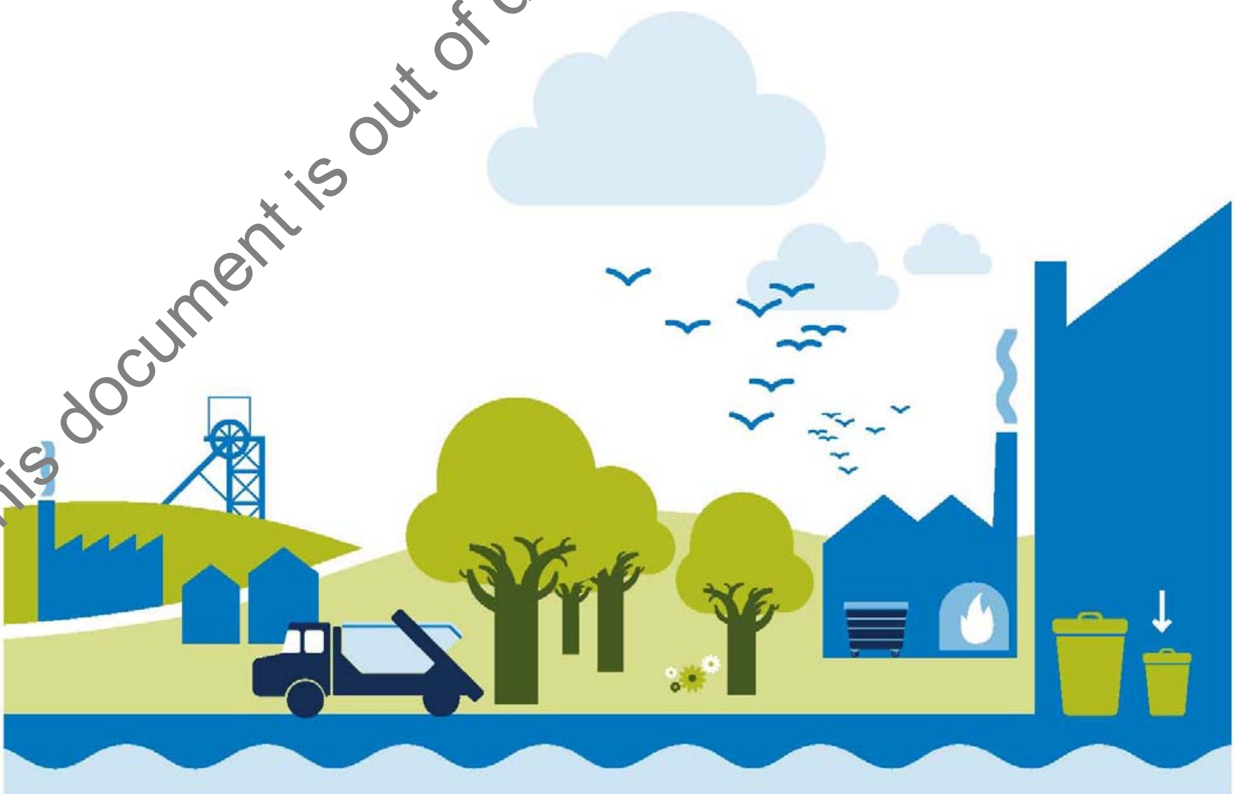
Horizontal guidance Note H1

- Annex J 3.

Additional guidance for hydrogeological risk assessments for landfills and the derivation of groundwater control levels and compliance limits



We are the Environment Agency. It's our job to look after your environment and make it a better place – for you, and for future generations.

Your environment is the air you breathe, the water you drink and the ground you walk on. Working with business, Government and society as a whole, we are making your environment cleaner and healthier.

The Environment Agency. Out there, making your environment a better place.

Published by:

Environment Agency
Horizon House, Deanery Road
Bristol BS1 5AH
Tel: 0117 934 4000
Email: enquiries@environment-agency.gov.uk
www.environment-agency.gov.uk

GEHO0212BULU-E-E, Version 2

Further copies of this report are available from our publications catalogue: http://publications.environment-agency.gov.uk or our National Customer Contact Centre: Tel: 03708 506506

Contents

Contents

Contents

Contents

Summary of changes

Below is a summary of changes made to this Annex since the launch in April 2010.

Annex version	Date	Change	Template version
Issue 2.1	December 2011	Reformatting to respond to general issues raised in the 2010 H1 public consultation. Minor revision and improvement to text and layout.	H1 April 2011

Acknowledgements

2003 version

Environment Agency: Hugh Potter, Jonathan Smith.

SLR Consulting Ltd: A. Edwards, J. Leeson.

2010 version

Environment Agency: Phil Fitzgerald, Tony Peacock, Peter Elliot, Tony Marsland, Rob Marshall, Helen Moorhouse.

Entec: Mike Carey, Nick Rukin, Alan Stuart.

2011 version

Environment Agency: Phil Fitzgerald

Introduction

About this guidance

This document provides guidance on the requirements for a hydrogeological risk assessment for landfills and the derivation of groundwater control levels and compliance limits[1]. It replaces our guidance: *Hydrogeological risk assessments for landfills and the derivation of groundwater control and compliance limits*, Environment Agency (2003; 2010). This guidance has been written by the Environment Agency and is therefore applicable to England and Wales.

The legislative changes relate to the relevant requirements of the Landfill Directive (1999/31/EC), the IPPC Directive (96/61/EC), the Water Framework Directive (2006/60/EC) and the Groundwater Directive (2006/118/EC) which are implemented by the Environmental Permitting Regime (EPR). The guidance describes a tiered approach to hydrogeological risk assessment for landfills and sets out how groundwater control levels and compliance limits (as required by the Landfill Directive) should be derived and used.

This document is one of a linked series of technical guidance documents that support both landfill operators and their advisors in the development and management of landfills, along with the Environment Agency and local authorities in making regulatory decisions. This document is non-statutory, but represents guidance that we will use and will expect others to use, except where there is adequate justification to do otherwise.

This guidance is specific to landfill activities and may not be applicable to other activities that must comply with the Groundwater Directive. For the purposes of this document, hydrogeological risk assessment has the same meaning as groundwater risk assessment.

Readers of this guidance are expected to be familiar with the Landfill Directive requirements and the national regulatory framework.

[1] For consistency with other permitting sectors and our environmental permits, the previous terminology ‘trigger levels’ (Environment Agency, 2003) have been redefined as compliance limits throughout this document. They have the same meaning.

Introduction

Layout of this document

Introductory section: Introduces the approach adopted in this guidance and includes the link to our Groundwater Protection (GP3) suite of documents and explains some key terminology that is used throughout

Chapter 1: The first section of Chapter 1 sets out the legislative background relative to landfill. The second part explains how this legislation is interpreted through this document.

Chapter 2: Introduces the development of the site conceptual model, the risk screening process, compliance points and Environmental Assessment Levels.

Chapter 3: Looks at the requirements for generic and detailed quantitative risk assessments.

Chapter 4: Introduces the concepts and requirements for developing groundwater control levels and compliance limits.

Chapter 5: The first part of Chapter 5 identifies the requirements for reporting via the Environmental Permitting regime and the planning system. The second part looks at monitoring, validation and the review process.

Appendices: Key appendices are included and should be read and used in conjunction with the text in the main report.

The approach described in this guidance also emphasises:

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

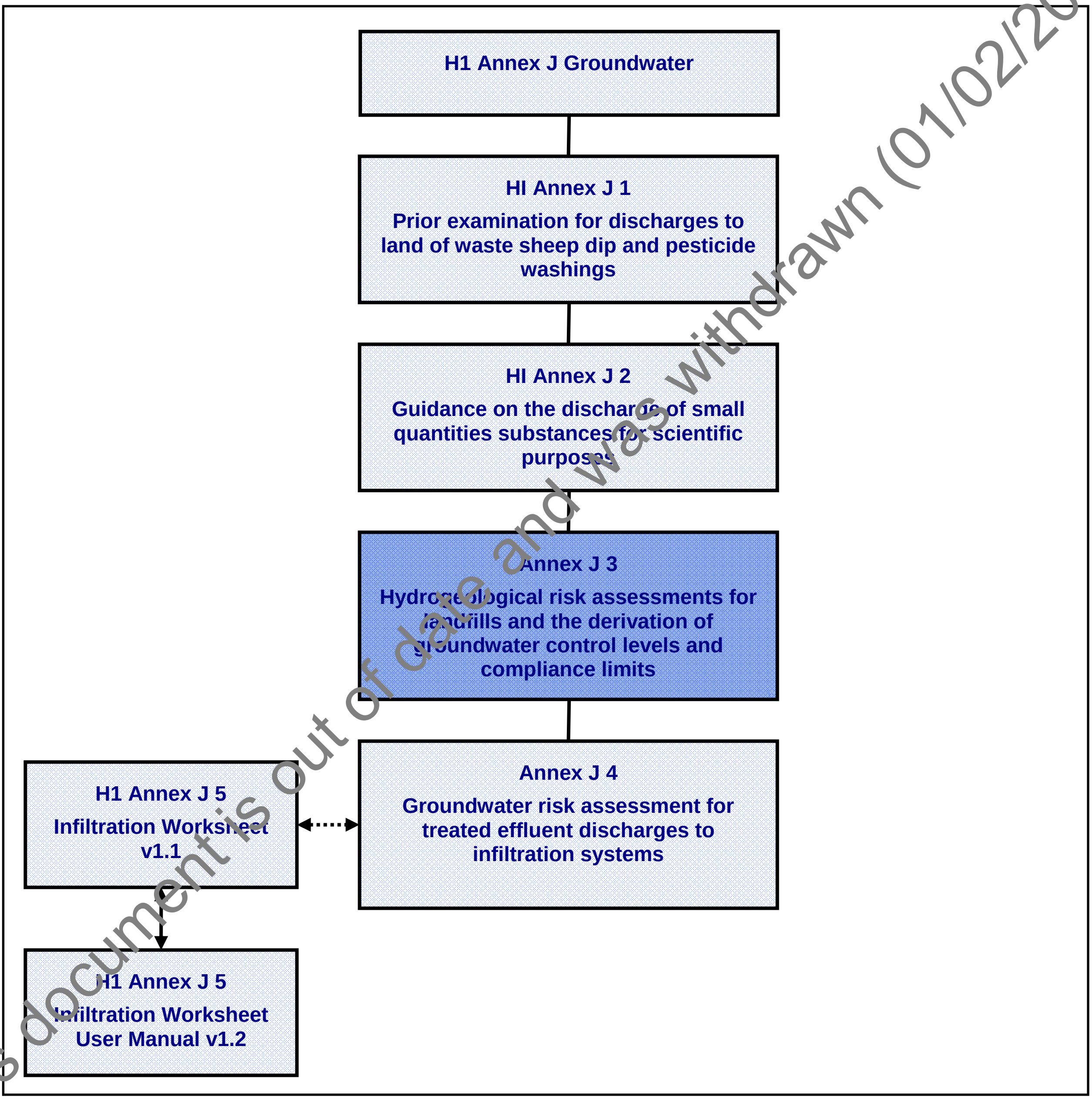
Introduction

H1 Guidance: Annex (j) groundwater

Our EPR H1 Environmental Risk Assessment guidance provides high level guidance on the broad principles of risk assessment, which underpin our decisions on the permitting of different activities, including landfill. It covers the need for risk assessments on concerns such as air quality, noise, stability, and potential impacts on surface water and groundwater. If appropriate, H1 then points you to more detailed sector specific annexes on how to undertake risk assessments.

How this document fits in with our other groundwater 'H1 Environmental Risk Assessment' guidance for is shown in Figure A.

Figure A. How the HI framework is structured specific to groundwater



Introduction

Link to our Groundwater Protection: Principles and Practice

Hydrogeological risk assessment is a key process in the evaluation of landfill developments. However, the process of site selection also needs to be set in the context of our Groundwater Protection: Principles and Practice (GP3) Environment Agency, 2006; 2012).[2]

In addition to presenting our 'landfill location position statement' and the 'solid waste management' sections of GP3 (Part 4, Environment Agency, 2012), explains how this will be applied to planning proposals for landfill, setting 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.

Through this framework, we seek to direct new landfills away from areas where sensitive groundwater resources are present and onto less vulnerable areas underlain by low permeability geologic formations. 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.

A revised suite of documents with direct relevance to landfill have been referenced throughout. These documents such as our revised 'Interpreting the landfill location position statement' and 'Assessing the discernibility of hazardous substances from discharges into groundwater' are planned to form part of our new GP3 Part 5 (Environment Agency, 2012).

Key terminology

Box A gives a brief overview of some key terminology used in this document.

Please note some of these terms may have other meanings not specific to landfill. For example, the setting and derivation of compliance points for permitted discharges or contaminated land risk assessment may differ to those for landfill.

[2] Groundwater Protection: Principles and Practice Part 4 and Part 5 in preparation

Box A Explanation of key terminology

Environmental standard: This is the standard that applies to the use of the water at the receptor. It is usually based on (but not necessarily equal to) standards such as Environmental Quality Standards (for rivers) or Drinking Water Standards (for water supply). In the case of inputs of hazardous substances to groundwater it may be based on the background groundwater quality, detection limits or a Minimum Reporting Value (MRV).

Environmental Assessment Level (EAL): This is value set at a compliance point calculated to be a maximum concentration allowable at that point in order to protect a receptor. An EAL may be either a theoretical value used in predictive modelling or a limit set for physical monitoring. It has the same general meaning as 'compliance value' (In literature associated with effluent discharge) or 'target concentration' (in literature associated with land contamination).

Compliance point: A compliance point is a point at which an EAL is set in order to ensure that a relevant environmental standard will be met at a receptor. A compliance point may either be located between the landfill and the receptor or at the receptor itself.

Control levels: These are specific assessment criteria that are used to determine whether a landfill is performing as designed and are intended to bring to attention of site management to the development of adverse trends in the monitoring data. They are a test of the significance of a deviation from baseline groundwater conditions, which is used to determine whether a landfill is performing as designed. Control levels should be regarded as an 'early warning system' to enable appropriate investigation or corrective measures to be implemented, rather than as an indication that groundwater pollution has occurred.

Compliance limit (formerly trigger level): Defined by the Landfill Directive 1999/31/EC (LFD) as levels at which significant (adverse) environmental effects have occurred. This relates to where the concentration has exceeded a level which means the environmental standard at a receptor will be breached and there is pollution. A compliance limit is a value specified in the permit which, if exceeded will require certain actions to be taken. Depending on where the compliance limit applies it may be the same as the EAL or calculated from the EAL in another compliance point.

The terms **control levels** and **compliance limits** are only specific to landfill

Chapter 1 - Regulatory context

1.0 Legislative background

1.1 Regulatory terminology used in this guidance

Within this guidance the Landfill Directive (99/31/EC) is referred to as LFD, the Groundwater Directive (2006/118/EC) as GWDD (the Groundwater 'Daughter' Directive) and the Water Framework Directive (2006/60/EC) as WFD. The Environmental Permitting Regulations (2007; 2010 or as amended) are referred to as EPR. The Waste Framework Directive is referred to in full in this document so WFD always relates to the Water Framework Directive. The original Groundwater Directive 80/68/EEC (referred to as GWD) is due to be repealed in December 2013.

1.1.1 Landfill Directive

The Landfill Directive is Council Directive 1999/31/EC on the Landfill of Waste. In England and Wales, the Directive is applied under the Landfill (England and Wales) Regulations 2002. The Environment Agency is the regulatory body responsible for implementing the Landfill Directive in England and Wales.

Landfill has the meaning given in Article 2(g) of the LFD, but does not include any operation excluded from the scope of that Directive by Article 3(2). Landfills must be classed as either for hazardous, non-hazardous or inert waste (Article 4, LFD) and are defined based on the type of waste they can accept.

1.1.2 Groundwater Directive

The Groundwater Directive 80/68/EEC (GWD) which is due to be repealed in December 2013, sets out the "prevent or limit" approach to protecting groundwater which was originally brought into law through the Waste Management Licensing Regulations (1994) and the former Groundwater Regulations (1998). Some of key requirements of the GWD remain valid, including the need for prior investigation and requisite surveillance, and these are brought forward into EPR alongside the requirements of later Directives.

1.1.3 Water Framework Directive and Groundwater Daughter Directive

Article 4.1(b)(i) of the WFD requires the implementation of measures necessary to prevent or limit the input of pollutants into groundwater. Further clarification on this point is provided in GWDD under Article 6. Article 11(3)(g) of the WFD requires measures to control point source discharges (such as those from landfill). These requirements are satisfied by EPR.

Under paragraph 7(4) of Schedule 22 to EPR (2010) a permit may not be granted without examination of:

(i) the hydrogeological conditions of the area concerned;

(ii) the possible purifying powers of the soil and subsoil, and,

(iii) the risk of pollution and alteration of the quality of the groundwater from the discharge

1.1.4 WFD, GWD and EPR definitions

In addition to the section on specific regulatory requirements relevant to this guidance (Section 1.2), background information on WFD, GWD and EPR legislative requirements for groundwater risk assessment are provided in our H1 Guidance: Annex (j) Groundwater (Environment Agency, 2011).

The WFD and the GWD refer to hazardous substances or non-hazardous pollutants. These are discussed in more detail in Section 1.2 and specific substances and groups of substances are given in Appendix 1 (Hazardous substances and non-hazardous pollutants).

EPR states that an environmental permit must include conditions requiring all necessary technical precautions as follows:

Paragraph 6 of Schedule 22: For the purposes of implementing the Groundwater Directive, the Water Framework Directive and the Groundwater Daughter Directive, the regulator must, in exercising its relevant functions, take all necessary measures—

(a) to prevent the input of a hazardous substance to groundwater;

(b) to limit the input of non-hazardous pollutants to groundwater so as to ensure that such inputs do not cause pollution of groundwater.

Guidance on what necessary technical precautions means in general is given in our H1 Guidance: Annex (j) Groundwater (Environment Agency, 2011). Interpretation of these requirements specific for landfill is given in Section 2.6 *(necessary technical precautions).*

1.1.5 Implementation of the Landfill Directive and IPPC Directive

In England and Wales, the requirements of the LFD and IPPC Directive (96/61/EC) are implemented through EPR. Landfill sites which ceased accepting waste before 16 July 2001 are not subject to the requirement of the LFD. Those that operated after that date are required to operate or close under the operational or closure requirements of the LFD.

Rather than repeat the detail of the LFD requirements, Schedule 10 of EPR (2010) makes direct reference back to the LFD with occasional clarification on interpretation.

1.1.6 Link to the Environmental Permitting Programme

The Department for the Environment, Food & Rural Affairs (Defra), the Department of Energy and Climate Change (DECC), the Environment Agency (EA) and the Welsh Government (WG) have introduced a major initiative, the Environmental Permitting Programme (EPP), that has created a single more modern permitting and compliance system.

The first part of the programme EPP1, streamlined the implementation of the IPPC Directive, the Waste Framework Directive (06/12/EC) and the LFD through the Environmental Permitting (England and Wales) Regulations 2007 (EPR 2007).

The second part of the programme EPP2, brings water permitting within this framework and implements the WFD and the GWDD through EPR.

EPR replaces the Groundwater Regulations (1998) and the transitional Groundwater Regulations (2009) in terms of the protection of groundwater.

1.1.7 Defra and Environment Agency general guidance on landfill

Readers of this guidance are expected to be familiar with the LFD requirements and the national regulatory framework:

Specifically, the Defra guidance document which sets out Government interpretation of the Landfill Directive for England and Wales:

- Environmental Permitting Guidance - The Landfill Directive: For the Environmental Permitting (England and Wales) Regulations (Defra, 2010)

Our EPR 5.02 document describes best practice for landfills, in compliance with both the Landfill and IPPC Directives:

- How to comply with your environmental permit: Additional guidance for landfill (EPR 5.02) (Environment Agency 2009)

More landfill guidance is available on our website on our Environmental Permitting and Landfill pages.

1.2 Specific regulatory requirements relevant to this guidance

1.2.1 The requirement for hydrogeological risk assessments

We have required risk assessment to establish the engineering precautions for landfill for many years. The LFD formalised this requirement in Annex I, paragraph 3:

> "If, on the basis of an assessment of environmental risks taking into account, in particular, Directive 80/68/EEC [the GWD], the competent authority has decided, in accordance with Section 2 ("Water control and leachate management"), that collection and treatment of leachate is not necessary or it has been established that the landfill poses no potential hazard to soil, groundwater or surface water, the requirements in paragraphs 3.2 and 3.3 above may be reduced accordingly."

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 life cycle. Therefore, the detailed hydrogeological risk assessment and related assessments (for example, landfill gas control, stability, etc.) should be used to determine the engineering standards and other operational controls necessary to comply with the LFD and the GWD (see LFD 1 (version 2) Understanding the Landfill Directive (Environment Agency, 2010d) 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.

1.2.2 Landfill life cycle: Operational, passive phase, post closure phase and aftercare requirements

Annex I paragraph 3.1 of the LFD requires that the protection of groundwater is achieved during the operational/ active phase by the combination of a geological barrier and a bottom liner/artificial sealing liner. Subsequently, during the passive phase / post closure, it is achieved by the combination of a geological barrier and top liner / cap.

This means that you must take into account the durability and longevity of the basal liner system to ensure that it will offer the desired degree of protection during the operational and active management phases. You must also consider the probable length of the post-closure period which will be relevant to the determination of appropriate financial provision. More information can be found in the Defra Environmental Permitting Guidance - The Landfill Directive: For the Environmental Permitting (England and Wales) Regulations (Defra, 2010) and our Regulatory guidance LFD 1 (version 2) Understanding the Landfill Directive (Environment Agency, 2010c).

1.2.3 The geological barrier

The need for a geological barrier is an absolute requirement in the LFD.

The geological barrier must provide sufficient attenuation between the landfill source and any potential groundwater receptor in order to protect soil and ensure compliance with the GWD.

The geological barrier is a vital component in providing environmental protection. The purpose of the geological barrier within the LFD is to provide sufficient attenuation capacity to avoid unacceptable impacts on soil and groundwater. The attenuation provided by the geological barrier is interpreted as having the same meaning as the purifying powers of the soil and sub-soil referred to in the GWD (see Appendix 3: The purifying powers of soils and sub-soils). 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 cycle of the site).

In the passive post closure phase, the LFD requires that environmental protection be achieved by a geological barrier and a top liner / cap. It does not place any reliance on the artificial sealing liner. This accepts the uncertainties in the durability and longevity of basal liners and reflects that groundwater protection must be ensured in the long term by the cap. The hydrogeological risk assessment must cover the entire period over which the landfill presents a hazard, such as the active and post closure / aftercare 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 life cycle of the landfill. For biodegradable landfill waste, the changing pollution potential of the leachate over time will be an important consideration in the long-term risk assessment and in the determination of completion criteria.

Provision exists within Annex I (3)(3.2) of the LFD to artificially complete and reinforce the geological barrier and this should be considered in the risk screening (Chapter 2).

Further guidance on our interpretation of the engineering requirements of Annex I of the LFD is given in LFD 1 (version 2) Understanding the Landfill Directive (Environment Agency, 2010d)

1.2.4 Articles 12 and 13 (LFD): Groundwater control levels and compliance limits

With regards to groundwater control levels and compliance limits, Annex III (4)(C) of the LFD states that:

> "Significant adverse environmental effects, as referred to in Articles 12 and 13 of this Directive, should be considered to have occurred in the case of groundwater, when an analysis of a groundwater sample shows a significant change in water quality. A trigger level [compliance limit] must be determined taking account of the specific hydrogeological formations in the location of the landfill and groundwater quality. **The trigger level [compliance limit] must be laid down in the permit whenever possible."**

Annex III (4)(C) of the LFD also states that:

> "The 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."

Groundwater Control Levels and Compliance Limits are discussed in detail in Chapter 4.

1.2.5 Direct and Indirect Inputs

Direct and indirect inputs in relation to groundwater are interpreted in Schedule 22 (2) of EPR as:

A **direct input** means:

> "The introduction of a pollutant into groundwater without percolation through soil or subsoil."

A **indirect input** means:

> "The introduction of a pollutant into groundwater after percolation through soil or subsoil.".

The seepage of landfill leachate through a natural geological barrier, then through the unsaturated zone to the water table is an indirect input whereas seepage directly into groundwater is a direct input. Seepage directly into groundwater would not be considered direct if it percolates through an artificial sealing layer and / or geological barrier designed to prevent unacceptable input.

Further guidance on preventing or limiting direct and indirect inputs in the context of the GWD is given in WFD Common Implementation Strategy (CIS) Guidance Document No. 17 (EC, 2007) and in our GP3 Part 5 (Environment Agency, 2012)

1.2.6 Fluctuating groundwater levels and sub water table landfills

Groundwater levels can 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, inputs should be treated for the purposes of the GWD as being potentially a direct input. In locations where the water table is artificially depressed through pumping, the possibility of rebound occurring during the biologically and / or chemically active life of the site should be considered. If the area has a long history of mineral extraction (and hence groundwater dewatering / abstraction) and there are no accurate data on former rest water levels, the advice of a groundwater resource hydrogeologist should be sought. Where it is anticipated that the local water table will rebound above the level of the base of the site, any inputs may at some time in the future become a direct input.

Where the base of the waste body is, or will be, below the water table there is the potential for both direct inputs of hazardous substances into groundwater and for groundwater ingress into the wastes. As with all landfills, sufficiently rigorous risk assessments will be required in order to establish the suitability of the landfill site. In addition to the hydrogeological risk assessment, these will include for example, stability (Environment Agency, 2003b) and landfill gas (Environment Agency, 2004a, CIRIA, 2007) risk assessments. Further information on the relative impacts to groundwater associated with different sub-water table landfill designs has been prepared by the Environment Agency (Environment Agency, 2004b), which should be referred to when planning site investigation and risk assessment for any sub-water table location.

1.2.7 Hazardous substances and non-hazardous pollutants

The assessment must demonstrate that all measures deemed necessary and reasonable are taken to avoid the entry of hazardous substances into groundwater.

For non-hazardous pollutants, the assessment must demonstrate that all measures necessary are taken to limit inputs into groundwater so as to avoid pollution or significant and sustained upward trends in the concentration of pollutants in groundwater or deterioration in status of the groundwater body.

Hazardous substances and non-hazardous pollutants are discussed further where relevant throughout this document. Reference should also be made to Appendix 1 and Box 1.1.

Box 1.1 Hazardous substances and non-hazardous pollutants
The original Groundwater Directive (80/68/EEC) defined two lists of substances that were deemed to pose the greatest risk to groundwater quality. These were referred to as List I and List II, with substances on List I being of most concern. The Water Framework Directive (WFD, 2000/60/EC) and the Groundwater Daughter Directive (2006/118/EC) consider a wider range of potential pollutants and refer to them as hazardous substances or non hazardous pollutants. This terminology is used in the Environmental Permitting Regulations and further details are provided below: **Hazardous substances** Hazardous substances are defined in the WFD as "substances or groups of substances that are toxic, persistent and liable to bio-accumulate, and other substances or groups of substances which give rise to an equivalent level of concern." Under EPR the Environment Agency is required to publish a list of hazardous substances and the Joint Agencies Groundwater Directive Advisory Group (JAGDAG) is the body that confirms these determinations. All former List I substances are hazardous substances. All radioactive substances are determined as hazardous substances. **Non-hazardous pollutants** A non-hazardous pollutant is any substance capable of causing pollution that has not been classified as a hazardous substance. The non-hazardous list of pollutants does not simply replace the old List II; it is wider, as for example, nitrate is now termed as being non-hazardous whereas before it was not a Listed Substance. Further information on the list of substances considered to be hazardous, can be found on the UKTAG website. All substances liable to cause pollution that are not considered hazardous are deemed non-hazardous pollutants.

1.3 Exclusions from control

1.3.1 Groundwater activities

Paragraph 3 of Schedule 22 of EPR (2010) notes that a discharge that would result in or might lead to the direct or indirect input of a pollutant into groundwater is not a groundwater activity if the input of the pollutant is of a quantity and concentration so small as to obviate any present or future danger of deterioration in the quality of the receiving groundwater. If the discharge is deemed to not be a groundwater activity by the Environment Agency then further assessment of the risk to groundwater would not be required. In effect, we may decide that these activities can be excluded. We must record all exclusions.

This exclusion refers to pollutants entering the groundwater at the water table rather than leaving the base of the landfill. So some recognition can be given to the effect of the unsaturated zone and overlying geology. Based on the characteristics of the source leachate it must however be self evident, without the need for investigations, modelling or other detailed assessment, that the discharge will not cause deterioration of the groundwater.

1.3.2 Inert waste landfills

Inert waste is defined by the LFD:

> "Inert waste" means waste that does not undergo any significant physical, chemical or biological transformations. Inert waste will not dissolve burn or otherwise physically or chemically react, biodegrade or adversely affect other matter with which it comes into contact in a way likely to give rise to environmental pollution or harm human health. The total leachability and pollutant content of the waste and the ecotoxicity of the leachate must be insignificant, and in particular not endanger the quality of surface water and/or groundwater."

Inert landfills should 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.

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 may be required.

Regardless of whether the GWD applies or not, the disposal activity must still comply with the requirements of the LFD and groundwater Control Levels and Compliance Limits must be set and environmental monitoring will be required.

Risk screening may indicate that there is no need to collect contaminated water and leachate, as the assessment of landfill location and waste types shows that the landfill poses a low potential risk to the environment (Annex I paragraph 2 of the LFD). We are only likely to decide that leachate collection is unnecessary if the waste is inert. In this situation, there would be no requirement for the installation of leachate management systems. In addition, there would be no need to provide any artificial containment but there still would be a requirement for some form of geological barrier. We have issued guidance on the engineering requirements of the LFD (Environment Agency, 2009b).

Therefore, if the risk screening process satisfies the above, then we do not require leachate collection at landfills for inert waste.

With regards to inert sites, if they do not pose a hazard to groundwater, then it follows that the required attenuating properties of the geological barrier may only need to be nominal to ensure compliance with the requirements of the GWD.

Risk screening and further quantitative risk assessment may still be required. Reference should be made to Figures 2.1 and 3.1.

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

1.3.3 Permanently unsuitable

Reference to groundwater that is "permanently unsuitable for other uses" in the original GWD and domestic legislation is not brought forward into the new water directives and EPR. However, EPR does implement the exemption within the WFD that allows direct inputs of substances from certain groundwater activities (for example, related to mining, oil exploration and storage of liquid petroleum gas, etc.) to be authorised to "geological formations which for natural reasons are permanently unsuitable for other purposes."

Although the terminology is similar, this exemption (effectively from the need to prevent a direct input of hazardous substances) no longer applies to any landfill related inputs. See also GP3 Part 5 (Environment Agency, 2012)

1.3.4 Landfill location

Landfill location is beyond the scope of this document. Reference should be made to our landfill location position statement (Environment Agency, 2012). We will base our decisions on these documents.

Chapter 2 - The Risk assessment process

2.0 Introduction

This chapter 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 site conceptual model and risk screening. Development of the site conceptual model involves defining the nature of the proposed landfill and the hydrogeological setting. More specifically, it should describe the design, construction and operation of a landfill, the nature of baseline environmental conditions as well as identifying possible sources, pathways and receptors and the processes that are likely to occur along each of those source-pathway-receptor (S-P-R) linkages.

2.1 Environment Agency requirements

We are required to ensure an appropriate risk assessment is undertaken for each site as part of the permitting and / or review process. It requires 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; and
- Management control systems.

A tiered framework should be adopted in assessing environmental risks, as advocated by our H1 guidance Annex (j) Groundwater (Environment Agency, 2011). Accordingly, the greatest effort and resources are likely to be focussed on data collection and quantitative assessment at those sites that are most environmentally sensitive, 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 groundwater control levels for the landfill that will indicate, with confidence, should the landfill not perform as expected or designed, and when remedial action is necessary. Risk assessment should be a structured, transparent and practical process that aids decision-making.

The recommended framework for environmental risk assessment and management is described in DETR (2000) and in our H1 Guidance: Annex (j) Groundwater (Environment Agency, 2011) as illustrated in Figure 2.1. 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.

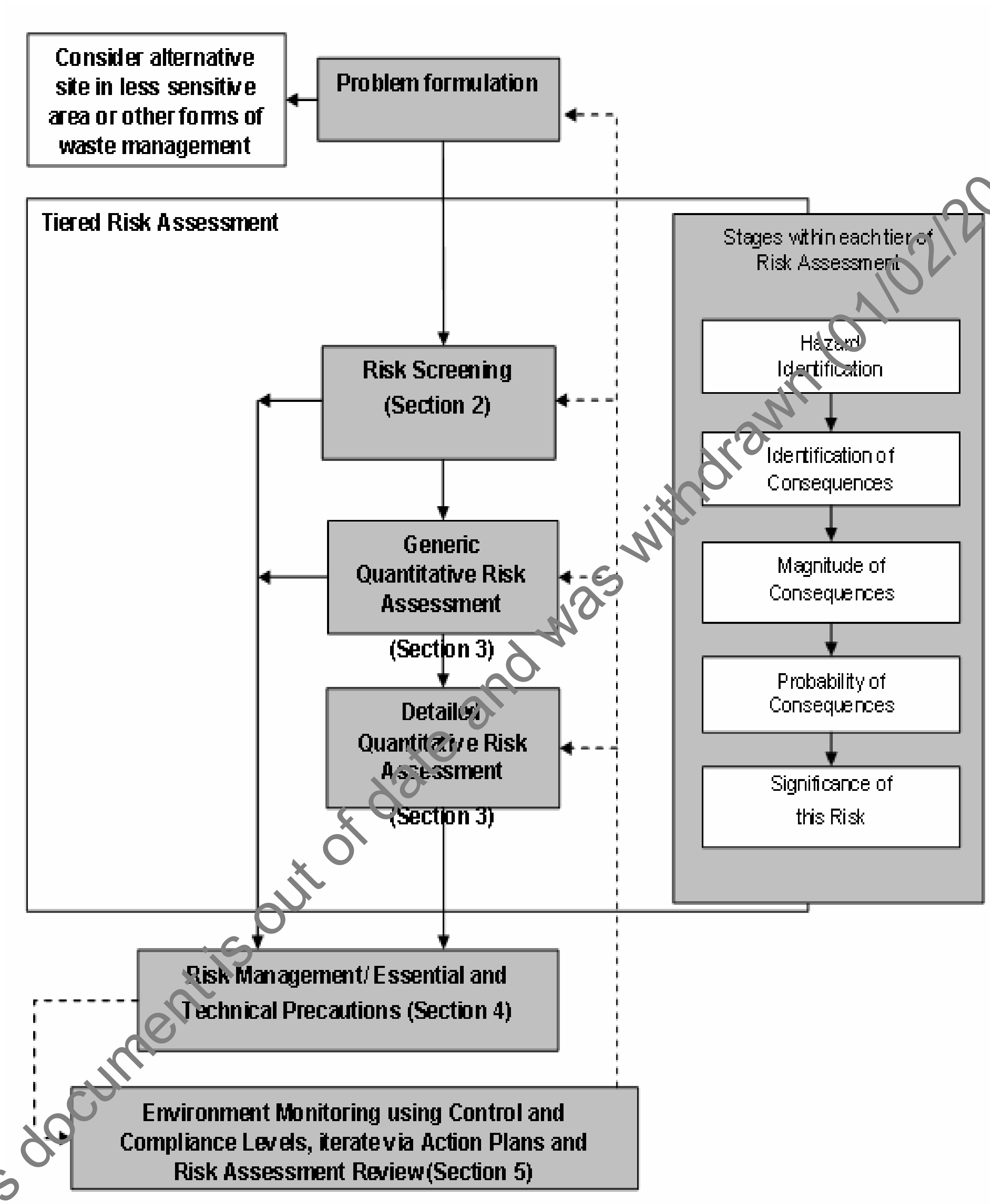


Figure 2.1 Framework for a tiered approach to risk assessment (DETR, 2000)

2.2 Conceptual model development

2.2.1 Developing the site conceptual model

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, in order to ensure that all of the relevant information is available at an early stage. Detailed, refinement of the conceptual model may not be required for the planning application stage but will be required at the environmental permitting stage in order to allow a robust understanding of the relevant processes acting on contaminating substances, and in most cases, their simulation by quantitative modelling.

The preparation of a site conceptual model is a critical element in successfully evaluating environmental risks. The development of a conceptual model underpins each stage of the risk assessment, such that its development and refinement is an iterative process within each level of risk assessment. Guidance on the development of conceptual site models has been published by us (Guide to good practice for the development of conceptual models and the selection and application of mathematical models of contaminant transport processes in the subsurface. National Groundwater & Contaminated Land Centre report NC/99/38/2, Solihull. Environment Agency, 2001a).

The conceptual model should describe potential environmental impacts associated with the site. As outlined above, the development of the site conceptual model must be an iterative process, with the model reviewed and updated as new information becomes available or as the understanding of the system is improved.

The initial site conceptual model should include reference to our Groundwater Protection: Principles and Practice (Parts 1 to 5, Environment Agency, 2006-2012), in particular whether or not it complies with our approach to landfill location.

There are three key stages to the development of a robust site conceptual 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.

The conceptual model must explicitly identify whether there is a potential for a direct or indirect input (Section 1.2.5) of any hazardous substances or non-hazardous pollutants (see Box 1.1 and Appendix 1) to groundwater. Where the potential for a direct discharge is identified in the conceptual model and risk screening stage, the subsequent risk assessment will be correspondingly more detailed (Chapter 3). Issues such as failure scenarios are considered in more detail in Section 3.7.

Another key output from the initial site conceptual model should be whether the landfilled waste would lie below the groundwater at any stage of its life cycle and therefore whether there is the potential for a direct input. This determination will have a bearing on the level of detail required in the risk assessment, the nature of the software and/or modelling used, as well as the nature of the landfill development.

2.2.2 Desk study and initial appraisal

The objectives of the desk study and initial appraisal should be to:

- Collect together all available and relevant information to characterise the site and its surroundings from literature, public registers and site reconnaissance.
- Develop an initial conceptual model for both the site and its hydrogeological setting. This should include summaries of information such as maps, plans, cross-sections and schematic diagrams, etc., which allow an easy understanding of the environmental setting.
- Determine, using the initial site conceptual model, the necessary site investigations and to develop a plan for those investigations.
- Obtain preliminary views of the Environment Agency and other interested parties (for example, Local Authorities) using the initial site conceptual model as a basis for discussion.

Table 2.1 lists many of the issues that need to be addressed, as well as setting out the information that should be reviewed, at the initial site conceptual model formulation stage. In addition, Appendix 2 (Geological and hydrogeological information requirements) sets out in more detail, the specific information requirements that relate to site geology and hydrogeology. Appendix 5 (Potential sources on information on leachate quality) sets out the possible sources of information that relate to determination of the potential or actual leachate quality. 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.

Following the completion of the desk study, it should be possible to develop an initial site conceptual 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 guide the development of the site investigation programme.

We recommend that following the development of the initial site conceptual model, the landfill developer / operator / consultant should discuss the findings and interpretation with us, in order to:

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

And with regard to these uncertainties:

- agree the objectives of any site investigations;

- discuss the level of risk assessment complexity that may be required for the site.

In order for a landfill developer to maximise the feedback obtained from us, we suggest that the discussions should be supported with relevant documentation that is submitted for consideration prior to those discussions taking place. The presentation of information in tabular and graphical forms is an effective way to provide succinct summaries of information gathered during the review. Similarly, tables that clearly illustrate the potential sources, hazards and pathways, drawings that show schematic cross-sections through the landfill development and the locations of potential receptors are a useful way of conveying this information

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

Issues	Information that should be reviewed	Potential sources of information that should be consulted
Site context	***For all sites*** • *Groundwater Protection: Principles and Practice*, Groundwater Vulnerability and Source Protection Zone information, and guidance on the location and impact assessment of landfill sites. • Waste Local Plan designation	***From the Environment Agency*** • Discussions with the Environment Agency and review of relevant technical guidance ***From the local authority*** • Discussions with the relevant local authority waste planning officer and review of relevant Waste Local Plan
The identification of the potential hazards	***For all sites***: Relevant and available information on the following (where appropriate): • History of development • Site surveys and local topography • 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. ***For sites already in operation***: • Actual waste types deposited (current and historical) and proposed waste types • Actual data on leachate quality and likely future leachate quality (including whether the site may give rise to the discharge of hazardous substances or non-hazardous pollutants) • Existing lining / drainage systems in current cells • Data from any monitoring including any leak detection layers ***For sites not yet in operation:*** • Proposed waste types to be deposited •	***From a site visit*** • 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. ***From the landfill operator*** • Site surveys showing progressive site development • Planning permissions and Environmental Statements • Waste Management Licence applications and supporting information such as Working Plans (for closed sites that have not transferred to the EPR Regime) • Environmental Permit applications and supporting information. • Leachate quality information for existing phases and/or landfills that receive similar waste streams, leachate level information and Environmental Monitoring Reviews • CQA reports • Previous correspondence with the Environment Agency and other third parties. ***From the Environment Agency*** • Discussions with the Environment Agency • The Public Register may hold leachate quality information for similar sites in the vicinity of the landfill undergoing assessment that are operated by a different waste management company ***From miscellaneous sources***

Issues	Information that should be reviewed	Potential sources of information that should be consulted
	• Likely leachate quality including whether the site may give rise to the discharge of potential pollutants. (DoE, 1995; Knox *et al*, 2000; Environment Agency, 2004b).	• Technical guidance and relevant publications
The definition of the Source, Pathway and Receptor Terms and the establishment of the baseline conditions	Relevant and available information on the following (where appropriate): • Geology • Hydrogeology including aquifer classification from groundwater vulnerability and groundwater Source Protection Zone information • Location of surface water bodies • Flood plain designation • Environmental monitoring of both groundwater and surface waters, including the location and construction details of all monitoring points • Groundwater and surface water quality (including variation over time and analyses for hazardous substances and non-hazardous pollutants) • The identification of receptors and their sensitivities. This may include groundwater resources, 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 • Existing site conceptual model and/or groundwater risk assessment report previously prepared	***From a site visit*** • 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. ***From the landfill operator*** • Site surveys showing all monitoring locations. • Planning permissions and Environmental Statements • Waste Management Licence applications and supporting information such as Working Plans (For closed sites that have not transferred to the EPR Regime) • Permit Applications and supporting information. • Groundwater and surface water monitoring data and environmental monitoring reviews • Previous correspondence with the Environment Agency and other third parties. ***From the Environment Agency*** • Discussions with the Environment Agency • Information relating to rainfall, licensed abstractions, groundwater vulnerability, Source Protection Zones, other permitted discharges to surface waters and groundwater, surface water flows/quality, groundwater levels/quality, designated conservation areas and flood potential • The Public Register may hold groundwater and surface water monitoring information for sites that may be adjacent to the landfill undergoing the assessment. ***From miscellaneous sources*** • Details relating to public water supplies, such as water quality, water levels and abstraction volumes, may be available from private water companies. • Information relating to private water supplies may be available from Local Authority Environmental Health Officers or from water users themselves • Information relating to rainfall and other meteorological parameters can be

Issues	Information that should be reviewed	Potential sources of information that should be consulted
		obtained from the UK Meteorological Office and Centre for Ecology and Hydrology website for gauged river catchments (www.ceh.ac.uk). • Technical guidance and relevant publications (for example, EA / British Geological Survey Aquifer Properties Manuals). Environment Agency website. • Geological and hydrogeological data from the British Geological Survey • Information on sites of ecological importance or for nature conservation (for example, Natural England, Countryside Council for Wales, Environment Agency)

2.2.3 Site Investigations

The objectives of site investigations are to increase the understanding of site-specific conditions, and thereby reduce 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 site conceptual model, in order to critically test the site conceptual model and to provide site-specific data for use in any risk evaluation.**

The level of site investigation should be adequate to provide sufficient confidence in the site conceptual model (or to allow it to be refined) and to provide site-specific data for use within the risk assessment. Information that is likely to be obtained during the site investigation includes the physical conditions of the site, waste types / leachate concentrations, and the groundwater/surface water quality and flow regimes (see Appendix 4 Potential site investigations) for more information. Site investigations should conform to current good practice and be sufficiently comprehensive to give all interested parties a level of confidence in understanding of the site that is appropriate to the overall 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 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 through good practice, the supervision and reporting of the investigations by suitably trained and experienced professionals and by adopting a robust QA/QC method and audit trail. General guidance on site investigations is available in a number of other documents (for example, British Standards Institute (1999; 2001), Environment Agency, 2003a). Some of the potential site investigations that may be required are summarised within Appendix 4.

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 purpose.

2.2.4 Monitoring to establish baseline conditions

Environmental monitoring plays a central role in environmental risk assessment and management and is undertaken in order to gain information before the landfill begins operating in order to determine the baseline conditions; impacts during landfill operation and continued performance post-closure. Guidance on the monitoring of landfill leachate, groundwater and surface water has been published by the Environment Agency (Environment Agency, 2003a), 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, in order to validate model assumptions and selection;
- as confirmation that risk management measures are performing as designed (**via the use of control levels**);
- as a mechanism of determining whether significant adverse environmental impacts have occurred (**via the use of compliance limits**); and
- as a means of determining whether a landfill meets completion criteria.

With respect to the development of the site conceptual model, 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. Monitoring data collected for other purposes (for example, landfill gas monitoring) should be reviewed and used where appropriate.

2.2.5 Leachate and its hydraulic containment

The passage of leachate through a substantial and intact mineral barrier (such as an artificially established geological barrier) can be regarded as analogous to percolation through the 'soil and subsoil' and as such any input 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 input may become direct.

Hydraulic conditions may vary around the site and with time. These variations need to be fully assessed, 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. The nature of the mineral components of the landfill containment and attenuation system should also be considered. 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 (such as 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 England and Wales 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.

2.2.6 Hydraulic containment

Hydraulic containment works on the principle of maintaining a hydraulic gradient into the landfill site. Under these conditions, operators should reduce hydraulic gradients into the site in order to minimise inward seepage that will add to leachate production. It is intended 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. Dependent upon 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. You should refer to How to comply with your environmental permit. Additional guidance for: landfill (EPR 5.02) Environment Agency, 2009.

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 is also more difficult to guarantee since the duration that hazardous substances remain un-degraded is increased.

Where a sub-water table site relies on the control of water levels by means of an engineered collection system (for example, a drainage layer or pumping wells) the water in that collection system always constitutes groundwater unless the collection system is hydraulically isolated from natural groundwater by the geological barrier. In other words, although the collection system forms part of the management system for the site, the prevent or limit requirements of the EPR apply to the water contained within it. Depending on the circumstances the drainage system could itself, act as a compliance point.

Where the potential for a direct discharge is identified in the conceptual model and risk screening stage, the subsequent risk assessment will be correspondingly more detailed. Issues such as failure scenarios are considered in more detail in Section 3.7.

2.3 Risk screening

Risk screening is the process used to determine whether the landfill development represents, or potentially represents, a hazard to groundwater and surface water resources. This process typically involves identification of possible S-P-R linkages from the conceptual model and an initial assessment of the likelihood and magnitude of any effects that could be associated with each S-P-R linkage. Based on the assessment of the likelihood and the consequences of effects, the risk screening stage should also prioritise the risks such that the efforts in any subsequent more detailed risk assessment stage can be focused on those risks identified as being most significant.

Risk screening can be undertaken as the first stage of the risk assessment process for an application for an environmental permit or as part of a scoping document for the purposes of 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 5.1), which should also include discussions on the assumptions included within the conceptual model. It is recommended that the risk screening and prioritisation assessment is submitted to us along with the initial site conceptual model.

This is to ensure that it is clear and documented where the subsequent risk assessment effort should be directed.

2.3.1 Risk screening objectives

The objectives of the 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 and EPR.
- Determine whether leachate needs to be collected, in accordance with Annex I (2) of the LFD enforced through EPR. 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.
- Confirm whether a natural geological barrier is present and to make an initial assessment of the likely attenuation that this geological barrier could provide.
- Determine the status of the landfill development with respect to our landfill location position statement (Environment Agency 2012).
- 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.

2.3.1 Screening based on size and quality of the discharge

If the actual or predicted leachate volume and chemistry are likely to exceed the thresholds of quantity and concentration as discussed in Section 1.3, then the discharge is a groundwater activity and requires a permit under EPR and the subsequent assessment (prior examination) must demonstrate that the geological, engineering and operational controls are adequate to meet the requirements of EPR.

In practice, for most landfills, the assessment of whether the potential or actual discharge comes within the scope of the GWD will be made on the concentration of hazardous substances and non-hazardous pollutants (Box 1.1 and Appendix 1) rather than their volume or the assumed characteristics of an unsaturated zone. The volume of discharge will invariably be significant and the un-quantified effect of an unsaturated zone cannot be relied upon other than to provide a degree of confidence where the decision is marginal.

Adequate leachate characterisation is required for all levels of risk assessment.

Appendix 5 presents the Potential sources of information on leachate quality 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.

For **hazardous substances,** an **analytical framework for screening leachates** has been developed to assess whether these are likely to be present in the leachate (Appendix 6). Where concentrations of the core determinands exceeds the Minimum Reporting Value (MRV - Appendix 8) for those substances in leachate, the subsequent assessment and environmental permit must have regard to the requirements of the GWD. Additionally, where the GCMS scan provides >80% confidence of the presence of such substances they must be reported and it may be necessary to undertake further quantification of individual identified compounds.

The majority of leachates from landfill sites have the potential to contain both hazardous substances and non-hazardous pollutants.

As a consequence of the requirements of the LFD (to reduce the biodegradable content of landfilled wastes) it is likely that the chemistry of leachate from wastes deposited recently and in the future will differ to that deposited historically (Environment Agency, 2004c).

2.3.2 Screening based on the collection of leachate

Following submission of the risk screening, we are only likely to decide that leachate collection is unnecessary if the waste is inert (see Section 1.3.2 Inert Waste).

Leachate chemistry should be compared to water quality standards to provide an assessment of its potential hazard. Only where the actual or predicted leachate quality presents a hazard should the sensitivity of the hydrogeological setting be considered. We anticipate that the only non-hazardous landfills that will not need to collect leachate will be those accepting a very limited range of low hazard wastes, such as landfills receiving homogeneous, well-characterised, low hazardous materials from a single or very limited number of sources, and for locations where there is no potential receptor.

2.3.3 Screening based on the nature of the geological barrier

The existence and extent of any natural geological barrier is an important requirement of the risk screening stage. The assessment of the attenuation that the natural or artificial geological barrier would provide is a vital consideration. The geological barrier must provide sufficient attenuation between the landfill source and any potential groundwater receptor in order to protect soil and ensure compliance with the GWD (see also Section 1.2.3).

For hazardous and non-hazardous landfill sites, significant attenuating properties will be necessary and it should not be automatically assumed the natural geological barrier will offer adequate attenuation. The geological barrier may be highly heterogeneous with lenses of higher permeability and other discontinuities. In these circumstances, the need for active control of groundwater inflow into the site, either during construction or landfilling, could give an indication as to whether the in-situ materials may act as a natural geological barrier or not.

This assessment of attenuation is the same as the consideration of the purifying powers of the soil and sub-soil (Appendix 3) to ensure that the attenuation capacity is sufficient to prevent a risk to groundwater (to avoid pollution of groundwater by ensuring there is no unacceptable input to groundwater).

The risk screening must be sufficient to give an initial indication as to whether the natural geological barrier would meet the LFD requirements in terms of there being sufficient attenuation capacity to protect groundwater. If not provision does exist within the LFD to artificially complete and reinforce the geological barrier (see Section 1.2.3).

2.3.4 Screening based on landfill location

As part of the consideration of sources, pathways and receptors, the risk screening stage must identify the aquifer classification, any groundwater Source Protection Zones (SPZs), the presence of drift above an aquifer and the likely water level(s). Alongside details of waste types and landfill operations, this will enable an assessment to be made against our landfill location position statement (Environment Agency, 2012). 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.

2.4 Compliance points

A principal requirement of EPR is to assess the actual or potential impact of the discharge on groundwater in the vicinity of the site (or prior examination and requisite surveillance). An important element of the risk screening process is the choice of the points at which compliance with the GWD will be evaluated.

A compliance point is a point at which Environmental Assessment Levels (EALs) are set in order to ensure that relevant environmental standards will be met at all the receptors at risk. It is therefore important to make a clear distinction between the concept of compliance point' and the receptors it aims to protect.

General guidance on compliance points is provided in our H1 Guidance: Annex (j) Groundwater (Environment Agency, 2011) and in the European Commission's Common Implementation Strategy (CIS) for the Water Framework Directive Guidance Document No 17 (EC 2007).

For landfill-related studies, typical compliance points are likely to include the following:

- The water table. This is not readily monitored beneath a landfill and therefore theoretical as only suitable as a basis for calculating concentrations of hazardous substances, to check whether the entry of hazardous substances to groundwater will be avoided.
- A point (for example, a monitoring borehole or spring suitable for monitoring) at the down-gradient edge of the landfill to check that:
  - monitored concentrations of hazardous substances are acceptable in terms of the 'prevent' objective;
  - calculated and monitored concentrations of non-hazardous pollutants will not cause pollution (such as harm to the surrounding groundwater resource or via groundwater flow to specific receptors such as abstractions, watercourses or ecologically sensitive sites.
- An off-site receptor (for example, abstraction borehole, spring, wetland, stream or river).

Illustration of the selection of compliance points is given in Figure 2.2.

More detail on the number and spacing of monitoring boreholes is given in our Guidance on monitoring of landfill leachate, groundwater and surface water (Environment Agency 2003a).

2.4.1 Compliance points for hazardous substances

EPR requires that the input of hazardous substances to groundwater must be prevented. An input is considered to have been prevented if the substance concerned is not discernible in the groundwater above natural background concentrations or a relevant minimum reporting value (MRV) after the immediate dilution as the discharge enters the groundwater (the interpretation of 'prevent' is further discussed in our H1 Annex (j) Groundwater (Environment Agency, 2011). Effectively the receptor at risk from hazardous substances is the groundwater immediately surrounding the area of discharge. Reference should also be made to our guidance: Assessing the discernibility of hazardous substances from discharges into groundwater (GP3 Part 5, Environment Agency, 2012).

Discernible discharge will be measured at a compliance point which, for predictive modelling of potential indirect inputs of hazardous substances, will normally be immediately down-gradient of the discharge, within the vertical mixing depth. A monitoring point for hazardous substances (and the point at which compliance with control levels and compliance limits are assessed) will normally be one or more boreholes directly adjacent to the landfill. This reflects the practical problems in collecting samples from beneath a landfill.

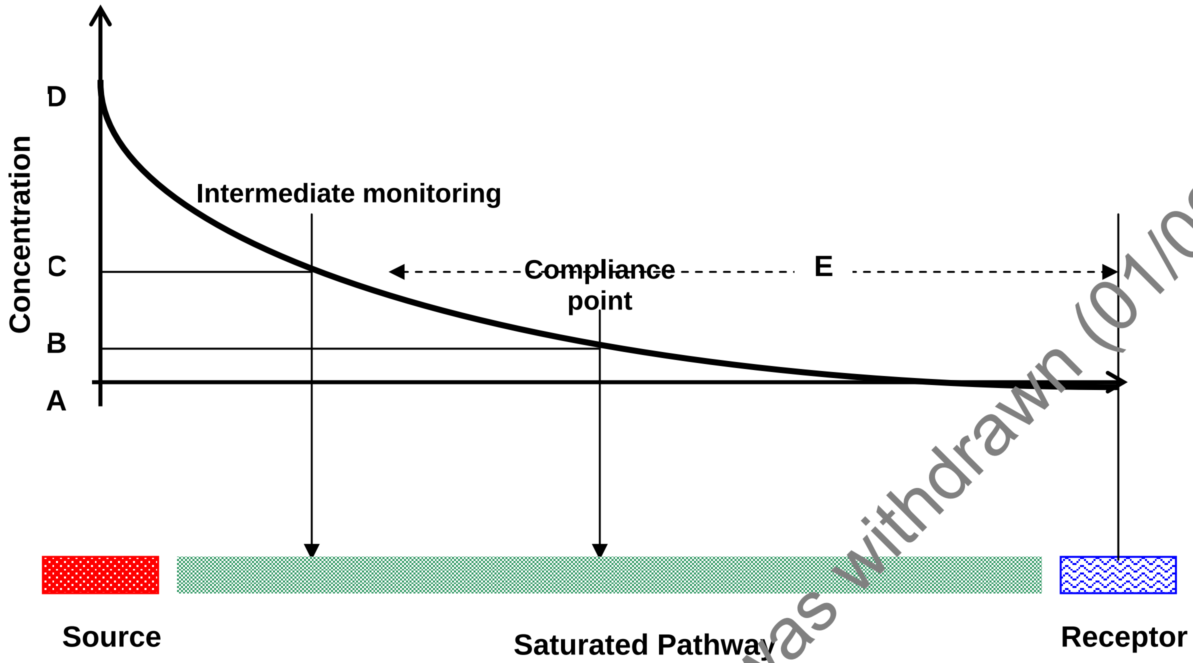
2.4.2 Compliance points for non-hazardous pollutants

Inputs of non-hazardous pollutants should be limited so as to avoid pollution of groundwater. In most instances the compliance point for non-hazardous pollutants will be monitoring boreholes adjacent to the landfill. In some instances, where groundwater has no current or potential future resource value, boreholes further from the site may be appropriate. The selection of a compliance point other than at the perimeter of the site would have to consider the sensitivity of the location of the landfill.

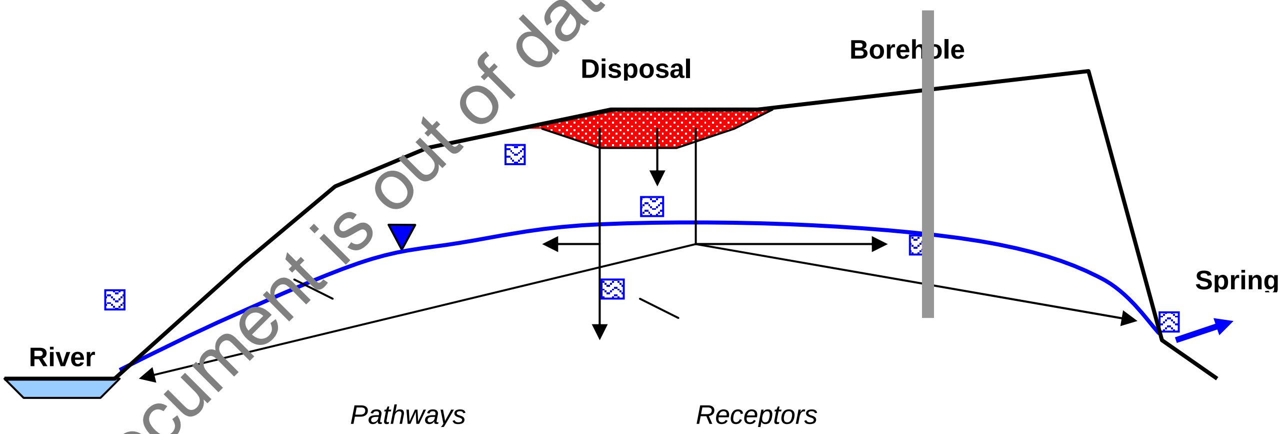
2.4.3 Surface water features as a compliance point

Where groundwater has not been determined as a receptor, the compliance point could be a surface water feature in the vicinity of the landfill. The selection of a surface water feature as a compliance point is only likely to be acceptable where the consideration of all the S-P-R linkages has identified the surface water as the highest priority risk, and where we agree that it represents the most significant (water) receptor for any contamination from the landfill (that is where groundwater is not a useable resource and is for example, Unproductive Strata).

Figure 2.2 Compliance point selection



Note: the above ***one dimensional*** *source-pathway-receptor relationship could translate into any number of possible 3D linkages, for example:*



Key to Figure 2.2 (Compliance point selection)

A = Environmental standard necessary to protect the **receptor**.

B = Environmental Assessment Level (EAL) at a **compliance point**, set to ensure the environmental standard at the receptor is/will be met (may be physical for example, an actual **monitoring point** or virtual for example, a point used for model prediction).

C = Quality measurement at **intermediate monitoring points** to provide advance information.

D = Discharge source concentration.

E = Possible range of compliance point locations according to site specific conditions – could be at the receptor itself, or some other point along the pathway.

2.5 The Selection of Environmental Assessment Levels (EALs)

An Environmental Assessment Level (EAL) is a value set at the compliance point calculated to be a maximum concentration allowable at that point in order to protect a receptor (see figure 2.2). An EAL could be either a theoretical value used in predictive modelling to assess the acceptability of a particular site design, or a value applied to physical monitoring point for the purposes of requisite surveillance. It may also form the basis of a compliance limit (see Chapter 4) where required.

The site conceptual model and risk screening should identify the receptors of the groundwater around the landfill and the most appropriate water quality standards that apply to them. Relevant water quality standards will generally be defined by UK Regulations (such as Water Supply (Water Quality) Regulations), EU Directives or another relevant source (such as non-statutory Environmental Quality Standards).

These quality standards and the baseline water chemistry should be used to derive appropriate EALs for each compliance point for each of the potentially polluting substances that might be present within the landfill leachate and used in the modelling or subsequent monitoring. All current and future potential uses of the groundwater would need to be considered for this purpose including any surface watercourses and ecologically sensitive features that depend on groundwater (see our H1 Annex (j) Groundwater. Environment Agency, 2011).

In some cases the compliance point will be the receptor itself; so the EAL may actually be the same value as the water quality standard for that receptor. If the compliance point is located at some other point along the groundwater pathway the EAL could be a higher concentration, back-calculated according to your understanding of the attenuation profile between the source and the receptor. If the attenuation profile is not known with any confidence the value of the EAL in a compliance point set between the source and the receptor may need to be the same as the water quality standard at the receptor. Each case demands a site specific consideration – drinking water standards or EQS values should not be assigned by default.

Some of the standards that should be considered in developing the most appropriate EALs for groundwater are currently being updated (GP3 Part 5. Environment Agency, 2012). An EAL should be based on the most stringent applicable standard applicable at the receptor. This will therefore provide the greatest level of protection.

Four problems typically arise in the selection of an EAL:

- ***No water quality standard is readily available for the relevant chemical species in the leachate*** – an appropriate EAL should be developed having regard to baseline groundwater chemistry and taking account of other published information. Determination of 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 Environment Agency.

- ***Baseline groundwater quality is naturally inferior to the most stringent water quality standard available*** – consider selecting other chemical species for use in setting of control levels and compliance limits or develop an appropriate EAL having regard to baseline groundwater chemistry.

Note: In setting a water quality standard where there is a significant natural background concentration, give consideration to 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*** – determine the EAL 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 inputs. Where possible, select chemical species not arising from the historical contamination. Develop the appropriate EAL having regard to natural baseline groundwater chemistry and the likely sources and duration of the historical contamination. Adopting this approach at this stage 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*** - the selection of an EAL may take account of the baseline levels of those substances in the receiving groundwater. The selected EAL is likely to be set so as to limit concentrations at the receptor to a point between baseline concentrations and the water quality standard, as long as in doing so this does not lead to a significant and sustained upward trend in the concentration of pollutants. 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 ~50 mg/l, DWS 250 mg/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 DWS' of 2 000 and 5 000 μg/l respectively. EQS' for copper (1 - 28μg/l) and zinc (8 - 500μg/l) are considerably lower (the range given for EQS' relates to hardness of the receiving water).

In many cases the EAL (at the compliance point) for groundwater in Principal and Secondary Aquifers will be derived from the need to ensure that either the Drinking Water Standard (DWS) or the Environmental Quality Standard (EQS) are met at the receptor, subject to consideration of natural hydrochemistry. However, such standards (and their compliance regimes), may not necessarily be appropriate environmental quality values for specific receptors at risk. For example, if an EAL is being set to protect the water quality at a known drinking water supply borehole it should be derived from a value which at the point of abstraction assures long term compliance with the DWS at the tap. For example, 0.75 x DWS or some other proportion might be considered a more appropriate environmental value at the receptor.

In the case of low permeability formations that do not represent a groundwater resource locally (or a potential groundwater resource), an EAL may only be required in order 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 our Remedial Targets Methodology (Environment Agency, 2006). The 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 current or potential future economic water resource but that it may still support important water resources or features such as wetlands or surface watercourses. Typically, base flow into the nearest surface water body should be protected to ensure no deterioration against baseline quality, or where baseline quality is currently impaired, base flow into the surface water should not exceed the relevant Environmental Quality Standards3.

You should confirm that low permeability formations, have no exploitable water resource value, or potential resource value. Some low permeability rocks 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. Under these circumstances the water bearing and transmitting horizon is likely to be considered the primary receptor. Our aquifer designation maps may assist in defining such areas. Our interactive maps are available via 'what's in your back yard' at www.environment-agency.gov.uk

2.6 Necessary technical precautions

In the context of the EPR, necessary 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 necessary technical precautions, which should be based on good practice requirements from guidance such as Environment Agency 2009a and 2009b. The risk assessment process must determine the acceptability of the proposed measures.

In practice we expect to see an assessment of indicative precautions in the conceptual model and the risk screening at the permit pre-application stage. Details of the engineering standards for those precautions should be presented at the permit application stage, 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 and it is anticipated that between the production of the conceptual model and the submission of the permit application that the design and operation of the landfill will have been revised on a risk basis. We do not expect to routinely see all the iterations between a submitted conceptual model and the final permit application.

Where a mineral material is used for a sealing liner or geological barrier (for example, clay, colliery spoil, bentonite enhanced sand, etc.) an assessment of the attenuation potential of the mineral component should be acceptable as part of the review of technical precautions,

---

[3] An EQS is a water quality standard that is protective of aquatic life in surface watercourses.

but only if the operator is able to provide evidence of that attenuation. Evidence of attenuation should be provided via testing of site materials for attenuating properties rather than reliance on literature-based values though this is dependent 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 1.2.6); although a substantial, intact mineral barrier may be viewed as preventing a direct input, the risks and consequences of direct inputs 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 the lining system must be considered in all situations.

Risk screening may also provide an initial indication as to the engineering standards and other operational controls necessary to comply with the LFD and GWD (see Environment Agency, 2009a, 2009b, for more information). It is likely that the risk screening will not provide sufficient confidence to determine the appropriate engineering requirements other than in a limited number of low sensitivity locations.

2.7 Further work

One output from the risk screening process should be a recommendation of the appropriate level of further risk assessment work. Chapter 3 discusses the applicability of generic quantitative and detailed quantitative risk assessments and gives an indication as to the circumstances where each may be appropriate.

Chapter 3 - Quantitative risk assessment

3.0 Introduction

Following the formulation of a robust site conceptual model and risk screening, subsequent hydrogeological risk assessment comprises a more detailed (quantitative) risk assessment. This more detailed risk assessment stage should be carried out at an appropriate level of complexity that is proportional to the potential environmental impacts that the site could cause, the level of uncertainty, and the likelihood of a risk being realised. **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.

The appropriate complexity of assessment for a site should be determined from the potential risks presented by the site, which are linked to the nature of potential hazards, the sensitivity of the surrounding environment, degree of uncertainty and likelihood of a risk being realised. The tiered approach (Figure 2.1) as 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 generic quantitative risk assessment, then more complex work may not be necessary. Equally if there is insufficient confidence in the assessment when considered at a simple level, then more complex work must be carried out in order to refine the risk assessment and test compliance with both the LFD and the GWD. An operator could proceed immediately to a higher level of complexity of risk assessment if it is considered to be an appropriate course of action.

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

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

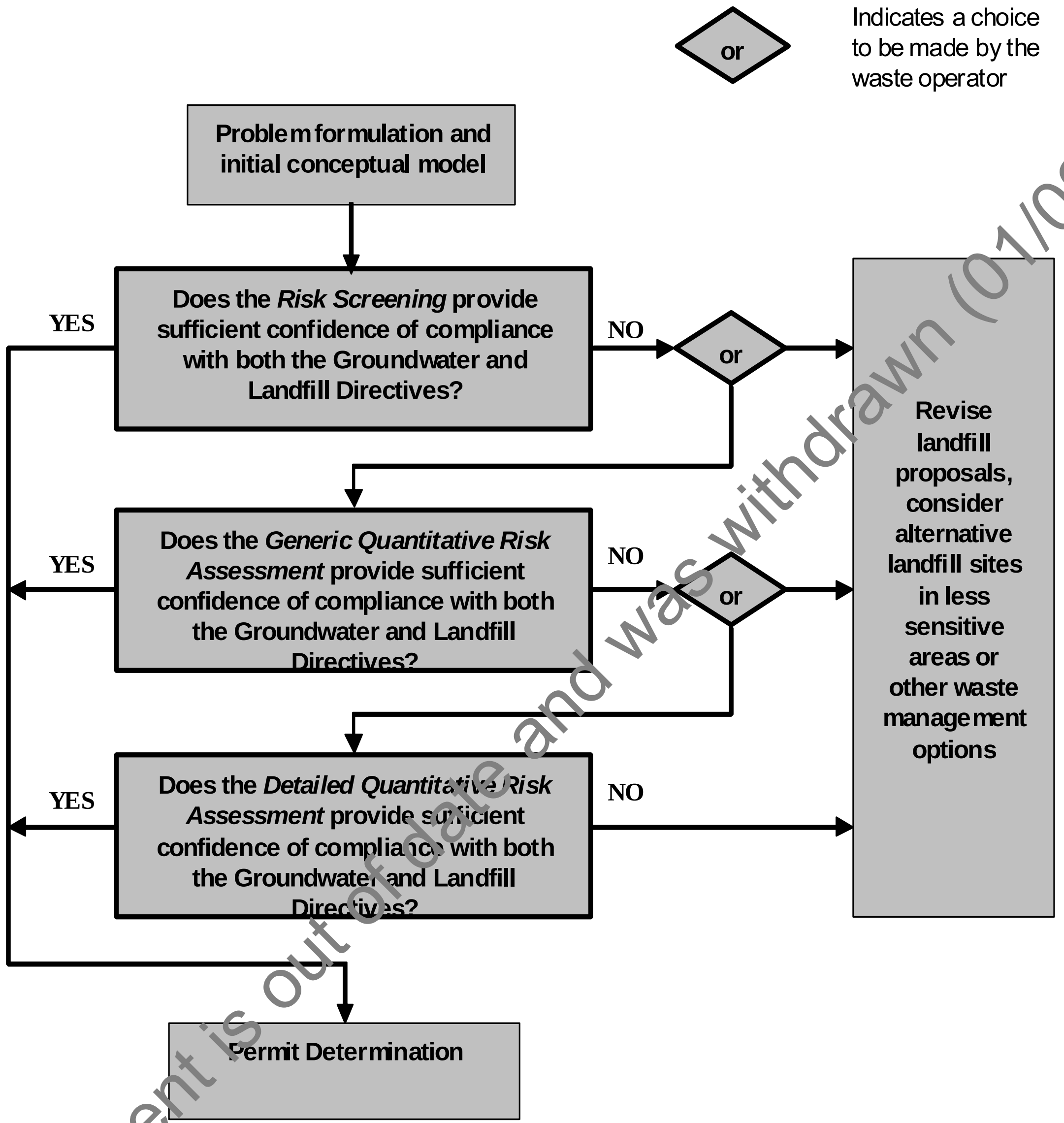
- To determine whether the development complies with the GWD. That is, the input of hazardous substances into groundwater will be prevented and there will be no pollution of groundwater (or associated receptors) by non-hazardous pollutants over the whole lifecycle of the landfill.
- To provide the basis for deciding whether the engineering measures and other proposed necessary technical precautions fulfil the requirements of the LFD and the GWD.

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.

In order to meet the above objectives the following 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 life-cycle of the landfill;
- quantify the S-P-R linkages over the whole life cycle of the landfill;
- investigate the likely impact of accidents;
- investigate means of limiting the transport of pollutants along the S-P-R linkages over the short and long-term; and
- develop indicative completion criteria with respect to groundwater.

Figure 3.1 Illustrative risk assessment framework



3.1 Generic quantitative and detailed quantitative risk assessment

There are two levels of quantitative risk assessment that may be used, generic and detailed, the nature of which are as follows. Please refer also to Table 3.1 which gives an overview of the indicative risk assessment requirements for a range of scenarios and landfill classifications.

3.1.1 Generic quantitative risk assessments

A generic quantitative risk assessment (GQRA) 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. Generic quantitative risk 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. They should be conducted where feasible S-P-R linkages are identified, or in preparation for conducting a more complex assessment, and where either:

- It is clear from the site 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, etc.

The assessment should include simple assessments of the predicted impact of the landfill on water quality, including groundwater. Many Unproductive Strata are underlain by, or contain, water-bearing horizons that may not be apparent by reference to either geological maps or information from the Environment Agency.

The geological barrier must provide sufficient attenuation between the landfill source and any potential groundwater receptor in order to protect soil and ensure compliance with the GWD. The assessment will be required to demonstrate if the environmental protection of this barrier is sufficient, or if it will need to be artificially enhanced. The assessment will need to demonstrate that the proposal poses little likelihood of unacceptable inputs to groundwater. By doing this it will demonstrate compliance with the GWD and the LFD.

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 can not be made using conservative inputs, methods and assumptions, then a detailed quantitative risk assessment should be carried out.

3.1.2 Detailed quantitative risk assessments

A detailed quantitative risk assessment (DQRA) should be carried out in a quantitative manner using stochastic (such as probabilistic) techniques to analytical solutions, or mathematical solutions. The use of more site characterisation data is crucial to a more detailed site-specific assessment. Such assessments 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.

Detailed quantitative risk assessments should be carried out where complete S-P-R terms are present and where either:

- The site setting is sufficiently sensitive to warrant a detailed assessment. For example, within a Source Protection Zone; on permeable strata (Principal and Secondary Aquifers); or close to other receptors such as surface water bodies or wetlands.
- There is uncertainty relating to any of the source, pathway or receptor terms such as variable leachate quality, undefined groundwater flow pattern, which cannot be overcome by the adoption of conservative inputs or assumptions.
- Where there is uncertainty in the generic quantitative risk assessment.

For detailed quantitative risk assessments additional data collection and calculations, or more sophisticated numerical analyses will be needed 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.

Table 3.1 Indicative risk assessment levels for a range of scenarios

	Landfill Classification (1)		
Landfill Setting (2)	**Inert**	**Non-hazardous**	**Hazardous**
Low permeability strata (for example, Unproductive Strata)			
No surface water or other receptors (for example, springs or abstractions)	RS	GQRA	GQRA / DQRA
Surface water, springs, abstractions, etc. present or significant uncertainty	RS / GQRA	GQRA / DQRA	DQRA
Below the water table	RS / GQRA	GQRA / DQRA	DQRA
Moderate permeability strata (for example, Secondary Aquifer)			
Outside SPZs, no surface water receptors, above the water table	RS	GQRA	GQRA / DQRA
Outside SPZs, no surface water receptors, below the water table	RS	GQRA / DQRA	DQRA
Outside SPZs, surface water receptors, below the water table or uncertainties	RS / GQRA	DQRA	DQRA
Within SPZ2 or SPZ3 no surface water receptors, above the water table	RS / GQRA	DQRA	DQRA
Within SPZ2 or SPZ3, no surface water receptors, below the water table	RS / GQRA	DQRA	DQRA
Within SPZ2 or SPZ3, surface water receptors, below the water table or uncertainties	GQRA	DQRA	DQRA
Highly permeable strata (for example, Principal Aquifer)			
No surface water receptors, above the water table	RS / GQRA	DQRA	DQRA
No surface water receptors, below the water table	GQRA	DQRA	DQRA
Surface water receptors, below the water table or uncertainties	GQRA	DQRA	DQRA
Within SPZ2 or SPZ3	GQRA	DQRA	DQRA

1. RS - Risk Screening; GQRA - Generic quantitative risk assessment; DQRA - Detailed quantitative risk assessment

2. This table is only intended as a 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 our Groundwater Protection: Principles and Practice (Environment Agency 2012).

3.2 Requirements of all risk assessments

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

3.2.1 Emissions to groundwater

We always aim to maintain existing groundwater quality. The risk assessment should estimate the potential magnitude of pollution threat presented by a landfill to groundwater resources and other resources and receptors that groundwater supports in both the short and long-term. In most cases, this will mean the predicted concentrations of contaminants at each receptor from the landfill (the impact of emissions on groundwater). More specifically, the risk assessment needs to establish whether the predicted inputs to groundwater from the landfill comply with the requirements of the GWD at all stages of the life of the landfill.

3.2.1.1 Hazardous substances

For hazardous substances, the assessment must demonstrate that all measures deemed necessary and reasonable are taken to avoid the entry of hazardous substances into groundwater.

The criteria applied shall typically be whether hazardous substances (normally those identified during the screening procedure described in Appendix 6 (Analytical framework for screening landfill leachate) or predicted on the basis of the proposed waste stream) are present in the leachate at concentrations that would give rise to a discernible input to groundwater immediately adjacent to the discharge area. This will involve comparison of predicted leachate chemistry (at the point of entry to the groundwater) with Minimum Reporting Values (MRV) for the substance in clean water (Appendix 8) and natural baseline water chemistry.

The assessment may further take account of attenuation processes in any landfill liner and unsaturated zone. It can allow for the immediate dilution in groundwater but attenuation and dispersion in the saturated zone or dilution from groundwater flowing outside the mixing zone can not be considered.

3.2.2.2 Non-hazardous pollutants

For non-hazardous pollutants, the assessment must demonstrate that all measures necessary are taken to limit inputs into groundwater so as to avoid pollution or significant and sustained upward trends in the concentration of pollutants in groundwater or deterioration in status of the groundwater body. Consequently, it will consider whether the predicted concentrations of non-hazardous pollutants are likely to exceed relevant use-based standards and other relevant environmental quality criteria at the receptors following dilution. Receptors include both the existing uses of the groundwater and all feasible future uses of the resource. For practical purposes, EALs will normally be set at monitoring boreholes at the downstream boundary of the landfill. The EALs in these compliance points will be set so as to take account of the predicted effects of attenuation and dilution as groundwater subsequently moves down-gradient towards the receptors.

For some substances, such as chloride, deterioration from baseline levels (typically less than 50 mg/l) to the drinking water standard (250 mg/l) may be unacceptable (the standard may not be appropriate to protect the groundwater resource). We will advise on these aspects, taking account of the local hydrogeological system in which the landfill is located and GWD requirements to avoid significant and sustained upwards trends in concentrations of pollutants.

The exact nature of the calculations that are required to support the assessment should be dependent upon the environmental setting of the site and the development proposals.

Examples of potential calculations are:

- 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, 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 at which active management of the landfill will cease (for example, extraction of leachate and maintenance of leachate collection systems).

In addition to the predicted contaminant concentrations, the risk assessment should estimate the likelihood of these concentrations being realised, which may be a qualitative description, or the output from a probabilistic quantitative assessment. We can only permit activities where it is shown, by **prior examination** (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 reliability of the data and the treatment of uncertainty.

The risk assessment process is not an abstract exercise but must be closely linked to the actual landfill design and operations, such as the necessary technical precautions (Section 2.6). There is no point in conducting a detailed quantitative risk assessment for a liner design that in reality could not be constructed or would be unstable. Similarly, assumptions on long-term leachate management should take account of the inevitable deterioration in the performance of engineered leachate collection and extraction systems (see Environment Agency 2002).

3.2.2 Degradation of engineering and management systems

The risk assessments must be carried out for the whole lifecycle of the landfill 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 lifecycle of the landfill. 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 and capping systems.

In this context, the term 'degradation' (of capping, liner and engineered systems) is used to refer to inevitable processes that will occur to the non-mineral capping and liner materials and structures within the landfill environment over time. These effects cannot be prevented, and the landfill design should take this into account in order to ensure adequate long-term performance. In addition, pollution may also result from failure of engineered systems due to poor design, assessment or construction, or by accidents and possible failure scenarios (see Section 3.7). These issues need to be addressed independently.

The approach to degradation of different components of the engineering and management systems incorporated into LandSim (v2.5+) is outlined in Box 3.1.

Box 3.1 Degradation of engineering and management systems

Geomembrane liners (for example, HDPE)

The material is expected to degrade over time as anti-oxidants 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, it is expected that after an initial period when the geomembrane performs as designed, the area of defects will 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 assumed to remain unchanged throughout the lifetime of a site. Although there may be a reduction in the attenuation capacity of a mineral liner over time as sorption / retardation sites are exhausted, sorption / retardation calculations and modelling (such as LandSim) assume that there is no limit on sorption sites and no change in this assumption over time.

Drainage system

This is expected to perform as designed until we agree through a permit variation that maintenance is no longer necessary. At that time the drainage system will become clogged very quickly (effectively instantly) due to biological, chemical and physical reactions. It will subsequently have permeability equal to that of the overlying waste.

Cap

All capping systems are assumed to allow their design infiltration after they are installed. Geomembrane caps will degrade and we will ensure through ongoing regulation that its performance will not reduce. Clay or geosynthetic clay liner (GCL) caps are expected to continue to perform to their design specification and require less maintenance.

Note: Deterioration in the performance of mineral (clay and GCL) caps is not included in LandSim 2.5. For more information please consult LandSim help files and User Manual.

Source: LandSim v2.5 (Environment Agency / Golder Associates, 2007)

3.3 Risk assessment tools

A number of assessment tools, including computer models can aid the hydrogeological risk assessment process. Table 3.2 presents some examples of the types of software assessment tools that are currently available. The choice of assessment tool should be a matter of professional judgement to be agreed between the assessor and the Environment Agency, dependent upon the nature of the proposed development, the setting of the site and the volume of available information.

Nevertheless, where site conditions are consistent with the conceptual model (in particular, above water table sites) incorporated into LandSim (v2.5 Environment Agency, 2007), this is the preferred model for assessing the risks to groundwater from landfill sites.

3.3.1 LandSim

LandSim (a software package that uses Monte Carlo stochastic techniques), is a customised risk assessment tool that has been produced specifically for the assessment of risks to groundwater from landfills. LandSim was introduced by the Environment Agency in 1996 and subsequently refined in order to: achieve a consistent approach to the estimation of hydrogeological risks of landfills; provide an audited and verified code that is widely accessible; and aid comprehensive reporting of input values, assumptions and results.

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 the life of a landfill site may not be applicable for another phase. For example, an operational cell where the liner has recently been installed is likely to be very different from the same site fifty years post closure (where there may have been degradation of the engineered liner, the leachate drainage systems and changes in the leachate quality). A variety of scenarios should be developed to reflect different phases of the life of the landfill.

Parameter values should, as far as possible, should 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 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, Kd) and, ideally, contaminant degradation rates.

Table 3.2 Summary of some risk assessment tools

Risk assessment tools	Applicability to differing levels of complexity used for risk assessments		
	Risk-screening	**Generic**	**Detailed**
Qualitative Assessment	√		
Proprietary spreadsheets (such as MS Excel™) used for calculations such as mass balance estimations, analytical and semi-analytical flow/transport solutions, etc. based on worst case (generic data)		√	
LandSim v2.5 (using worst-case generic assumptions)		√	
RAM		√	√
LandSim v2.5 (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			√

3.3.2 Cation exchange capacity

An overview of the available Cation Exchange Capacity (CEC) is given in Box 3.2. CEC relates to the total number of negative charge sites in a given amount of solid at which reversible sorption and desorption of cations can occur. Only the effects of cation exchange reactions on ammonium transport are represented in LandSim v2.5.

Box 3.2 Cation exchange capacity: LandSim

Retardation factors determined on the basis of an experimentally derived K_d will include an assessment of the potential impact of cation exchange reactions. Cation exchange capacity (CEC) is modelled differently from partition factors in that it is an attenuating process that reduces the impact of leachate concentrations on a receptor, whereas retardation factors merely slow the contaminant transport rate.

LandSim includes a facility to model the effects of CEC on the unsaturated zone and in the clay engineered barrier (if present). Only the effects of cation exchange reactions on ammonium transport are represented since ammonium is known to be sensitive to cation exchange processes and to have a low rate of exchange reversal (Heikkinen et al, 1995).

The CEC of a soil depends upon a number of factors, including soil mineralogy, the ionic strength of the leaking leachate and the relative concentrations of cations within the leachate. As a result, it is difficult to determine the effects of cation exchange capacities in non-laboratory situations. The LandSim approach is based on work carried out at Gorsethorpe Landfill (Report to DoE, CWM 034/92).

The vulnerability of a site can be evaluated by considering a time when all potential exchange sites have been taken up and cation exchange is no longer a process aiding attenuation. The time for this to occur is not considered when retarded travel times are calculated since the retardation factor should implicitly take account of cation exchange process. Retarded travel times should therefore include the effects of cation exchange.

When the unretarded travel time is calculated for ammonium, the transport time is increased by adding the time to exhaust the CEC.

For the specific equations and further details please refer to the LandSim Help files.

Source: LandSim2 Help Files

3.3.3 Use of alternative models to LandSim

It is unlikely that we will accept alternative models as we would have to benchmark one model against LandSim, our preferred model. This is very complex and we would not have the resource to do it. If an alternative model is presented, the alternative model will need to have evaluated against LandSim as a benchmark and the results of that evaluation have been documented and agreed by us. If we agree to alternative models being used we will need a working copy of the model to be supplied to us so that we can properly evaluate the model output. However, we may not be able to run this software. There may be cases where LandSim is not appropriate. For example, sub water table sites where the diffusion spreadsheet may be more applicable. You are advised to liaise with us first before using a different model to LandSim.

Although LandSim, and other modelling software, are useful tools, they comprise only one component in the assessment process. Models are aids to decision making – they do not make any decisions themselves. The assessor must make the decisions, using the model results and an 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 us 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 prior to the risk assessment outputs being reviewed.

3.4 Priority contaminants to be modelled

The actual contaminants that should be modelled at a site will depend upon the nature of the wastes deposited.

The number and range of potentially polluting substances that should be modelled should be determined on a site-specific basis, using the following screening process:

- Establish the presence of **hazardous substances** within a landfill leachate using the analytical screening procedures set out in Appendix 6. Where the screening procedure identifies elevated concentrations of hazardous substances (thresholds are given in Appendix 6), the individual compounds should be speciated and 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.
- To minimise workload, obtain information on **non-hazardous pollutants** in leachate as set out in Appendix 5. 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. If an appropriate selection of indicator species is made, including

conservative and persistent species, it should normally be possible to assess the site using less than 10 substances (Note: applies to non-hazardous pollutants).

The modelling and conclusions should be quality assured by a competent person.

The exact contaminants that are appropriate for a risk assessment are 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 3.3.

Table 3.3 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

3.5 Confidence levels

Stochastic (probabilistic) analysis is likely to be a commonly used assessment tool during a detailed quantitative risk assessment and predictions may be made at a range of confidence levels. These outputs indicate the degree of confidence that you can have about a particular outcome.

For these assessments the acceptable probability of an undesirable outcome occurring is commonly set at the 95%ile. This represents the point at which the assessor can be 95% certain that the actual outcome will be less than the maximum acceptable level (assuming the model and data is representative of the real system). For example, in a LandSim assessment, the 95%ile of the predicted concentration on water quality represents the level at which the assessor can be 95% certain that the actual concentrations will be less than the maximum acceptable concentrations (for example, EALs for non-hazardous pollutants). The 95%ile 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 generic quantitative risk assessments, low probability conditions (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 the person undertaking the risk assessment experience and knowledge of the processes being simulated in any model. This means the ability to determine whether the assumptions made are conservative and whether the estimated resultant concentrations could be regarded as being 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 are simplified representations of reality and should be viewed as aids to the decision-making process. Decisions as to whether the site complies with the LFD and the GWD must combine professional judgement, the model results and 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 the legal requirements, the waste operator can consider the following options to:

- Collect additional site-specific data (such as attenuation properties or groundwater levels, etc.) to reduce uncertainty and allow the use of less conservative assumptions in the model.
- Carry out more detailed risk assessment work at a higher level of complexity (only applicable if the risk assessment has been carried out at a simple level).
- Alter the nature of the development so that 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, etc.).
- 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 (such as the level of harm that could result if the landfill fails). Even a detailed quantitative risk assessment may not provide sufficient confidence in a landfill project with a long-term pollution potential if it is located in a particularly sensitive position. Such locations are identified in our Groundwater Protection: Principles and Practice (Environment Agency, 2012).

3.6 Hydrogeological completion criteria

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 (Environment Agency, 2010c). 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 is dependent 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 (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 un-managed 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 Chapter 5).

3.7 Accidents and possible failure scenarios

The inevitable degradation, over time, of engineered systems should form part of the normal risk assessment process. This should aim 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 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 in terms of 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 may be considered.

Table 3.4 Examples of accidents and possible failure scenarios	
Accident	**Direct consequence of an 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 only be required if there is evidence of recent near surface seismic activity.

Identification of possible accident scenarios should, where possible, is provisionally agreed at the environmental permit 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).

There have been a number of recorded incidents of damage to liner systems. Other structures including leachate extraction wells and drainage pipe work are also prone to damage from accidents. In order 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 accidents and failure is a more difficult process than the estimation of their consequences.

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

Chapter 4 - Groundwater control levels and compliance limits.

4.0 Introduction

Groundwater control levels and compliance limits form the basis for assessing groundwater-monitoring data at landfill sites. They are intrinsically linked to environmental monitoring which:

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

This Chapter deals with the reporting requirements for groundwater control levels and compliance limits.

4.1 Groundwater control levels

Groundwater control levels are site-specific assessment criteria that are used to determine whether a landfill is performing as designed and are intended to draw the attention of site management 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 investigation 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 our technical guidance on the monitoring of landfill leachate, groundwater and surface water (Environment Agency, 2003a).

4.1.1 Aims of control levels

Control levels should:

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

4.1.2 Deriving control levels

Control levels must be set for all landfills where monitoring is needed. They must be set so that are appropriate for each individual landfill and its local setting, taking into account factors such as historical groundwater contamination, poor natural groundwater quality, baseline trends in groundwater chemistry, etc.

Control levels should be set for each parameter for which a compliance limit has been set but 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 Environment Agency to identify at an early stage, whether the performance of the landfill is deviating from its design performance, as assumed within the site conceptual model.

Control levels should give an early warning that allows action to be taken by the operator to avoid pollution.

The approach taken to derive control levels for hazardous substances and non-hazardous pollutants is likely to differ, and appropriate methods are described below.

4.1.2.1 Hazardous substances:

The GWD requires that entry of hazardous substances into groundwater is prevented, which means that there should be no discernible increase in their concentration in groundwater.

Since the compliance limits for hazardous substances will generally be very low (at background or MRV concentrations), it will not be feasible to use a lower concentration as a control level.

It is recommended for hazardous substances, other parameters are considered which control the potential for hazardous substances to enter groundwater, such as leachate chemistry and leachate head. Appropriate parameters should be selected having regard to the site conceptual model 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 is a significant deviation from the assumed values incorporated within the site conceptual model. For example, if leachate is assumed to have a concentration of a hazardous substance no greater than 250 µg/l, it would be appropriate to set control levels (applied to leachate monitoring data) at for example, 250µg/l plus 10%, 20% and 50% (that is 275, 300 and 375 µg/l respectively). Increasing levels of contingency action would be instigated at each point (see Table 4.1). Additionally, it is recommended that the trend in pollutant concentration over time is reviewed to check whether concentrations are rising towards the values assumed within the site conceptual model.

Similarly, if leachate head is a sensitive parameter in the risk assessment and it is assumed within the site conceptual model that leachate head will not exceed for example, two metres above the base of the site, then 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, review of trends in monitoring data is important to check whether the control levels are likely to be compromised in the near future.[4]

4.1.2.2 Non-hazardous pollutants:

The GWD requires that the input of any non-hazardous pollutants should be limited such that it does not cause pollution or significant and sustained upwards trends in concentration or deterioration in the status of the groundwater body.

Consequently, an increase in the concentration of non-hazardous pollutants in groundwater may be acceptable so long as its impact does not cause pollution. It will normally be possible to detect concentrations of non-hazardous pollutants in groundwater before they cause pollution.

It is recommended that control levels for non-hazardous pollutants 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 compliance limit, 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 NH_4+, in groundwater at the site boundary will be 0.2 mg/l and the compliance limit is set at 0.5 mg/l, then control levels at 0.25 and 0.35 mg/l could be appropriate, that is 25% above predicted maximum and half-way between predicted concentration and the compliance limit. Simultaneously, the trends in pollutant concentrations in the groundwater should be reviewed to check whether there are

[4] Note: a deteriorating trend may be a linear increase in concentration or an increase in frequency of peak concentrations.

unexpected trends, and whether control levels and compliance limits are likely to be breached in the near future.

4.1.3 Control level testing.

The most basic control test is to look for trends in the data by plotting the monitoring data against time in order to detect adverse or unpredicted temporal variations (see Environment Agency, 2003a for more information).

In addition, examples of potential methods that could be used are as follows:

- a simple breach of the compliance limit, 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 environmental monitoring plan. In particular, the basis of the assessment process and for instigating contingency actions must be clearly documented.

4.1.4 The 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 hydrogeological environment and likely risks posed by the landfill, as described in Environment Agency 2003a. The monitoring frequency may need to be increased when there appears to be a danger of the compliance limits 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 us.

We expect operators to develop control levels and maintain them in their operational documents to help them identify potential pollution

Figure 4.1 Illustration of general principles of groundwater control levels and compliance limits (after Environment Agency, 2003a)

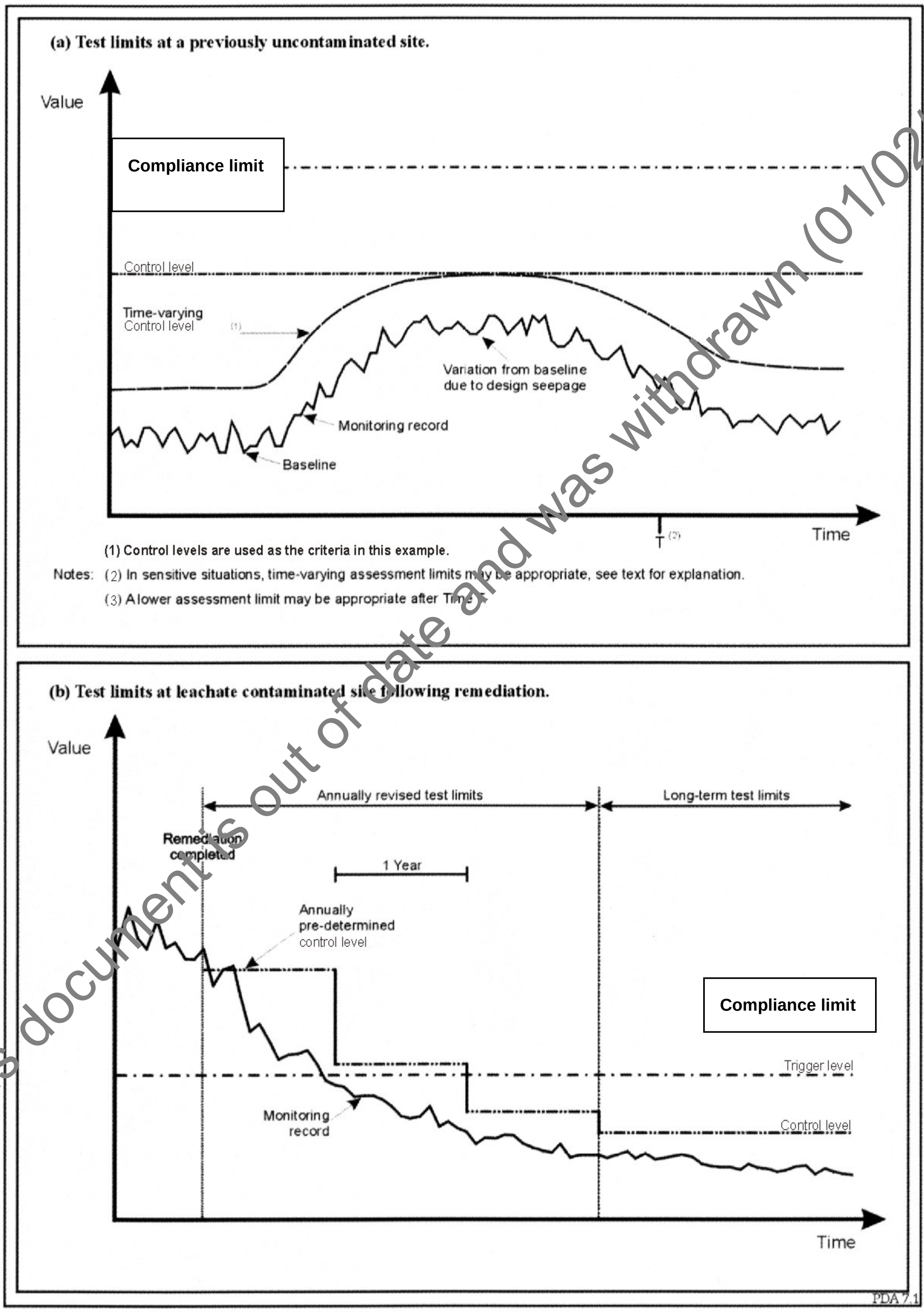
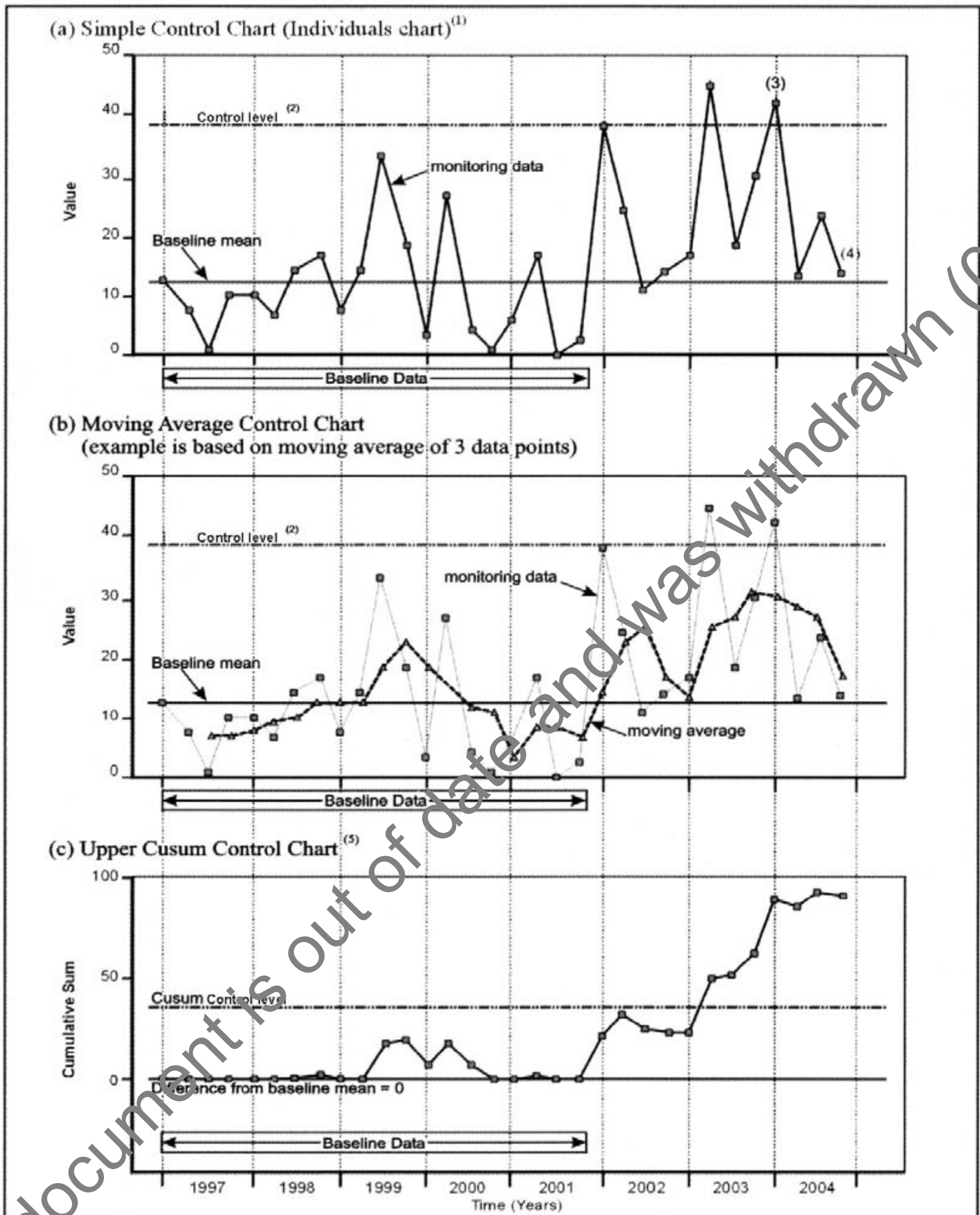


Figure 4.2 Examples of use of control charts to interpret trends in monitoring data (after Environment Agency 2003a)



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 chart is calculated as the cumulative summation of the positive difference between the baseline mean and the actual recorded value.

PDA 7.2

4.2 Compliance limits

Compliance limits are as referred to in Articles 12 and 13 of the LFD. Compliance limits 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:

Compliance limits represent the level of contamination that constitutes pollution.

This means that a change in water quality to a concentration below the compliance limits would be acceptable, but a concentration at or above the compliance limit would be unacceptable.

Compliance limits will be specified within the environmental permit. When a compliance limit is breached, the operator must notify us in accordance with their permit. The operator should then verify the breach by repeating the sampling and analysis. If the breach is verified the notification must be amended to include a contingency plan (see Section 4.3 Contingency actions - risk management) that explains how the breach will be mitigated.

There are three main considerations in setting Compliance Limits.

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

4.2.1 Selection of substances for which compliance limits are required

Compliance limits 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 minimum number of substances that are representative of the compounds present (or predicted to be present) within the leachate should be selected. In order to fit the compliance limits within the monitoring regime of the landfill, reference should be made to our guidance on landfill monitoring (Environment Agency, 2003a).

Compliance limits should be set for the same substances that are considered in the risk assessment. This will be a site-specific determination depending upon the proposed waste types and the baseline water quality. Section 3.4 (Priority contaminants to be modelled) gives some examples of both the categories of parameters and some examples of substances within these categories. The specialist advice of a chemist should be taken in determining what appropriate indicator species to select. As a general rule, compliance limits should be set for at least three, but no more than 10 substances.

4.2.2 Selection of concentration limits for compliance limits

4.2.2.1 Hazardous substances

For hazardous substances compliance limits 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 immediate dilution at the water table), while having regard to baseline water chemistry. For practical purposes, the Minimum Reporting Values (MRVs) for analyses of hazardous substances in groundwater (Appendix 8) should be used as the compliance limits for hazardous substances. These should be applied at the closest monitoring points to the waste body, unless baseline groundwater chemistry exceeds these levels.

The compliance limits should be set:

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

More details on appropriate statistical methods can be found in other guidance (for example Environment Agency, 2002c). Where a declining historical source is affecting baseline water quality the Compliance Limits 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 compliance limits specified for discrete time periods.

4.2.2.2 Non-hazardous pollutants:

Compliance limits for non-hazardous pollutants should be set at the most appropriate EALs which will have been determined having regard to baseline hydrochemistry and the identified compliance points. It is recognised that EALs may change with time, owing to the alteration of either water quality standards or the quality of the upstream groundwater. However, pragmatism is required when evaluating the ongoing performance of existing phases of the site against revised EALs / compliance limits that may have either increased or decreased.

Where the compliance points are perimeter monitoring boreholes, the compliance limits should be set at the EAL for each of the indicator substances.

In the situation where the nearest compliance point is at some distance from the landfill or perhaps a specific receptor has been selected as a compliance point a back-calculation would be required to produce an EAL / compliance limit for a perimeter monitoring borehole.

In practice this means that a higher level of contamination would be acceptable at the monitoring borehole to take account of 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 compliance limit for a non-hazardous pollutant will not be equal to an EAL used for risk assessment purposes is when the baseline groundwater quality is impaired by anthropogenic inputs. Under 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 compliance limit will normally take account of the other pollutant inputs (and thereby be a higher concentration). This is necessary to ensure that compliance can be assessed practically. Where there is poor baseline quality due to other anthropogenic impacts, setting a higher compliance limit must not result in or lead to a delay in the improvement of water quality as other sources of pollution decline or lead to a long term trend of increasing concentration.

4.2.3 The intervals between compliance limit reviews

The frequency of compliance limit reviews (to determine whether a compliance limit has been breached or not) should be set out in the environmental permit. However, as a minimum, it should occur at least once a year and reported in the ‘annual report’ of performance. Notwithstanding this, the control level reviews, which should be carried out each time new groundwater monitoring data are obtained, will also constitute an informal compliance limit review.

The regular intervals specified within the environmental permit should be viewed as minimum requirements, as there may be some circumstances when more frequent testing is appropriate (for example, if groundwater monitoring has detected breaches of a control level which indicates a potential breach of a compliance limit in the near future). The operator should then continue to analyse compliance limit conditions to obtain landfill management information.

4.2.4 The period of monitoring used for the analysis

A minimum of one year of baseline monitoring data should be used to underpin the assessment of compliance, as described in Environment Agency (2003a). However, this period of monitoring may need to be increased if it provides insufficient volumes of information to allow viable and robust assessment.

4.3 Contingency actions (risk management)

Article 12 of the LFD, regarding control and monitoring procedures in the operational phase, requires that the operator of a landfill should carry out a control and monitoring programme. Article 13, regarding closure and aftercare procedures, requires that monitoring and control is 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 (the Environment Agency) and must follow the decision of the Environment Agency on the nature and timing of corrective measures to be undertaken. The remedial measures should be carried out at the operator's expense.

The actions to be taken following breaches of both control levels and compliance limits 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, an assessment of the assumptions within the conceptual model should be undertaken, and the risk assessment may need to be revisited 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 levels and compliance limits may be re-evaluated in consultation between the site operator and the Environment 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.

4.3.1 Breach of compliance limit

If there are breaches of compliance limits, then the operator must notify us in accordance with their permit.

If a breach of a compliance limit occurs as a result of migration of substances from the landfill, this indicates non-compliance with both the LFD and the GWD. The operator should immediately take the following steps:

(a) where it is likely that the source of the contamination is the landfill, reduce on-going inputs to groundwater to an acceptable level; and

(b) determine by risk assessment the potential impact of those inputs on identified sensitive receptors.

These steps must form part of an action plan included with the permit application. It must include a higher frequency of groundwater monitoring, both in the vicinity of the site and up-gradient and a review of the essential and technical precautions required by the environmental permit. If the assessment confirms that the landfill is the source of the contamination, then appropriate remedial action must be taken to minimise on-going releases.

Whilst some corrective action may be relatively simple to undertake (for example, reducing leachate heads) other corrective action can be very costly and technically complex (such as in-situ groundwater remediation). The need for remediation should be balanced against the risk posed to groundwater and surface water receptors (and other receptors such as wetlands, etc.) and the environmental benefits gained by remediation. However, further pollution must be avoided. In complex cases, specialist advice should be taken and remedial actions and their objectives approved by the Environment Agency. Not withstanding the above, we have the power to require corrective measures.

All elements of the contingency plans should be documented within the monitoring plan. The monitoring plan and therefore, the contingency plans should be kept under periodic review.

These reviews should be carried out as a part of the normal review process of the permit.

Table 4.1 Examples of contingency actions

Appropriate contingency actions	Following a breach of a:	
	Control level	Compliance limit
Advise the site management	√	√
Advise the environmental manager of landfill operating company	√	√
Advise the 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 compliance limit	√	
Review the assumptions incorporated into the site conceptual model	√	√
Review existing hydrogeological risk assessment, control levels and compliance limits[5]	√	√
If risks are unacceptable set in place procedures for implementing corrective measures in consultation with or required by the Environment Agency		√

[5] This should include a re-evaluation of whether the baseline conditions have changed since the last risk assessment.

Chapter 5 - Reporting

5.0 Introduction

Hydrogeological risk assessment may be undertaken as part of the planning process as well as the permitting process. An Environmental Impact Assessment (EIA) undertaken for the purposes of planning permission may fulfil many of the requirements of the conceptual model and risk screening stage. Where the environmental permit 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 the IPPC, Landfill and Groundwater Directives, now implemented through EPR that must be addressed at the permit stage. This Chapter will deal specifically with the permit requirements.

We anticipate that the main use of this guidance will be in preparing and supplementing the permit application form for new and existing landfill sites. It is important therefore, that the reporting requirements for the risk assessment fulfil all of the requirements of the permit application. There are two main stages in the environmental permit application process: pre-application and the submission of the actual application. Following the issue of a permit there are further requirements for monitoring, interpretation of those results and reviews all which 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.

5.1 Environmental permit pre-application

We recommend that as part of the pre-application stage the site conceptual model and risk screening assessment should be submitted to us. We should accept the initial risk screening as the first stage of the risk assessment process for an application for an environmental permit or as part of a scoping document for the purposes of an EIA. Where this is prepared as part of the permitting process it should form part of the pre-application discussions, which should also include discussions on the assumptions included within the site conceptual model. It should then be used to ensure that it is clear and documented where the subsequent risk assessment effort should be directed.

This would 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. Any review we undertake would constitute part of the 15 hours allowed for pre-application discussions.

Appendix 7 presents a groundwater risk assessment checklist, which should be used as an indicative guide to what should be considered for the development of the site conceptual model.

We recommend that you consider the following elements:

- the landfill proposals and environmental setting presented in the site 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 Environment 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 groundwater control levels and compliance limits assigned to them;
- the models that are to be used within the risk assessment process. This should include the validation and verification of models;
- the input parameters and any assumptions that are to be used within the assessment; and
- appropriate EALs and proposed compliance limits.

Following the completion of any required site investigations, the site conceptual model should be reviewed and refined where necessary.

A conceptual model will always be a simplified representation or working description of the processes that are 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 important to be aware of the implications of these assumptions, whether simplifications are likely to be conservative or otherwise and to be able to justify the decisions that are made.

5.1.2 The environmental permit application

With respect to the permitting of landfill, risk management should essentially involve deciding between the following options:

- Rejection of the landfill application because the proposed site poses an unacceptable environmental risk over its lifecycle.
- Acceptance of the current landfill application.
- As the risks and corrective measures are acceptable as presented.
- With a reduction of the risks to an acceptable level by modifying wastes types, change to 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, (when initially using conservative assumptions), there is also the option to collect additional data and undertake a more detailed quantitative risk assessment to determine whether the proposed landfill operations are acceptable, using more realistic assumptions. To reiterate, 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 greater 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, but in more sensitive locations we 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, we may object to its development because of the lack of certainty about environmental protection measures over the long-term. Our guidance on groundwater protection and landfill location (Environment Agency 2012) are of particular relevance in this context, particularly 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 aids our decision-making process regarding the environmental permit;
- 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; and
- it encourages communication between the risk assessor and ourselves, ensuring 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 (2001d and 2003a).

5.2 Emissions to groundwater

Section B - Hydrogeological Risk Assessment Report of Part B of the Application Form for the Landfill Sector deals specifically with EPR Schedule 22, Section 7(3) requirement for an examination of:

(a) the hydrogeological conditions of the area concerned;
(b) the possible purifying powers of the soil and subsoil; and
(c) the risk of pollution and alteration of the quality of the groundwater from the discharge.

The requirements of this section of the application should be met by the submission of a hydrogeological risk assessment document. The refined site conceptual model should be presented within the hydrogeological risk assessment document.

Appendix 7 (Groundwater risk assessment checklist) 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, etc;
- The conceptual hydrogeological model, including a consideration of all of the potential source, pathway and receptor terms, including 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, etc;
- Sufficient investigations that have taken place for example, of the purifying powers of the soils and sub-soils (Appendix 3) and any mineral component of the engineered lining systems (if used within assessment) such as the attenuation capacity of the geological barrier;
- Necessary 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; and
- The acceptability of the input of polluting substances to the environment such as 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 the life cycle of the landfill.

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 is only a guide.

5.3 Accidents and their consequences

The environmental permitting process requires the identification of accidents and their consequences. The reporting of accidents that are relevant to the hydrogeological risk assessment can be reported either within the assessment itself or as a separate document that considers all of the appropriate accidents that are relevant to the site and the potential hazards that it presents. However it is reported, the relevant section should cover the assessment and analysis of the consequences of accidents (Chapter 3). A permit may only be issued where the landfill site does not pose an unacceptable risk to the environment or human health and the consideration of the likelihood and consequences of accidents and failures will form a 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.

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

5.4 Completion

Site closure, after-care and completion need to be considered as part of the environmental permit application process. A landfill should not be permitted unless the risks have been considered for the whole life of the site up until the point where the site 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; and
- 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 5.5.1).

5.5 Monitoring, validation and review

5.5.1 Review of the risk assessment

EPR requires that all environmental permits for groundwater activities must be reviewed by the end of 2012, although this will not include any new environmental permit issued under the transitory Groundwater Regulations (2009). It effectively continues the Groundwater Regulations (1998) requirement to review all authorisations at least once in every 4 years. A new timetable for subsequent reviews will come in after 2012 (this is likely to be every 6 years to coincide with WFD review cycles).

Article 12 of the LFD requires the reporting of aggregated monitoring data at a frequency specified by the Environment Agency, and in any event at least once a year. An annual review of monitoring data against the risk assessment assumptions and predictions will be required through the landfill permit. Where the monitoring data (for example, on leachate levels, leachate quality, groundwater levels and groundwater quality) show significant deviations from those assumed or derived from the risk assessment, then there may be a need to review the site conceptual model and risk assessment ahead of its scheduled review.

The hydrogeological risk assessment should not be an abstract exercise divorced from the reality of the landfill facility. Fundamental assumptions are made in the risk assessment with respect to the performance of lining systems (in terms of permeability and defect rates) and similarly with respect to drainage systems. 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. For example, leachate management (specifically volumes generated and removed or re-circulated). Waste types and inputs rates, phasing, intermediate capping, etc. and any failures of systems such as drainage pipe-work, leachate extraction points are all relevant.

Landfill monitoring is dealt with in separate guidance (Environment Agency 2003a) and has a clear relationship to comparing performance with risk assessment assumptions. For example, assumptions will have been made about leachate quality that only monitoring can validate. In particular the concentrations of specific hazardous substances are difficult to predict with any confidence. Leachate heads are another 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 identify which are the critical assumptions and ensure that validation of these assumptions is part of the formalised review process.

The overall groundwater monitoring programme for the landfill must be developed on the basis of our guidance on landfill monitoring (Environment Agency 2003a) and must therefore be based on the understanding of the S-P-R linkages. The monitoring must take place in each identified groundwater receptor and pathway.

Compliance limits should be set for each of the down-gradient, or potentially down-gradient, monitoring points that are included in the overall groundwater monitoring programme. This could include both monitoring wells and relevant groundwater resurgences (such as springs). Since the compliance limits represent the point at which pollution can be said to have occurred, the limits 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 compliance limit should individual boreholes be allocated specific (different) compliance limits.

The following is a checklist of issues for review.

- **Site conceptual model** (for example, groundwater level monitoring may indicate a possible change in the hydrogeological regime);
- **Essential and necessary 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 levels and compliance limits?);
- **Baseline groundwater quality** (for example, could the groundwater 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, which could have 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 difference in monitoring results);
- **The requirements for additional boreholes**;
- **The requirements for increased frequency of monitoring**;
- **The validity of risk assessment modelling approach and software used.**

5.5.2 Monitoring reporting

The monitoring reporting forms will be specified in the environmental permit and the following is an indication of the appropriate information.

5.5.2.1 Routine survey documentation

Routine survey documentation is primarily concerned with conveying to site management the details of works undertaken, results obtained and the implications of the results. This information does not necessarily need to be compiled into a formal report, although it should be available for inspection by us on request. This documentation should be up-dated following each monitoring event and should conclude with statements regarding:

:

- whether any breaches in control levels or compliance limits have been noted;
- whether any adverse trends are apparent;
- any significant changes in the rate of change of concentrations of constituents; and
- proposals for varying the frequency and range of monitoring.

5.5.2.2 Notification reports

Notification reports should be seen as the prime means of disseminating information for which action is required by site management. Notification reports will be required when breaches in compliance limits have occurred. These reports should provide clear, concise information and carry a recommendation for action (or advice of action taken). The time scales for issuing reports will be specified by the permit conditions (the environmental permit will specify the notification requirements).

In instances where compliance limits are regularly being breached you must refer to our Compliance Classification Scheme which details how we will manage CCS scoring. Our scheme provides consistency across different regulatory regimes in the reporting of non-compliance with permit conditions and the action we take.

The CCS scheme categorises non-compliance based on the potential to cause environmental damage. This damage is related to the impacts described in our Common Incident Classification Scheme (CICS).

5.5.2.3Review (or compliance) reports

Review (or compliance) reports should be prepared at least annually as required by the LFD and the environmental permit. They should summarise the monitoring data collected at the site with respect to compliance with the EALs set for the site. The main purpose of this report is to inform site management and the Environment Agency of 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 presented to us.

References

British Standards Institute, 1999. BS5930:1999. *Code of Practice for site investigations.*

British Standards Institute, 2001. BS10175:2001. *Investigation of potentially contaminated sites - Code of Practice.*

CIRIA, 2007. *Assessing risks posed by hazardous ground gas to buildings.* Report ref. C665, ISBN 978-0-86017-665-7.

Department of the Environment, 1995. *A review of the composition of leachates from domestic wastes in landfill sites*. Report prepared for the UK Department of the Environment by Robinson H D of Aspinwall & Co Ltd under contract number PECD 7/10/238, Ref DE0918A/FRA1, August 1995.

Department of the Environment, Transport and the Regions, Environment Agency and the Institute for Environment and Health, 2000. *Guidelines for environmental risk assessment and management – Revised Departmental Guidance*. The Stationery Office, London.

Department for Environment Food and Rural Affairs, 2010. *Environmental Permitting Guidance. The Landfill Directive. For the Environmental Permitting (England and Wales) Regulations*. Defra, 2010.

Environment Agency, 1998b. *Groundwater tracer tests: A review and guidelines for their use in British aquifers*. R&D Technical Report P139.

Environment Agency, 2000a. *CEC and Kd determination in landfill performance evaluation: A review of methods and preparation of standard materials for laboratory analysis*. R&D Technical Report P340.

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

Environment Agency, 2001a. *Guide to good practice for the development of conceptual models and the selection and application of mathematical models of contaminant transport processes in the subsurface*. National Groundwater & Contaminated Land Centre report NC/99/38/2, Solihull.

Environment Agency, 2001b. *Cation-exchange capacity (CEC) of selected lithologies from England, Wales and Scotland.* R&D Technical Report P2-222/TR.

Environment Agency, 2001d. *Guidance on the assessment and interrogation of subsurface analytical contaminant fate and transport models*. NGWCLC report NC/99/38/1, Solihull. (Available from www.environment-agency.gov.uk).

Environment Agency, 2002 *Landfill engineering: Leachate drainage, collection and extraction systems*. R&D Technical Report P1-397/TR.

Environment Agency 2003*. Hydrogeological risk assessments for landfills and the derivation of groundwater control and trigger levels*. Environment Agency 2003 (withdrawn).

Environment Agency, 2003a. *Guidance on monitoring of landfill leachate, groundwater and surface water.* Environment Agency, Bristol, February 2003. ISBN 1:1-84432-159-2*.*

Environment Agency, 2003b. *The stability of landfill lining systems*. R&D Technical Reports P1-385/TR1 & 2.

Environment Agency, 2004a. *Guidance on the management of landfill gas*. LFTGN 03.

Environment Agency, 2004b, *Contaminant fluxes from hydraulic containment landfills - a review,* Environment Agency Science Report SC0310/SR, September 2004, ISBN: 1844323153.

References

Environment Agency, 2004c. *Improved definition of leachate source term from landfill*. Science Report P1-494/SR1, prepared by Robinson, H.D., Knox, K. and Bone, B.D., September 2004, ISBN: 1 844 32 3269, 240pp.

Environment Agency, 2006. *Groundwater Protection: Policy and Practice, Parts 1-3* Environment Agency 2006.

Environment Agency, 2006. *Remedial Targets Methodology, hydrogeological risk assessment for land contamination*, Product Code: GEHO0706BLEQ-E-E.

Environment Agency, 2007. *LandSim Release 2.5: Landfill performance simulation by Monte Carlo method, software and user manual.* Environment Agency R&D Publication 120 prepared by Golder Associates, Nottingham.

Environment Agency, 2009a. *How to comply with your environmental permit. Additional guidance for: Landfill* (EPR 5.02). Environment Agency, Bristol, March 2009.

Environment Agency, 2009b. Landfill Engineering Guidance. Documents LFE1 – LFE10 on different aspects, at www.environment-agency.gov.uk/business/sectors/108918.aspx.

Environment Agency 2010 *Hydrogeological risk assessments for landfills and the derivation of groundwater control levels and compliance limits*. Environment Agency 2010 (superseded).

Environment Agency 2010a. H1 Environmental Risk Assessment Guidance: *Annex (i) Landfills*

Environment Agency, 2010b. *The Surrender of permits for the permanent deposit of waste. Technical guidance on surrender of permits for landfills, deposit for recovery sites and mining waste operations*, Environment Agency 2010.

Environment Agency, 2010d. *EPR (England and Wales) 2007. Regulatory Guidance Series, No LFD 1. Understanding the Landfill Directive*. Version 2, Environment Agency, 2010

Environment Agency 2011. H1 Environmental Risk Assessment Guidance: *Annex (j) Groundwater*

Environment Agency, 2012. *Groundwater Protection: Principles and Practice, Part 4 and Part 5.* Environment Agency 2012 (in preparation).

European Communities, 2007. CIS Strategy for the WFD (2000/60/EC). Guidance Document No. 17. *Guidance on preventing or limiting direct and indirect Inputs in the context of the GWD 2006/118/EC*. ISBN 978-92-79-06277-3.

Knox K, Robinson HD, van Santen A and Tempany PR, 2000. *The occurrence of trace organic components in landfill leachates and their removal during on-site treatment*. IWM Scientific and Technical Review, November 2000, pp5-10.

Robinson H D and Knox K, 2001. *Pollution Inventory discharges to sewer or surface waters from landfill leachates,* Ref REGCON70, Report prepared for the Environment Agency.

United States E.P.A. 1992. *Guidance for data usability in risk assessment (Part A)* Final Publication 9285.7-09A. Office of Emergency and Remedial Response.

Glossary and abbreviations

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 designation	Designation given to water-bearing strata by the Environment Agency and published as maps available via 'What's in Your Back Yard.' They link to our positions described in the document Groundwater Protection: Principles and Practice (GP3).
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 (e.g. 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 an environmental 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.
Compliance limit	New term for trigger level with no change in meaning. Trigger levels are defined by the LFD as levels at which significant (adverse) environmental effects have occurred. For non-hazardous pollutants the Compliance Limit will generally equal the EAL for that location; for hazardous substances concentrations would need to be discernible.

Glossary and abbreviations

Compliance point	Compliance points are used to determine whether a discharge is acceptable and that identified receptors are adequately protected by setting Environmental Assessment Levels (EALs) at these locations.
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.
Conservative contaminants	Contaminants which can move readily through a permeable medium with little or no reaction and which 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 level and / or a compliance limit.
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 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).
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).
Direct input	The introduction of a pollutant into groundwater without percolation through soil or subsoil.
Discernibility	The GWD states that all measures necessary to prevent the input of any hazardous substance into groundwater must be taken. An input is prevented if is not discernible in comparison to either the natural background concentration of groundwater or a minimum reporting value if this is at a higher concentration.

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 compliance value set at a compliance point. It is calculated to be a maximum concentration allowable at that point in order to protect a receptor. An EAL may be either a theoretical value used in predictive modelling or a limit set for physical monitoring.
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. The term ground waters is generally redundant and only relevant where the term 'controlled waters' remains in use.
Groundwater	In this document the definition used is that given in the Water Framework Directive (2000/60/EC) as "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.
Hazardous waste	Any waste which is covered by Article 1(4) of Council Directive 91/689/EEC of 12 December 1991 on hazardous waste(7)
Hazardous substances	Defined in the WFD as: "Substances or groups of substances that are toxic, persistent and liable to bio-accumulate, and other substances or groups of substances which give rise to an equivalent level of concern."
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 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.

Glossary and abbreviations

Indirect input	The introduction of a pollutant into groundwater after percolation through soil or subsoil.
Inert waste	Waste that does not undergo any significant physical, chemical or biological transformations.
Landfill	Site used for waste disposal into or onto land.
Leachate	Liquor formed by the interaction of water with wastes.
Minimum Reporting Value (MRV)	The lowest concentration of a substance which is reported in the results of an analysis. It is not necessarily the detection limit.
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 which, without human intervention, reduce the concentration, mass, flux or toxicity of contaminants in groundwater and surface water.
Non-hazardous pollutant	Any substance capable of causing pollution that has not been classified as a hazardous substance. The non-hazardous list of substances does not simply replace the old List II Substances, as for example, nitrate is now termed as being non-hazardous pollutant whereas before it was not a Listed Substance.
Non-hazardous waste	Waste which is not covered by paragraph (c) (definition of hazardous waste).
Pathway	The route alone 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	Pollutant is defined under the Water Framework Directive as: “any substance liable to cause pollution, in particular those listed in Annex VIII [of the WFD]”.

Glossary and abbreviations

Pollution	Defined in EPR (2010) 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 or other legitimate uses of the environment."
Integrated Pollution Prevention and Control (IPPC)	Refers to the provisions of the Landfill Regulations (England and Wales) 2002 and minor modifications to the Pollution Prevention and Control Regulations 2000, both made under the PPC Act 1999. These implemented the EU Integrated Pollution Prevention and Control Directive in England and Wales until EPR (2007). Sometimes referred to as PPC.
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.
Principal Aquifer	Geological strata that exhibit high permeability and usually provide a high level of water storage. They are capable of supporting water supply on a strategic scale and are often of major importance to river base flow (formerly known as Major Aquifer subject to boundary changes).
Receptor	An entity / organism or 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 treatment of 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 the significance of that risk 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.
Secondary Aquifer	A wide range of geological strata with a correspondingly wide range of permeability and storage. Depending on the specific geology, these subdivide into permeable formations capable of supporting small to moderate water supplies and baseflows to some rivers, and those with generally low permeability but with some localised resource potential. (Includes the former Minor Aquifers but also some of the former Non-Aquifers).
Sorption	Absorption and adsorption considered jointly
Time-series	A graphical representation of data arranged sequentially by time or date.
Trigger level	See compliance limit.
Unproductive Strata	These are geological strata with low permeability that have negligible significance for water supply or river base flow (formerly part of the Non-Aquifers).
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. 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.

List of abbreviations

CCS	Compliance Classification Scheme
CEC	Cation Exchange Capacity
CQA	Construction Quality Assurance
DECC	Department of Energy and Climate Change
DEFRA	Department for the Environment, Food & Rural Affairs
DQRA	Detailed Quantitative Risk Assessment
DWS	Drinking Water Standard
EAL	Environment Assessment Level.
EIA	Environmental Impact Assessment
EPP1; EPP2	Environmental Permitting Programme
EPR	Environmental Permitting (England and Wales) Regulations.
EQS	Environmental Quality Standard
Foc	Fraction of organic carbon
GCL	Geosynthetic Clay Liner
GCMS	Gas Chromatography-Mass Spectrometry
GP3	Groundwater Protection: Policy and Practice
GQRA	Generic Quantitative Risk Assessment
GWD	Groundwater Directive (80/68/EEC)
GWDD	Groundwater Daughter Directive (2006/118/EC)
GWR 1998	Groundwater Regulations 1998
GWR 2009	Groundwater Regulations 2009
IPPC	Integrated Pollution Prevention Control Directive (96/61/EC).
JAGDAG	Joint Agencies Groundwater Directive Advisory Group
LFD	Landfill Directive (1999/31/EC),
LOD	Limit of Detection
LPG	Liquid Petroleum Gas
MRV	Minimum Reporting Value
QA	Quality Assurance
QC	Quality Control
RS	Risk Screening
S-P-R	Source-Pathway-Receptor
SPZ	Source Protection Zone
UKTAG	United Kingdom Technical Advisory Group
WG	Welsh Government
WFD	Water Framework Directive (2006/60/EC
WQS	Water Quality Standard

Appendices

Appendix 1 – Hazardous substances and non-hazardous pollutants

Hazardous substances are defined in the WFD as "substances or groups of substances that are toxic, persistent and liable to bio-accumulate, and other substances or groups of substances which give rise to an equivalent level of concern".

This includes in particular the following substances listed where they fulfil these criteria:

- organohalogen compounds and substances which may form such compounds in the aquatic environment;
- organophosphorous compounds;
- organotin compounds;
- substances and preparations, or the breakdown products of such, which have been proved to possess carcinogenic or mutagenic properties or properties which may affect steroidogenic, thyroid, reproduction or other endocrine-related functions in or via the aquatic environment;
- persistent hydrocarbons and persistent and bioaccumulable organic toxic substances;
- cyanides;
- metals (in particular cadmium and mercury) and their compounds;
- arsenic and its compounds;
- biocides and plant protection products.

The identification of hazardous substances in England and Wales is the responsibility of the Environment Agency, whose decisions will be reviewed by the Joint Agencies Groundwater Directive Advisory Group (JAGDAG). JAGDAG is a body comprising the Environment Agency (EA), the Scottish Environment Protection Agency (SEPA), the Northern Ireland Environment Agency (NIEA) and the Environmental Protection Agency Ireland (EPA) ('the Agencies'), together with the Department for Environment, Food and Rural Affairs (Defra), Welsh Government (WG), Health Protection Agency (HPA) and industry representatives.

Further information on the work of JAGDAG, including the list of substances considered to be hazardous, can be found on the UKTAG website.

All substances previously confirmed as List I substances are considered to be hazardous.

All substances that are not considered hazardous are **non-hazardous pollutants.**

Appendix 2 – 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 an exhaustive list. Further discussion is provided in our H1 Guidance: Annex (j) Groundwater (Environment Agency, 2011). Notwithstanding this, 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 patchiness 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 the confirmation of the location of the site with respect to the sensitive areas outlined in our guidance on the location and impact assessment of landfills (Environment Agency, 2012).

(a) Saturated zone

The following is required:

- Details of all relevant strata whether Principal or Secondary Aquifers, or Unproductive Strata;
- Details of the hydraulic properties of the saturated zones:
    - hydraulic conductivity /effective porosity / storage characteristics;
    - predominant type of flow (fissure, intergranular or dual);
    - fissure characteristics & orientation (including the likelihood and significance of karst features);

- ➢ flow patterns (vertical & horizontal hydraulic gradients and likely flow regimes and directions).

- Identification of probable discharges (natural or artificially induced). For example, 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, etc., 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 appropriate,
  - ➢ details of the rate of decline of the pollution source should be included).

- Basic mineralogy for example, carbonate content, clay content, CEC and foc values, etc.

(b) Unsaturated zones

This should include assessment of 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, karst features and man made features such as old boreholes and mine shafts);
- Basic mineralogy, for example, carbonate content, clay content, CEC and foc values, etc.

Where the "purifying powers of the soils and sub-soils" (Appendix 3) 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 location of the site. Site-specific testing must be carried out if attenuation (such as cation exchange capacity) is relied upon within the hydrogeological risk assessment. Although theoretical assumptions or literature data[6] 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[7] for the key parameters. Appendix 3 provides further comment on the consideration of the purifying powers of soils and sub-soils.

(c) Potential receptors

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

---

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

[7] Environment Agency, 2000a, *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.

- current licensed/exempt abstractions of water and the nature of its use for example, domestic, agricultural, industrial or other:
- existing natural/induced discharges (such as springs, wetlands, etc.);
- unused groundwater 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.

Appendix 3 – The purifying powers of soils and sub-soils

The term "purifying powers of the soils and sub-soils", although used in the 1980 Groundwater Directive (GWD) and EPR, is not defined there.

There are several documented processes that can take place in the soil and the unsaturated zone which may, to some extent, attenuate the passage through to the saturated zone of contaminants present in leachate. 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 such as the mineralogical composition of the soil, a range of chemical properties associated with the ions contained in the leachate (ionic radius, electronegativity and charge, etc.) 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 the 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, whilst these values are acceptable for screening purposes they should not be used (for the key variables) for either generic or detailed quantitative risk assessments.

For the purposes of 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 which are the subjects of the tests (for example, NH_4^+, Cd^{2+} etc.), the test methods and manner in which the values are used should be agreed in advance with us and further technical guidance on this matter has been prepared.[8]

[8] Including:

- Environment Agency, 2000a, *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; and
- Environment Agency, 2000b, *Guidance on the Assessment and Monitoring of Natural Attenuation of Contaminants in Groundwater*' R&D Publication 95

Appendix 4 – Potential site investigations

Site conceptual model issue	Potential site investigations	Additional comments
The identification of the potential hazards	Field observations of the landfill development.	Can provide invaluable information relating to the potential pathways that may be in existence at the site for example, the observation of perched leachate escaping over outer bunds, the surface run-off of re-circulated leachate that has failed in infiltrate into the waste mass.
The definition of the source, pathway and receptor Terms and the establishment of the baseline conditions	Field observations of geological exposures and hydrogeological features such as springs.	Can provide invaluable information relating to geology and hydrogeology of an area.
	Installation and logging of geological boreholes and groundwater wells.	• To investigate geological stratigraphy and structure. • To determine water table and piezometric levels. • It is important to note that: 1. 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. 2. 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. 3. The drilling of boreholes should not create new pathways for groundwater. contamination through the interconnection of layers (strata) that would otherwise be isolated. Careful design and supervision is therefore required.

Site conceptual model issue	Potential site investigations	Additional comments
The definition of the source, pathway and receptor Terms and the establishment of the baseline conditions ***continued***	Installation and logging of geological boreholes and groundwater wells. *continued*	• 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. • 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.
	Installation and logging of leachate wells	May be required to investigate leachate levels and quality within a specific area of the landfill. It is important to note that: 1. 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 process. 2. Particular attention should be paid to the observation and recording of leachate strikes and entries, their relative rates of flow and temporary standing leachate. 3. 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.
	In-situ testing to determine bulk formation properties.	Includes tests such as falling-head tests and pumping tests which will provide information on parameters such as permeability and specific yield.

Site conceptual model issue	Potential site investigations	Additional comments
	Laboratory testing of soil and rock materials.	• To potentially include properties such as: 1. Partition coefficients (Kd) – to determine the degree specific contaminants are retarded within the tested materials.[10] 2. Particle size analysis – to characterise the materials and provide approximate estimations of permeability for certain materials. 3. Undisturbed permeability of clays. 4. Cation exchange capacity (CEC) – to characterise the ability of the materials to attenuate cationic contaminants such as ammonium.[10] 5. Fraction of Organic Carbon (foc) – to characterise the general ability of the material to retard organic contaminants.
	Laboratory testing of soils and rocks.	• This may include 1. Partition coefficients (K_d) – to determine the degree specific contaminants are retarded within the lining materials.[9] 2. Remoulded permeability of clays – to determine the likely performance of a clay lining material. 3. Cation exchange capacity (CEC) – to characterise the ability of the potential lining materials to attenuate cationic contaminants such as ammonium.[10] 4. Fraction of Organic Carbon (foc) – to characterise the general ability of the lining materials to retard organic contaminants.

[9] Environment Agency, 2000a, 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

Site conceptual model issue	Potential site investigations	Additional comments
The definition of the source, pathway and receptor Terms and the establishment of the baseline conditions ***continued***	Tracer tests.	To determine actual groundwater flow directions and rates. It is important to note that 1. The tracer material must be suitable for the site setting and the environmental conditions. 2. 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 Environment Agency and with mind to Environment Agency guidance.[10] 3. All tracer tests should only be carried out following agreement with the Environment Agency.
	Leachate monitoring	• The existing monitoring may need to be augmented in order to provide information on 1. The movement of leachate within the landfill and its interrelationship with the outside groundwater. 2. The potential contaminative sources that are present within the leachate.
	Detailed environmental monitoring over a period of time.	• To include both groundwater and surface water in order to establish baseline conditions • Information could include both water levels and flow rates as well as water quality • It is important to 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.

[10] Environment Agency, 1998b. *Groundwater Tracer Tests: A Review and Guidelines for their use in British Aquifers*. R&D Technical Report P139

Site conceptual model issue	Potential site investigations	Additional comments
The definition of the source, pathway and receptor Terms and the establishment of the baseline conditions ***continued***	Non-intrusive surface geophysics	• A range of tests is available to augment borehole information to assist characterising ground conditions. • 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. • The surveys should be integrated with the intrusive investigation and sufficient borehole control provided to enable calibration and validation of the geophysical results.
	Down-hole borehole geophysics.	• Carried out prior to the installation of well lining in order to obtain information relating to the geological and hydrogeological structure of the borehole.

Appendix 5 – Potential sources of information on leachate quality

Development scenarios	Information sources	Additional comments
New landfill where the assessment is required as part of a permit (no current information)	• No existing leachate information is available. Consequently, leachate quality has to be determined from: ▪ Literature.[11] ▪ Similar landfills that the operator may own. ▪ Information on landfills that take similar waste streams that are operated by a third party. This information is available from the public register.	• This scenario demands complete reliance on information gathered from other sources. Consequently the comparability of the information must be assured. In order to do this, the procedure should be followed: ▪ Obtain information about waste stream and potential leachate quality, ▪ Review data usability (completeness, comparability, representative, precision, accuracy)[12] ▪ Data review and identification of chemicals of concern. ▪ Calculation of the source term. • It should be noted 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 (2004).

[11] Potential sources of information include:

Development scenarios	Information sources	Additional comments
New landfill where the assessment is required as part of a permit (no current information) *continued*	In addition to the above for some waste types, such as soils and inert materials, it may be appropriate to carry out leaching tests.	• Leaching tests should be undertaken using an appropriate test method[13], 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. • Extreme care should be exercised when interpreting leaching test results owing to the potential heterogeneous nature of some waste materials and their potential inability to fully replicate the leaching process under landfill conditions. • The determinands to be tested should have been identified in the site conceptual model. They will be dependent on the properties of the wastes being analysed. The basic monitoring suite should however comply with 'guidance on the monitoring of landfill leachate, groundwater and surface water' (Environment Agency, 2003a). • It is strongly recommended that that we are consulted during the specification of the

- 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. IWM Scientific and Technical Review, November 2000, pp5-10.
- Robinson H D and Knox K, 2001. Pollution Inventory discharges to sewer or surface waters from landfill leachates, Ref REGCON70, Report prepared for the Environment Agency.
- Environment Agency, 2004a. Improved Definition of Leachate Source Term from Landfill. R&D Technical Report P2-173/TR/1. Science Report P1-494/SR1, prepared by Robinson, H.D., Knox, K. and Bone, B.D., September 2004, ISBN: 1 844 32 3269, 240pp.
- Environment Agency, 2007. LandSim Release 2.5: Landfill Performance Simulation by Monte Carlo Method, software and user manual. Environment Agency R&D Publication 120 prepared by Golder Associates, Nottingham. Latest version at time of this report release was 2.5.17 dated April 2007.

[12] 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.

[13] 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.

		leaching test methodology and determinands in order to ensure that valid and relevant information is collected.

Development scenarios	Information sources	Additional comments
At an existing landfill site, either to: • Evaluate a waste stream to determine suitability for disposal (in compliance with permitted conditions); or for the: • Permitting of an extension or modification to an existing landfill.	• 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. • This information may need to be supplemented by the following ▪ Additional leachate sampling and analysis for specific hazardous substances and non-hazardous pollutants of interest (Appendix 6). ▪ Literature. ▪ Similar landfills that the operator may own. ▪ Information on landfills that take similar waste streams that are operated by a third party. This information is available from the public register.	▪ 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. ▪ As with the above scenario, it should be noted that Landfill Classification, as a result of the implementation of the LFD, could potential 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 (2004a).

Appendix 6 – Analytical framework for screening landfill leachates

The basic monitoring regime for all leachate at landfills should comply with our current guidance on the monitoring of landfill leachates.[14] 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 included within a monitoring programme should be sufficient to establish the potential of a site to discharge non-hazardous pollutants. For sites that take wastes containing hazardous substances, or which have the potential to generate hazardous substances in their leachate, appropriate additional determinands will be required.

Where the waste types permitted by the permit are specific enough to allow an accurate prediction of all hazardous substances that may potentially 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 specify such a list.

If there is any doubt about the possible range of hazardous substances that may 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. There is no single analytical technique that is capable of identifying the entire range of hazardous substances. To provide an adequate definition a combination of six different analytical methods is required:

i) GCMS scan for volatiles;
ii) GCMS scan for semi-volatiles;
iii) derivitised GCMS scan for semi-volatiles;
iv) extraction of organotin compounds;
v) reduction of mercury compounds; and
vi) 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 our satisfaction that the alternatives will provide results comparable with those specified in the framework, particularly with respect to the lower reporting levels and core determinands. Where there is any doubt about the equivalence of tests, the advice of the Environment Agency's National Laboratory Service should be sought.

The report of the analyses submitted to us should include the name of the laboratory; details of the analytical methods used and the details of all substances detected that have the potential to be classified as hazardous substances. For the GCMS results, the report should detail **all** peaks identified with a confidence level greater than 80%. 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 in accordance with the environmental permit or whenever we feel it necessary to request them. Article 12 of the LFD requires the reporting of aggregated monitoring data at a frequency specified by the Environment Agency, and in any event at least once a year.

The requirement to screen the leachate for hazardous substances should be included in your environmental 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 guidance reference should be made to our guidance on the monitoring of landfill sites. If the analytical framework set out in tables 6.1 to 6.7 is adopted, the cost of the analysis is likely to be of the order of £500[15] per sample (at 2010 prices). Note, for a site specific assessment of known substances, the requirement for a more specific analysis would invariably involve different costs. You should liaise with us before undertaking a different analysis to the one given outlined here.

Note on method performance: This applies to Tables 6.1 to 6.6.

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 6.1 Volatiles

Basis of Test	Purge & Trap or Headspace GCMS, full scan EI mode (e.g. EPA 8260)
Mass Scan Range	35 to 300
Lower Reporting Level for core determinands	<10 µg/l
Core Determinands (C.D.)	chlorobenzene, trichloroethene, tetrachloroethene, 1,2 dichlorobenzene
Precision % (on C.D.)	25 @ 100 µg/l
Bias % (on C.D.)	20
Spiking Recovery % (on C.D.)	>50
Internal Standards (I.S.)	e.g. pentafluorobenzene, difluorobenzene, chlorobenzene-d5, 1,4-dichlorobenzene-d4 (required to overlap with semi-volatile analysis). Surrogates e.g. BCTFE, fluorobenzene, p-bromofluorobenzene (BFB), dibromofluorometane, toluene-d8. Use a minimum of 3

[15] Source: Environment Agency National Laboratory Service.

	surrogates.
Calibration	Normal MS tune/sensitivity checks. Calibrate using C.D./I.S.
Minimum QC requirements	1 AQC sample (C.D. @ ~ 100 µg/l plus I.S.) with every 10 samples, taken throughout the entire procedure
Reporting	Report all peaks with a library match confidence of >80%
Libraries	NIST, Wiley

Table 6.2 Semi volatiles

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

Table 6.3 Semi volatiles – derivatised

Basis of Test	Liquid/liquid extraction (e.g. DCM, iso-hexane, hexane) at pH<2, then esterification (e.g. diazomethane#, TMAH) followed by GCMS full scan EI mode
Mass Scan Range	35 to 650
Lower Reporting Level	<10 µg/l
Core Determinands (C.D.)	2-chlorophenol, dichlorprop, PCP, bromoxynil, 2,4,6-trichlorophenol, ioxynil
Precision % (on C.D.)	25 @ 100 µg/l
Bias % (on C.D.)	20
Spiking Recovery % (on C.D.)	<50
Internal Standards (I.S.)	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 2 surrogates
Calibration	Normal MS tune/sensitivity checks. Calibrate using C.D./I.S.
Minimum QC requirements	1 AQC sample (C.D. @ ~ 100 µg/l plus I.S.) with every 10 samples, taken throughout the entire procedure
Reporting	Report all peaks with a library match confidence of >80%
Libraries	NIST, Wiley

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 heath and safety hazards, which are more easily controlled.

Table 6.4 Organotin compounds

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

Table 6.5 Mercury

Basis of Test	Mercury compounds reduced to elemental mercury (e.g. using stannous chloride) then measured by AFS or Cold Vapour AAS
Lower Reporting Level	<1 µg/l
Core Determinands (C.D.)	Mercury (II) nitrate
Precision % (on C.D.)	10 @ 10 µg/l
Bias % (on C.D.)	10
Spiking Recovery % (on C.D.)	>75
Calibration	Normal instrument tune/sensitivity checks. Calibrate using C.D.
Minimum QC requirements	1 AQC sample (C.D. @ ~ 10 µg/l) with every 10 samples, plus spiking recovery for each sample
Reporting	Report as total mercury.

Table 6.6 Cadmium

Basis of Test	Cadmium compounds are brought into solution by acid digestion (e.g. HNO3) then measured by ICP or EAAS
Lower Reporting Level	<1 µg/l
Core Determinands (C.D.)	Cadmium Chloride
Precision % (on C.D.)	10 @ 10 µg/l
Bias % (on C.D.)	10
Spiking Recovery % (on C.D.)	>75
Calibration	Normal instrument tune/sensitivity checks. Calibrate using C.D.
Minimum QC requirements	1 AQC sample (C.D. @ ~ 10 µg/l) with every 10 samples, plus spiking recovery for each sample matrix
Reporting	Report as total cadmium.

Appendix 7 – 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 Environment Agency and the formulation of our response. The purpose is to help focus on key issues. There may be other factors relevant to a particular site or study to which reference is not made on this table and reference should be made to all relevant sections contained within this guidance. Part B of the permit 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 (<u>Y</u>es/<u>N</u>o/<u>S</u>ee Note)			**Y**	**N**	**S**
Installation details	Location	Grid references. Site plans, etc.			
	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.			
Conceptual model	Source term characteristics	Leachate heads. Chemical characteristics. Likely hazardous substances and non-hazardous pollutants present and short and long term changes in quality with time. Screening for the actual or potential presence of pollutants.			
		Water Balance Considerations			
		Consideration of whether EPR applies.			
		Consideration of whether arrangements need to be made to collect contaminated water and leachate			
	Wider geological and geographical setting	General site context with respect 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, groundwater vulnerability.			
	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 the geological barrier. Stratigraphic, structural and topographic controls, influence of preferential flow via fissures, drainage systems, and man made structures, old mines, boreholes etc. 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			

Site:_________________________________ Sheet 2 of 4

Does the report adequately address the following aspects? Please tick columns (<u>Y</u>es/<u>N</u>o/<u>S</u>ee Note)	**Y**	**N**	**S**

Prior investigation	Soil/rock characterisation	Lithology and its vertical and lateral variability. Relevant hydrogeological parameters (e.g. 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 groundwater 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.			
Technical precautions	Engineering and operational controls	Design meets requirements of the LFD & 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 & GWD, capping proposals and long term leachate management. Estimation of hydrogeological completion criteria and potential timing.			
	Short and long term failure scenarios	Potential for future degradation or failure of pumped systems, drains, linings to occur. Likelihood of mining related subsidence, differential settlement, structural failure.			

Risk assessment	Nature of Risk Assessment	Full justification for the risk assessment methodology used (risk screening, or generic or detailed quantitative).			
	Likely/plausible worst case impacts	Quantified likely or plausible worst case impact 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.			

Site:____________________________________ Sheet 3 of 4

Does the report adequately address the following aspects? Please tick columns (Yes/No/See Note)			**Y**	**N**	**S**
Use of numerical models	Rationale	Adequate prior discussion/agreement with EA (internal consultation with EA specialists)			
		Justification for using particular computer models			
		Model selection and suitability to represent conceptual model including hydrogeological conditions (for example,. below water table) 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: • modelled head above liner v field constraints • hydraulic gradients compatible with permeability Reporting of maximum acceptable leachate head and contaminant concentrations			

	Supply of models to EA	**All** models that are relied upon should be supplied to the EA in an electronic format. Where third party model or code are developed or used, adequate verification that they are accurate and robust will be expected. All relevant equations and supporting documentation should be supplied.			
Requisite surveillance ***(see Environment Agency, 2003a)***	Risk-based monitoring scheme	• Minimum requirements of the LFD need to be considered • Location for compliance monitoring • Critical appraisal of the adequacy of any existing monitoring. • Risk-based leachate, groundwater and surface water monitoring scheme needs to be developed, recommended and implemented			
	Groundwater control levels and compliance limits	Groundwater control levels and compliance limits have been determined for appropriate contaminants at appropriate locations. Consideration of methods used and associated uncertainties.			
Acceptability of discharge to the environment	Applicable quality criteria	Assessment of applicable criteria i.e. the use of the EAL for non-hazardous substances and minimum reporting values for hazardous in groundwater, as a basis for determining acceptability of risk assessment output. Not forgetting background water quality.			
	Direct inputs	Particular attention paid to risk assessments where potential exists for direct input of pollutants to groundwater (for example, groundwater outside liner) and supporting justification.			
Surrender Evaluation	Time to surrender	Estimate of time until an application to surrender the permit will be made.			

Notes

Date: Signed:

Appendix 8 – Assessing discharges of hazardous substances to groundwater. Minimum Reporting Values for selected substances in clean water.

The table below presents typical Minimum Reporting Values (MRVs) for selected hazardous substances in clean groundwater (as required of Environment Agency National Laboratory Service).

Substance	**MRV (µg/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	
chloroform	0.1	
chloronitrotoluenes	1	2,6-CNT; 4,2-CNT; 4,3-CNT; 2,4-CNT; 2,5-CNT each to 1µg/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 0.005µg/l
endrin	0.003	
fenitrothion	0.001	
fenthion	0.01	
hexachlorobenzene	0.001	

hexachlorobutadiene	0.005	
hexachlorocyclohexanes	0.001	α-HCH, γ-HCH and δ-HCH each to 0.001µg/l β-HCH to 0.005µg/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 0.001µg/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 3µg/l. May not be possible to separate m- and p-xylene.

Would you like to find out more about us, or about your environment?

Then call us on

03708 506 506 (Mon-Fri 8-6)

Calls to 03 numbers cost the same as calls to standard geographic numbers (i.e. numbers beginning with 01 or 02).

email

enquiries@environment-agency.gov.uk

or visit our website

www.environment-agency.gov.uk

incident hotline 0800 80 70 60 (24hrs)
floodline 0845 988 1188

Environment first: Are you viewing this on screen? Please consider the environment and only print if absolutely necessary. If you are reading a paper copy, please don't forget to reuse and recycle if possible.