (that is, the use of the most stringent EAL for List II substances and lower reporting limits for List I substances in groundwater) as a basis for determining acceptability of risk-assessment output.			
	Direct discharges	Particular attention paid to risk assessments where potential exists for direct discharge (for example, groundwater outside liner) and supporting justification.			
<b>Surrender evaluation</b>	Time to surrender	Estimate of time until an application to surrender the PPC permit will be made.			

Site: \_\_\_\_\_

Sheet 4 of 4

**Notes**

**Dates:**

**Signed:**



## Appendix 11: Worked examples

### Example 1: Initial conceptual model

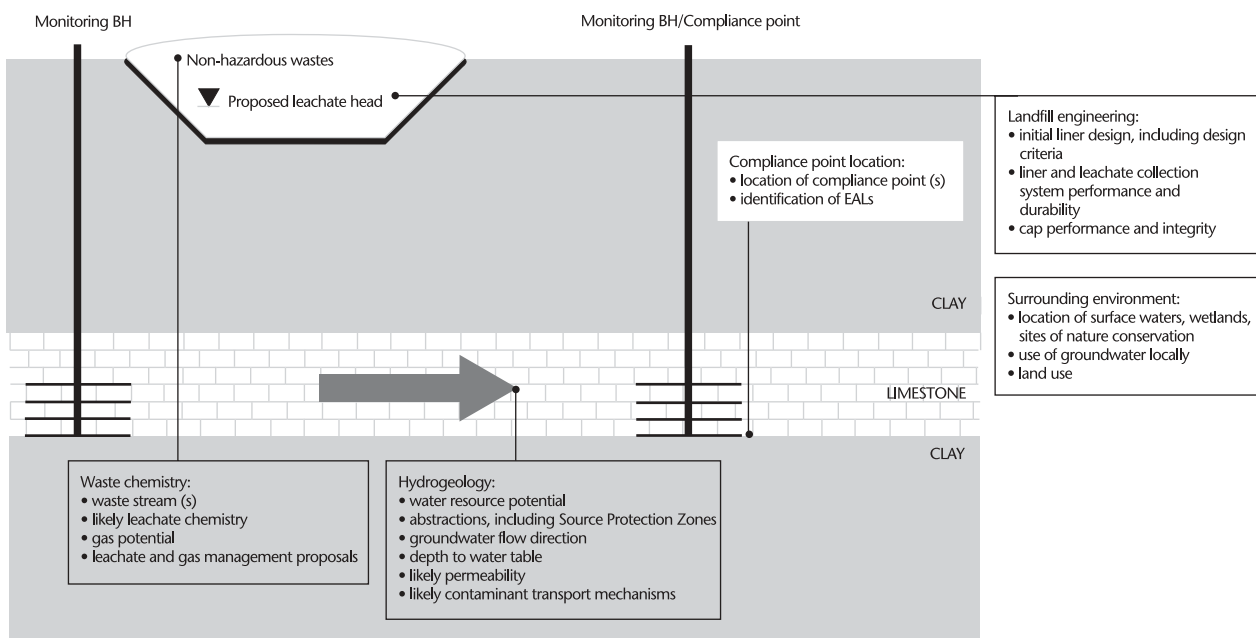
An operator proposes to develop a new non-hazardous waste landfill. On the basis of the likely waste materials to be deposited, it has been established that Site A falls within the scope of the Groundwater Directive (that is, leachate is likely to contain listed substances).

The preferred site is located on an outcrop of a thick sequence of clay strata, with subordinate inter-bedded limestone horizons. The Groundwater Vulnerability map indicates that this geological formation is classed as a non-aquifer by the Agency, and consideration of the *Policy and Practice for the Protection of Groundwater* and guidance on landfill location identifies no policy objections on the grounds of general environmental setting.

An initial conceptual model is developed by collecting existing data on relevant aspects, such as those indicated on Figure A11-1, below. Requirements for further site characterisation are then identified and designed to reduce uncertainties in the key processes for subsequent, more detailed, stages of the risk assessment.

Having established an initial conceptual model, which often describes only the aspects identified above in a qualitative manner, it is possible to progress to prioritisation of risks and to identify the likely complexity of risk assessment that may be necessary.

Figure A11-1 | Typical issues to be covered by landfill conceptual model



## Example II: Risk screening

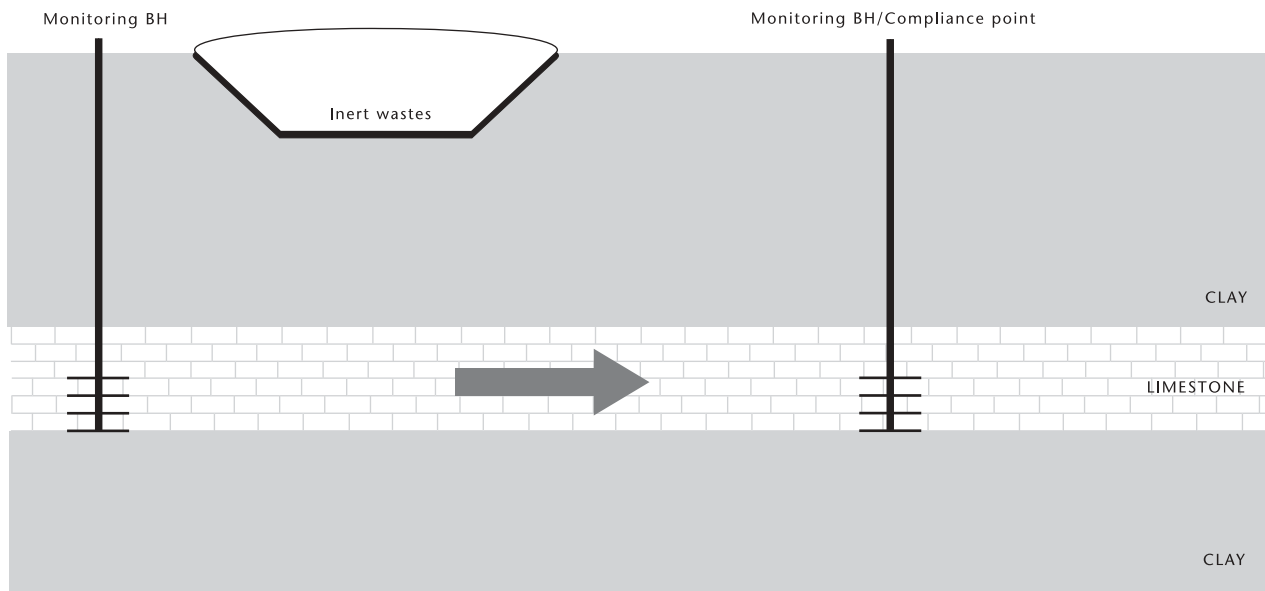
Consider a second proposed landfill, Site B, for which, following development of an initial conceptual model it is decided that risk screening is likely to be adequate to assess whether risks to the water environment are unacceptable. The site (Figure A11-2) is located on a similar non-aquifer (with little groundwater resource value) and the landfill is proposed to receive inert wastes that pose a minimal groundwater pollution hazard.

Following an initial assessment of the hazard posed by the site, it is decided that the risk of groundwater pollution is minimal and that quantitative risk assessment (such as simulation of contaminant transport processes in the subsurface) is unnecessary. It is identified that, in this instance, establishment of, and compliance with, robust waste-acceptance criteria is key to ensuring that the wastes pose no significant risk to groundwater. Further, it is established that on the basis of anticipated leachate chemistry there is no requirement (from the Landfill Regulations) to collect and manage leachate.

Note that risks to other receptors (for example, landfill stability assessment and impact on nearby structures) may be a higher priority than the risk to groundwater and consequently require more detailed assessment.

With regard to Control and Trigger levels for groundwater, it is established that compliance should be measured at monitoring boreholes in the water-bearing limestone horizon. In the first instance, background groundwater chemistry and the drinking water standards are compared to select an Environmental Assessment Limit (EAL). This is because the limestone horizon could, feasibly, be used for potable supply (to local dwellings) in closer proximity to the site than other receptors, such as surface watercourses into which groundwater ultimately discharges.

Figure A11-2 | Schematic cross-section of inert landfill considered by risk screening



<i>Determination of Environmental Assessment Limits (Section 2.5)</i>	Groundwater in underlying limestone band			
	Determinand	Maximum background conc. in limestone groundwater (mg/l)	Drinking Water Standards (mg/l)	Selected EAL (mg/l)
	ammonium (as NH <sub>4</sub> <sup>+</sup> )	<0.2	0.5	0.5
	chloride	78	250	250
	magnesium	23	50	50
<b>Note:</b> 1 EU and UK Drinking Water Standards taken to be most stringent applicable EAL 2 Determinands in groundwater chosen after review of indicator species in potential leachate.				

Having established EALs and points of compliance (in this instance, two monitoring boreholes located down-gradient of the site), it is possible to establish Control levels

<i>Setting of Control and Trigger levels (section 4)</i>	Control levels for selected pollutants (Section 6.3)		
	<b>List I substances:</b> <ul style="list-style-type: none"> <li>no Groundwater Control levels set for List I substances: no expectations of wastes containing List Is.</li> </ul> <b>List II substances and other pollutants:</b> <ul style="list-style-type: none"> <li>trend of increasing and adverse concentrations in target compounds: three consecutive samples with increasing concentrations between background concentration and Trigger levels. Test applied to:               <ul style="list-style-type: none"> <li>- ammonium</li> <li>- chloride</li> <li>- magnesium.</li> </ul> </li> </ul>	<b>An assessment for each of the monitored substances (Sections 4.2 and 4.3):</b> <ul style="list-style-type: none"> <li>Control level reviews to be conducted each time monitoring data are obtained;</li> <li>formal annual review and report.</li> </ul> <b>Appropriate response time:</b> <ul style="list-style-type: none"> <li>Control level reviews to be completed within one month of sampling event.</li> </ul> <b>Trigger levels for selected substances</b> Groundwater Trigger levels are set for two down-gradient monitoring boreholes at concentrations equal to the EAL. Background (up-gradient) water quality should be reviewed if a Trigger level is breached to ascertain that it is not due to other anthropogenic sources.	
	Contingency actions		
	Action	Control level breach	Trigger level breach
	<b>Issue notification report</b> <ul style="list-style-type: none"> <li>advise site operator</li> <li>advise Agency</li> </ul>	*	*
Conduct confirmatory sampling	*	*	
Determine degree of risk presented by breach	*	*	
Review conceptual model, control and trigger levels	*	*	
Agree any corrective/remedial measures with Agency		*	

A Control level on the leachate chemistry (for example, periodic leach testing of representative samples of deposited wastes) may also be required to confirm that waste-acceptance criteria are effective in ensuring the landfill does not pose a pollution hazard. The decision should be made taking account of the confidence in compliance with the waste-acceptance criteria and the likely consequences of elevated leachate concentrations on groundwater and other receptors, such as soil ecosystems.

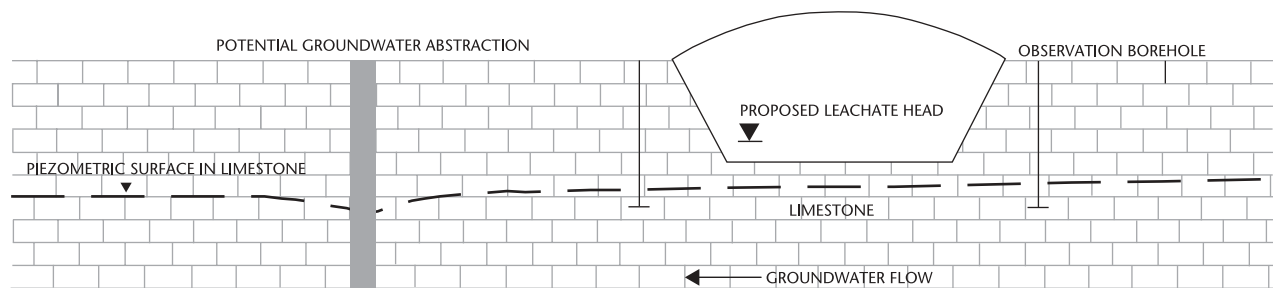
### Example III: Simple risk assessment

A third landfill, Site C, is proposed. A non-hazardous waste facility is proposed for a sensitive Major Aquifer, but non-SPZ, location. The operator notes the Agency's position documented in the *Policy and Practice for the Protection of Groundwater* and guidance on landfill location, but decides to proceed with a design that accelerates waste stabilisation and therefore aims to avoid long-term reliance on engineered pollution- prevention measures.

Following the development of an initial conceptual model and risk screening, the operator recognises that the site is in a very sensitive location with respect to groundwater. He realises that, for the Agency to accept such a proposal, a complex risk assessment will be necessary because of the potential environmental impacts. Nevertheless, the operator chooses to perform a simple risk assessment initially to help decide whether the additional expenditure of comprehensive site characterisation and complex modelling is warranted.

From published information and site-specific leachate data from a nearby site receiving similar wastes, the operator establishes that the likely leachate has the potential to cause pollution of groundwater. Background water quality is obtained from an on-site monitoring borehole (drilled for the purpose of this investigation) and EALs are derived. The ratio of EAL to likely leachate quality is then determined to highlight the substances of greatest concern.

Figure A11-3 | Schematic of landfill proposed in Major Aquifer



Determination of Environmental Assessment Limits	Primary receptor identified as groundwater in aquifer						
	Determinand (selected from more extensive list)	Maximum recorded groundwater concentration from baseline monitoring (mg/l)	Typical leachate chemistry (mg/l)	DWS (mg/l)	EQS (mg/l)	Selected EAL (mg/l)	Leachate chemistry: EAL ratio (AF <sub>v</sub> )
	ammonium	<0.1	4000	0.5	-	0.5	8000
	chloride	28	8000	250	250	40	200
	mecoprop	<0.00004	0.2	0.001	0.02	0.00004*	5000
toluene	<0.004	200	-	50	0.004*	50000	

\* List 1 substances. EALs selected on basis of Lower Reporting Limit (Appendix 7), noting that background groundwater quality is below these limits.

The operator notes that to achieve Groundwater Regulations compliance at this site, an unsaturated zone attenuation factor (AF<sub>v</sub>) in excess of  $5 \times 10^5$  will be necessary. AF<sub>v</sub> describes the necessary concentration reduction due to degradation, sorption, diffusion and dispersion processes within the landfill liner and in the unsaturated zone.

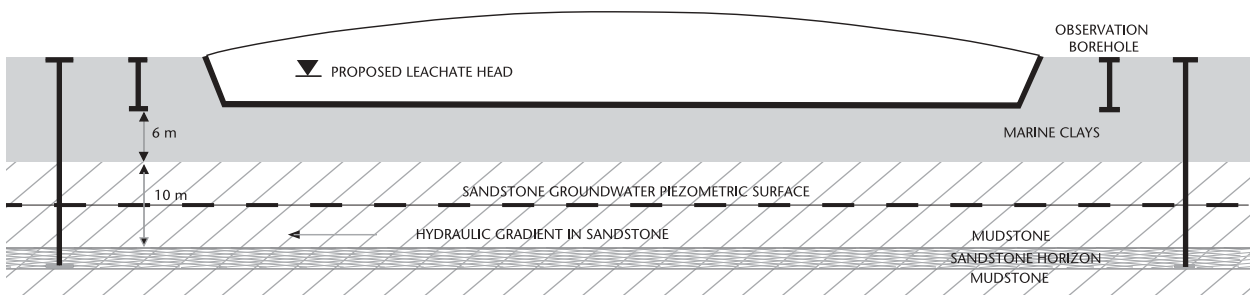
Noting the high AFU required, the uncertainties over long-term geomembrane performance (particularly with accelerated waste stabilisation) and the sensitivity of the groundwater beneath the proposed site, the operator decides not to proceed with further design and assessment of the site. He decides to identify an alternative location where the proposed facility would pose a lower risk to groundwater resources.

#### Example IV: Simple risk assessment

Another landfill, Site D, is proposed. Following the development of an initial conceptual model and risk screening, the operator decides that assessment is needed for Groundwater Directive purposes, and that the appropriate level of assessment for a non-hazardous waste landfill on a sequence of clay strata should be a simple risk assessment. This approach relies on generic (conservative) assumptions and data in the absence of detailed site-specific data. The general location of the site, which is part of the basic conceptual model, is depicted below.

The proposed landfill is located within a sequence of uniform marine clays, which overlie mudstones. The marine clays are classed as non-aquifer by the Agency, and the mudstone a Minor Aquifer. Neither support large public supply abstraction, although groundwater from subordinate sandstone horizons within the mudstones is abstracted for agricultural purposes (spray irrigation) locally. At this site, the shallowest sandstone horizon is about 16m below the base of the proposed landfill.

Figure A11-4 Schematic cross-section of non-hazardous landfill considered by simple risk assessment



It is decided that the groundwater receptor at this site is groundwater within the sandstone horizon(s). Compliance for List I substances must be considered at the point below the landfill at which those substances enter the sandstone, while the likely impact of List II substances (and other potential pollutants) are considered at a monitoring borehole on the down-gradient site boundary.

Leachate from a nearby landfill receiving similar wastes is used as the basis for predicting likely leachate chemistry. Indicator parameters are selected based on anticipated leachate chemistry, and the concentrations of the same substances in background groundwater and their water quality standards are used in deriving EALs.

The impact to groundwater was simulated using a simple spreadsheet model, assuming plug-flow in the unsaturated zone and a simple advection/dispersion solution in the saturated aquifer. Site-specific data and worst-case literature values were used to generate a conservative (worst-case) prediction of impacts on groundwater.

Control and Trigger levels were derived for groundwater for those substances deemed to pose the greatest hazard (by reference to the ratio of EAL to anticipated leachate chemistry, necessary to ensure no unacceptable discharge occurs). In addition, permit conditions for other parameters that could affect risk to groundwater, such as leachate head, were set.

<i>Determination of Environmental Assessment Limits</i>	Primary receptor identified as groundwater in sandstone horizon						
	Determinand (selected from more extensive list)	Typical leachate chemistry (mg/l)	Maximum recorded groundwater concentration from baseline monitoring (mg/l)	DWS (mg/l)	EQS (mg/l)	MRV for clean water (List I) (mg/l)	Selected EAL (mg/l)
	ammonium	2000	1.2	0.5	-	-	1.5
	chloride	4500	350	250	250	-	400
	potassium	540	8	10	-	-	10
	copper	750	1	2	0.028	-	1
	phenol	50	<0.005	0.0005	0.03	-	0.0005
	toluene	80	<0.004	-	0.05	0.004	0.004
<b>Note:</b> 1 EAL for NH <sub>4</sub> <sup>+</sup> , Cl <sup>-</sup> and Cu <sup>2+</sup> selected on basis of groundwater monitoring data that exceed water quality standards. 2 EAL for K <sup>+</sup> and phenol reflective of respective DWS (lowest relevant water quality standard). 3 EAL for toluene (List I substance) reflective of minimum reporting value in groundwater (that is, discernibility).							

The impact to groundwater was simulated using a simple spreadsheet model, assuming plug-flow in the unsaturated zone and a simple advection/dispersion solution in the saturated aquifer. Site-specific data and worst-case literature values were used to generate a conservative (worst-case) prediction of impacts on groundwater.

Simple risk assessment – Calculations using largely generic (conservative) assumptions to assess risk to groundwater				
Risk assessment (Section 3)	Factor	Nature of input values	Resultant calculation (maximum concentration after 100,000 years)	
	Potential rate of leachate leakage.	Adequate characterisation data from existing landfill liner and geology.	61 l/day	
	Unretarded travel time for leachate to reach groundwater.		4,452 years	
	Potential concentration of List I substances in porewater immediately before discharge to groundwater.	Assumed (conservative) hydrogeological data detailing hydraulic conductivity, gradient and attenuation processes.  Leachate source characterisation data from nearby site.	toluene	<0.001ug/l
	Potential concentration of List II substances in groundwater at down -stream site boundary.		ammonium	0. 1mg/l
			chloride	57 mg/l
			potassium	4 mg/l
copper			0.08mg/l	
Potential attenuation of ammonium within mineral portion of liner.	phenol	<1x10 <sup>-9</sup> mg/l		
<b>Summary of results</b>			Retarded plug flow time 9,978 years	
Proposed development compliant with Landfill Directive.				
Proposed development compliant with Groundwater Directive.				

Control and Trigger levels were derived for groundwater for those substances deemed to pose the greatest hazard (by reference to the ratio of EAL to anticipated leachate chemistry, necessary to ensure no unacceptable discharge occurs). In addition, permit conditions for other parameters that could affect risk to groundwater, such as leachate head, were set.

<b>Derivation of Control and Trigger levels (Section 4)</b>	<b>Identification of Control and Trigger level assessment point (Sections 2.6.3, 4.2 and 4.3)</b>	
	Four down-gradient groundwater monitoring boreholes (in the sandstone horizon) located on predicted 'plume' centreline.	
	<b>The Trigger levels for each potential pollutant (Sections 2.6.1, 4.2 and 4.3)</b>	
	<b>List I substances</b> – samples with concentrations above minimum reporting values for water sampled from designated monitoring boreholes. <b>List II substances</b> – concentrations in groundwater at designated boreholes greater than:	
	ammonium	1.5 mg/l
	chloride	400 mg/l
	potassium	10 mg/l
	copper	1 mg/l
	<b>Control levels for each potential pollutant (Section 6.3)</b>	
	<b>List I substances:</b> <ul style="list-style-type: none"> <li>concentrations in leachate exceed maximum predicted concentration in leachate by factor of two (for example, 160 mg/l for toluene)</li> </ul> <b>List II substances:</b> <ul style="list-style-type: none"> <li>trend of increasing and adverse concentrations in target substances and;</li> <li>Three<sup>1</sup> (or more) consecutive groundwater samples exceed the 75<sup>th</sup>ile of the baseline groundwater quality, which is:             </li> </ul>	
ammonium	0.8 mg/l	
chloride	275 mg/l	
potassium <sup>2</sup>	none set	
copper	0.6 mg/l	
<b>Notes</b> <sup>1</sup> This aims to ensure that occasional "spikes" (natural noise) in groundwater-quality data do not routinely cause control level exceedence. <sup>2</sup> No Control level set for potassium: 75 <sup>th</sup> ile of background groundwater quality (5mg/l) is so close to the predicted potassium concentration (4mg/l) that it is considered inappropriate to set a control level for potassium. An alternative determinand could be selected instead.		
<b>An assessment test for each of the monitored chemicals of concern (Section 6.3.3 and Section 6.4.2):</b>		
<ul style="list-style-type: none"> <li>Control level reviews to be conducted each time monitoring data are obtained;</li> <li>formal annual review and reporting.</li> </ul>		

### Example V: Complex risk assessment

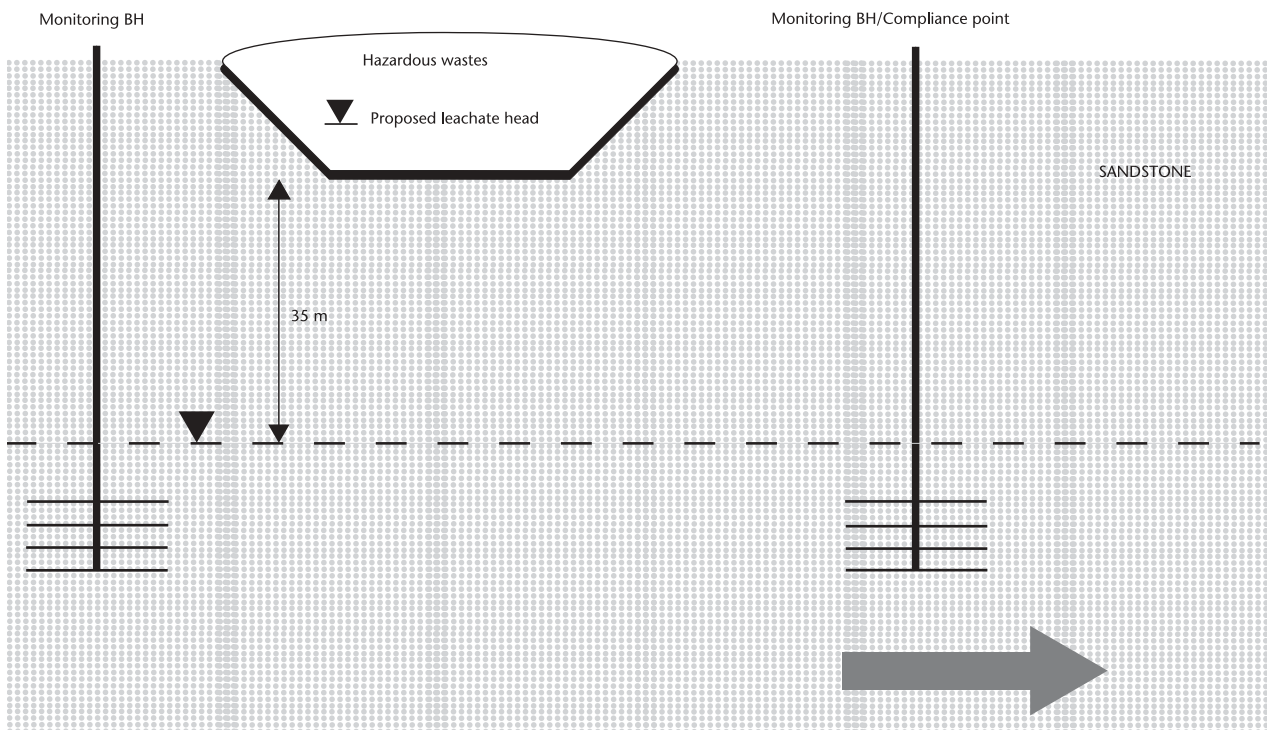
An operator proposed to develop a hazardous waste landfill, Site E, on a sandstone formation, which constitutes a Major Aquifer locally. The sandstone is capable of supporting abstraction, but is not used for that purpose at present. The site is not within a Source Protection Zone and the closest groundwater discharge is to a river 400m away.

Recognising the significant hazard that the hazardous waste represents and the potential resource value of the sandstone aquifer in this location, the operator decided that a complex risk assessment is most appropriate, using site-specific data and detailed assessment techniques. Comprehensive site characterisation has been undertaken to develop and refine the initial conceptual model of the landfill and hydrogeological processes around the site.

Site-specific data on groundwater levels and flow, geochemical properties that control retardation of key pollutants, and waste characterisation have been undertaken over a period of two years to allow adequate data to construct a groundwater flow model, if that is necessary.

The groundwater receptor at Site E is deemed to be groundwater in the sandstone aquifer beneath the landfill site. Points of compliance are the base of unsaturated zone for List I substances (to ensure no discernible discharge to groundwater) and the receiving groundwater (immediately after dilution) for other potential pollutants.

Figure A11-5 | Schematic cross-section of hazardous waste landfill considered by complex risk assessment



Having established EALs for a range of pollutants it emerges that, because of the nature of the waste stream, the risk to groundwater from organic substances, such as mecoprop and toluene, is likely to be less than the risk from heavy metals. A robust understanding of site-specific sorption and retardation processes that could limit the migration cations is important.

The cation exchange capacity (CEC) of both the underlying sandstone and the mineral portion of the proposed liner are established by laboratory analysis. Further, the partition co-efficients for key substances are obtained from batch and column tests using surrogate leachate that reflects the anticipated leachate chemistry at Site E, with the mineralogy of liner and sandstone. The operator decides that, since this process is likely to be a key one in the overall risk assessment, more realistic modelling techniques are necessary. He chooses to couple a probabilistic LandSim2 assessment (to simulate fluid flow) with more detailed geochemical speciation modelling in the unsaturated zone, using PHREEQC, for a number of potential landfill liner design options.

Following assessment, it is concluded that, at the 95 percentile (worst case) of the resulting distribution, the concentrations of potential pollutants at the base of the unsaturated zone (for List Is), and at the site boundary (for List IIs), do not represent an unacceptable discharge when compared to the EALs established for the site. The assessment of whether an unacceptable discharge occurs was made over a period of 50,000 years following construction of the landfill. Assessment over a longer period (around 1,000,000 years) would indicate slightly higher impacts by contaminants, but the uncertainty associated with an assessment over this extended timescale is large. Taking account of conservatism inherent within the LandSim2 assumptions, it is considered appropriate to assess the impacts over a period of 0 to 50,000 years, with particular focus on the impact between years 0 to 10,000 in this instance.

<i>Potential leachate composition</i>	List I substances					
	Determinand	Max predicted concentration in leachate (µg/l)	Lower Reporting Level (µg/l)	Max background groundwater chemistry (µg/l)	Selected EAL (µg/l)	
	mecoprop	50	0.04	<0.04	0.04	
	benzene	200	1	<1	1	
	cadmium	3000	0.1	4	5*	
	toluene	50	4	3	4	
	List II substances					
	Determinand	Max concentration in leachate (mg/l)	Max background groundwater chemistry (mg/l)	DWS (mg/l)	EQS (mg/l)	EAL (mg/l)
	ammonium	750	0.8	0.5	-	1*
	chloride	15000	180	250	250	250
potassium	7000	4	10	-	10	
lead	10000	0.003	10	4	4	
nickel	7000	0.006	20	50	20	
* EAL for cadmium (List I substance) and ammonium (List II) selected as background concentration +25% to take account of natural background concentration, where this exceeds water quality standards.						

Taking results from predictions simulating the impact of a landfill with a double composite liner, the maximum predicted impacts at relevant compliance points were as follows:

Trigger and Control levels are selected for a relevant range of substances considered during the risk assessment. In this instance, controls on mecoprop, benzene and toluene are not considered necessary and effort is focussed on heavy metal and major ion pollutants.

	Substance	EAL	units	50%ile of contaminant concentration	95%ile of contaminant concentration
<i>Risk assessment: predicted contaminant concentration from detailed modelling</i>	mecoprop	0.04	µg/l	$1 \times 10^{-5}$	$3 \times 10^{-4}$
	benzene	1	µg/l	$3 \times 10^{-8}$	$3 \times 10^{-6}$
	cadmium	5	µg/l	0.3	0.46
	toluene	4	µg/l	$1 \times 10^{-8}$	$1 \times 10^{-6}$
	ammonium	1	mg/l	0.18	0.27
	chloride	250	mg/l	177	238
	potassium	10	mg/l	3.8	7.5
	lead	4	mg/l	0.31	0.39
	nickel	20	mg/l	11	16

<i>Derivation of Trigger levels</i>	<b>The Trigger levels for each potential pollutant</b>		
	<b>List I substances:</b>		
	<ul style="list-style-type: none"> <li>cadmium – concentrations above 5 µg/l (after EAL that takes natural water chemistry into account).</li> </ul>		
	<b>List II substances</b>		
	<ul style="list-style-type: none"> <li>concentrations greater than:</li> </ul>		
	ammonium	1 mg/l	
	chloride	250 mg/l	
	potassium	10 mg/l	
	lead	4 mg/l	
	nickel	20 mg/l	
	<b>Control levels for each potential pollutant</b>		
	<b>List I substances:</b>		
<ul style="list-style-type: none"> <li>concentrations in leachate above twice their predicted concentration in leachate (for example, 100 µg/l for mecoprop).</li> </ul>			
<b>List II substances</b>			
<ul style="list-style-type: none"> <li>75<sup>th</sup>ile of risk assessment resultant concentrations:</li> </ul>			
ammonium	0.85 <sup>1</sup> mg/l		
chloride	178 mg/l		
potassium	5.6 mg/l		
lead	3 mg/l		
nickel	15mg/l		
<b>Notes</b>			
<sup>1</sup> ammonium control level set at 0.85 mg/l on basis of background monitoring data and EAL			
<b>An assessment test for each of the monitored substances of concern (Sections 4.2 and 4.3):</b>			
<ul style="list-style-type: none"> <li>Control-level reviews to be conducted each time monitoring data are obtained;</li> <li>formal annual review and reporting.</li> </ul>			
<b>Appropriate response time:</b>			
<ul style="list-style-type: none"> <li>Control-level reviews to be completed within one month of sampling event.</li> </ul>			
<b>Action</b>	<b>Control level breach</b>	<b>Trigger level breach</b>	
Issue notification report: <ul style="list-style-type: none"> <li>advise site operator;</li> <li>advise Agency.</li> </ul>	*	*	
Conduct confirmatory sampling.	*	*	
Determine degree of risk presented by breach.	*	*	
Review existing hydrogeological risk assessment, control and trigger levels.	*	*	
Agree any corrective/remedial measures with Agency.		*	



## Appendix 12:

# Use of water quality standards at different stages of decision-making

<p><i>Deciding whether the Groundwater Directive applies</i></p>	<p>Water-quality standards for potable use (Appendix 8) may be employed as benchmarks to determine whether the concentration of individual listed substances <b>in the source leachate</b> represents a concentration “so small as to obviate any present or future danger of deterioration of the quality of receiving (ground)water”. If the concentration and volume are consistent with this assessment then the Groundwater Directive does not apply.</p> <p>In the case of List I substances presented as groups of substances in the Groundwater Directive:</p> <ul style="list-style-type: none"> <li>• undertake screening as described in Appendix 6;</li> <li>• If there is greater than 80 per cent recognition of individual List I substances, analyse (quantify) for those specific substances;</li> <li>• if the concentration of speciated substances exceeds its recognised water-quality standard for potable use (see Appendix 8), the directive applies.</li> </ul>
<p><i>Assessing whether a predicted discharge complies with the requirements of the Groundwater Directive</i></p>	<p><b>List I substances</b> Agency must “prevent substances in List I from entering groundwater”</p> <p>The Agency will consider whether there is likely to be a discernible discharge of List I substances to groundwater (the water table). The test shall be applied at the point where leachate enters groundwater and <b>shall not take account of the effects of dilution</b> in that groundwater.</p> <p>The criteria applied shall typically be whether List I substances (normally those identified during the screening procedure described in Appendix 6, or predicted on the basis of the proposed waste stream) are present in the leachate at concentrations that would give rise to a discernible discharge to groundwater. This will involve comparing predicted leachate chemistry (at the point of entry to the groundwater) with Minimum Reporting Values for the substance in clean water (Appendix 7) and natural baseline water chemistry.</p> <p>The assessment may take account of attenuation processes in any landfill liner and unsaturated zone, but may not take account of dilution or attenuation in groundwater.</p> <p><b>List II substances</b> Agency must “limit the introduction of List II substances into groundwater so as to avoid pollution”</p> <p>The Agency will consider whether the predicted concentrations of List II substances are likely to exceed relevant use-based standards, other relevant environmental quality criteria, or cause an unacceptable deterioration in water quality in the groundwater following dilution. For practical purposes, this will typically comprise assessing whether concentrations of List II exceed relevant standards at monitoring boreholes immediately adjacent to the landfill site (that is, after dilution in the groundwater).</p>

<p><i>Assessing whether a predicted discharge complies with the requirements of the Groundwater Directive (cont.)</i></p>	<p>For some substances, such as chloride, deterioration from baseline levels (typically less than 50mg/l) to the drinking water standard (250mg/l) may be unacceptable (the standard is not appropriate to protect the groundwater resources). The Agency hydrogeologist will advise on these aspects, taking account of the local hydrogeological system in which the landfill is located.</p>
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