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Hydrogeological Risk Assessments for Landfills and the Derivation of Groundwater Control and Trigger Levels

Legislative Update for EPR

Reference number/code [Sector Code]

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Hydrogeological Risk Assessment for Landfills and the Derivation of Groundwater Control and Trigger levels.

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This document describes the Environment Agency's recommended approach to assessing the risks to groundwater from landfill developments permitted under the Environmental Permitting Regulations (2010). It is supported by a number of appendices which provide more detailed information on specific activities.

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Forward

Legislative Update For EPR, 2010

This document provides an update, in terms of legislative context only, of the Environment Agency (February 2003) guidance "*Hydrogeological Risk Assessments for Landfills and the Derivation of Groundwater Control and Trigger Levels*". The legislative changes relate to the relevant requirements of the Landfill Directive (1999/31/EC), IPPC Directive (96/61/EC), Water Framework Directive (2006/60/EC) and Groundwater Directive (2006/118/EC) now captured by the Environmental Permitting Regime (EPR).

Whilst there have been changes to the layout to accommodate the introduction of EPR, much of the technical content of the original document remains. The document provides a largely stand alone and sector specific guidance to our 'H1 Environmental Risk Assessment guidance" (Environment Agency, 2010a), which in turn is supported by our 'H1 Environmental Risk Assessment: Annex (j) Groundwater' (Environment Agency, 2010b). How this document fits in with our H1 guidance is explained further in Section 1.1.4.

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

Readers of this guidance are expected to be familiar with the Landfill Directive requirements and the national regulatory framework. Specifically, the DEFRA guidance document "*Environmental Permitting Guidance - The Landfill Directive: For the Environmental Permitting (England and Wales) Regulations*" (DEFRA, 2009 – as updated by EPR 2010), which sets out how Government expects the permitting regime to operate for landfill sites. Further, the Environment Agency's "*How to comply with your environmental permit: Additional guidance for Landfill (EPR 5.02)*" (March 2009 as updated by EPR 2010) document describes best practice for landfills, in compliance with both the Landfill and IPPC Directives.

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Contents

1 Introduction

1.1 Purpose of Guidance and the Link to Other Guidance

1.1.1 Purpose of this Guidance

This document provides guidance on the requirements for groundwater risk assessment of landfills and the setting of groundwater Control and Trigger levels. It provides an update, in terms of legislative context only, of the Environment Agency (February 2003) guidance "*Hydrogeological Risk Assessments for Landfills and the Derivation of Groundwater Control and Trigger Levels*". The legislative changes relate to the relevant requirements of the Landfill Directive (1999/31/EC), IPPC Directive (96/61/EC), Water Framework Directive (2006/60/EC) and Groundwater Directive (2006/118/EC) now being captured by the Environmental Permitting Regime. The guidance describes a tiered approach to hydrogeological risk assessment for landfill and sets out how Control and Trigger levels for groundwater (as required by the Landfill Directive) should be derived and used.

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

1.1.2 Link to Environmental Permitted Programme

DEFRA, Department of Energy and Climate Change (DECC), the Environment Agency and Welsh Assembly Government have introduced a major initiative, the Environmental Permitting Programme (EPP), that has created a single more user-friendly and modern permitting and compliance system.

The first part of the programme, EPP1, streamlined the implementation of the IPPC Directive (96/61/EC) and the Landfill Directive (99/31/EC) 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 Water Framework Directive (2006/60/EC) and Groundwater Directive (2006/118/EC) through the Environmental Permitting (England and Wales) Regulations 2010 ("EPR 2010"). EPR 2010 supersedes the Groundwater Regulations (1998) and the transitional Groundwater Regulations (2009) in terms of the protection of groundwater.

Both EPR 2007 and EPR 2010 have equivalent legislation in Scotland and Northern Ireland.

1.1.3 DEFRA and Environment Agency General Guidance on Landfill

Readers of this guidance are expected to be familiar with the Landfill Directive requirements and the national regulatory framework. Specifically, DEFRA guidance document "*Environmental Permitting Guidance - The Landfill Directive: For the Environmental Permitting (England and Wales) Regulations*" (DEFRA, 2009 – as updated by EPR 2010), which sets out how Government expects the permitting regime to operate for landfill sites. Further, the Environment Agency's "*How to comply with your environmental permit: Additional guidance for Landfill (EPR 5.02)*" (March 2009) describes best practice for landfills, in compliance with both the Landfill and IPPC Directives.

1.1.4 H1 Guidance Annex (j) on Groundwater

The 'EPR H1 Environmental Risk Assessment guidance' documents provide high level guidance on the broad principles of risk assessment, which underpin our decisions on the Environmental 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 guidance modules on how to undertake specific risk assessments. For groundwater, Part 1 includes general guidance on groundwater risk assessment. Part 2 provides more detailed sector specific guidance such as hydrogeological risk assessment for landfill. How this sector specific guidance fits in with the H1 Framework is illustrated in Figure 1.1

Part 1 of the *H1 Guidance Annex (j) Groundwater* (Environment Agency, 2010b) provides high level guidance on the broad principles of risk assessment specific to groundwater. This guidance is supported by Part 2 Sector Specific Guidance, which provides more specific information relevant to certain activities. The *HI Guidance: Annex (i) Landfills* should also be referred to.

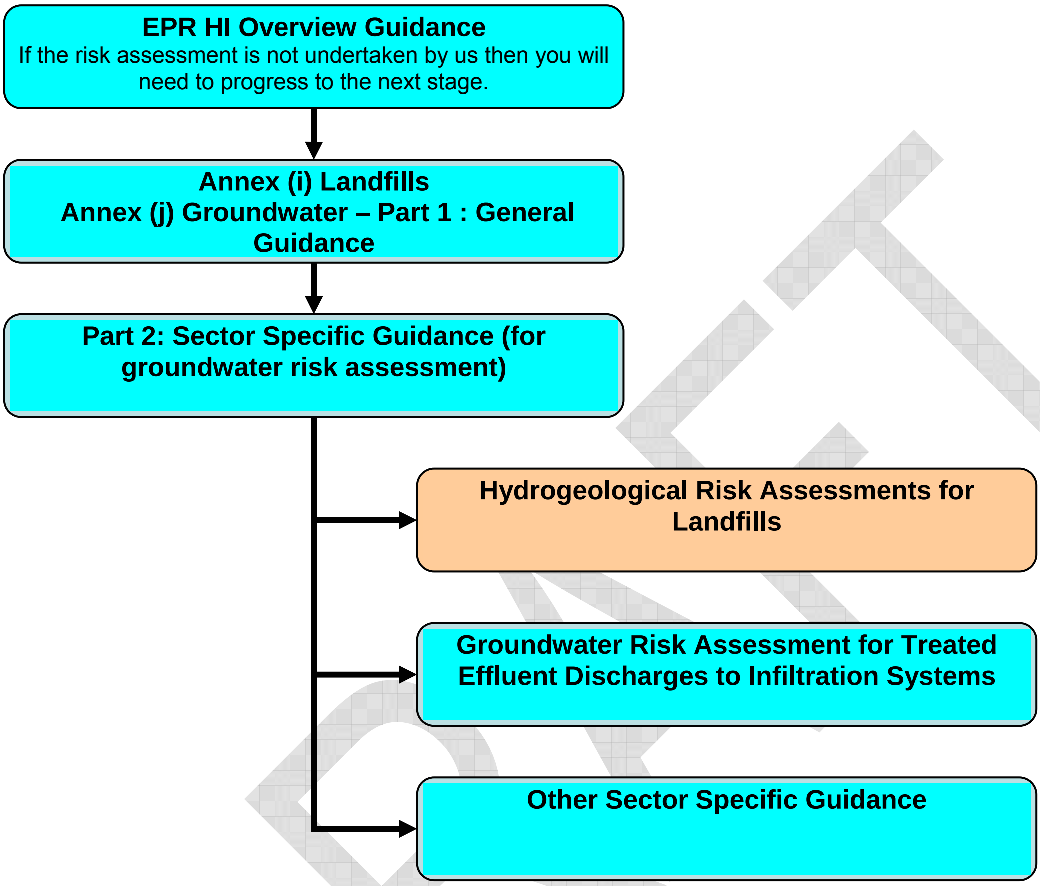


Figure 1.1 How the HI Framework is Structured Specific to Groundwater

1.1.5 Link to our Groundwater Protection: Policy and Practice

Hydrogeological risk assessment is a key process in the evaluation of future landfill developments. However, the process of site selection also needs to be set in the context of our *Groundwater Protection: Policy and Practice* ('GP3' Part 4, Section 3, Environment Agency, July 2008 as revised). In addition to presenting the Landfill Location Policy, Section 3, Solid Waste Management, explains how the policy will be applied to planning proposals for landfill, setting out the Environment Agency's 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, the Environment Agency seeks 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, not just the comparatively short operational phase.

1.2 Regulatory Context

1.2.1 The Groundwater Directive (80/68/EEC)

This Directive, 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 Groundwater Regulations 1998. Some of its key requirements remain valid, including the need for prior investigation and requisite surveillance, and these are brought forward into EPR 2010 alongside the requirements of later Directives.

1.2.2 The Water Framework Directive and its Daughter Directive on Groundwater

Article 4.1(b)(i) of the Water Framework Directive (2006/60/EC) requires the implementation of measures necessary to prevent or limit the input of pollutants into groundwater. Further clarification on this point is provided in Groundwater Directive (2006/118/EC) under Article 6.

Article 11(3)(g) of the Water Framework Directive requires measures to control point source discharges (such as those from landfill). These requirements are satisfied by the Environmental Permitting (England and Wales) Regulations (2010).

Under EPR (2010), a permit may not be granted without 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 (Schedule 22, Section 7).

1.2.3 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 GWD and the Water Framework Directive (2006/60/EC) as WFD. The Waste Framework Directive is not referred to in this document and so **WFD always relates to the Water Framework Directive**.

1.2.4 WFD, GWD, EPR (2010) and Definitions

In addition to Section 1.2.2, background information on WFD, GWD and EPR (2010) legislative requirements for groundwater (hydrogeological) risk assessment are provided in our *H1 Guidance: Annex (j) Groundwater* (Environment Agency, 2010b).

For the purposes of this document, hydrogeological risk assessment has the same meaning as groundwater risk assessment.

Schedule 22(7) of EPR (2010) states that an environmental permit must include conditions requiring all necessary technical precautions to be observed to:

- Prevent the input of a hazardous substance into groundwater;
- Limit the input of non-hazardous pollutants to groundwater so as to ensure that such inputs do not cause pollution of groundwater.

The WFD (2000/60/EC) and its daughter GWD (2006/118/EC) refer to hazardous substances or non-hazardous pollutants. These are discussed in more detail later and specific substances and groups of substances are included in Appendix 1.

Guidance on what necessary technical precautions means in general is given in our *H1 Guidance: Annex (j) Groundwater* (Environment Agency, 2010b). Interpretation of these requirements specifically for landfill is given in Section 2.7.

1.2.5 Implementation of the Landfill Directive and IPPC Directive

Landfill sites which ceased accepting waste before 31 October 1999 continue to be governed by the conditions of their Waste Management Licences, although these have now become environmental permits. Those that operated after that date would be required to operate or close under the operational or closure requirements of the Landfill Directive respectively.

The requirements of the Landfill Directive and IPPC Directive (96/61/EC) have been implemented through the Environmental Permitting (England and Wales) Regulations 2010 and equivalent legislation in Scotland and Northern Ireland.

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

1.3 Specific Regulatory Requirements Relevant to this Guidance

1.3.1 Landfill Directive and Definitions

The requirement for Hydrogeological Risk Assessments

The LFD drives the need for two separate risk assessments, as follows:

- **Annex I (2) of the LFD** allows the Environment Agency to waive the need for a landfill operator to collect contaminated water and leachate if an assessment based on consideration of the location of the landfill and the wastes to be accepted shows that the landfill poses no potential hazard to the environment. The risk screening process described in Section 2.2 of this guidance addresses this particular requirement. We interpret this to mean that if there is no unacceptable risk of pollution due to the low hazard of the waste and the low sensitivity of the location, then there may be no requirement to line the site for the purposes of leachate collection.
- **Annex I (3) of the LFD** specifies engineering standards for the different classes of landfill. Annex I (3)(3.4) allows these requirements to be reduced, where assessment of environmental risks demonstrates, to the satisfaction of the competent authority (the Environment Agency), that collection and treatment of leachate is not necessary (as above) or it has been established that the landfill poses no potential risk to soil, groundwater or surface water. We interpret this to mean that the risk assessment process must demonstrate that a proposed landfill design will not result in an unacceptable discharge at any stage of its life cycle. Therefore the detailed groundwater risk assessment (Section 3 of this guidance) and related assessments (e.g. landfill gas control, stability) should be used to determine the engineering standards and other operational controls necessary to comply with the LFD and the GWD (see LFD 1 Understanding the Landfill Directive (Environment Agency, 2008) 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.

Annex I (3)(3.1) of the LFD requires that the protection of groundwater is achieved during the operational, active and post closure (*i.e.* pre-surrender) phases by the combination of a geological barrier and a bottom liner/artificial sealing liner. Subsequently, during the passive phase/post surrender, it is achieved by the combination of a geological barrier and top liner/cap.

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

The fundamental requirement for a geological barrier in all instances, and a bottom liner, wherever leachate needs to be collected, cannot be altered by the outcome of the risk assessment

process. Both of these elements are always required wherever there is a need to collect leachate. It may not be a requirement to collect leachate at inert sites.

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

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

Further guidance on the Environment Agency's interpretation of the engineering requirements of Annex I of the LFD is given in *LFD 1 Understanding the Landfill Directive* (Environment Agency, 2008).

Control and Trigger levels

Control levels are 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 and the Environment Agency to the development of adverse trends in the monitoring data. If breached, they indicate that the landfill may not be performing as predicted. They should be regarded, therefore, as an early warning system to enable appropriate 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 the Environment Agency's technical guidance on the Monitoring of Landfill Leachate, Groundwater and Surface Water (Environment Agency, 2003a).

Trigger levels are defined as levels at which significant adverse environmental effects, as referred to in *Articles 12 and 13 of the LFD*, have occurred. In other words, the compliance value for a specific groundwater receptor has been breached and there is pollution. It follows, therefore, that the Trigger level for a particular contaminant will be the most stringent Environmental Assessment Level (EAL) for that substance given the environmental setting of the site. Where there is poor baseline quality due to other anthropogenic impacts, the Trigger levels should be derived to take account of those impacts, but they must not bring about a delay in the improvement of water quality as other sources of pollution decline or lead to a long term trend of increasing concentration. Section 4.3 of this guidance deals with the setting of Trigger levels.

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

With regards to Control and Trigger levels, 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 must be determined taking account of the specific hydrogeological formations in the location of the landfill and groundwater quality. The trigger level 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."*

Trigger levels are directly comparable to compliance values as defined within our *H1 Guidance: Annex (j) Groundwater* (Environment Agency, 2010b), i.e. "The compliance value at a receptor is the relevant minimum reporting value, water quality standard or background concentration that needs to be achieved to prevent pollution of that receptor." Differing actions are required for breaches of groundwater Control and Trigger levels at landfills. These actions, as well as the derivation and use of groundwater Control levels and the use of Trigger levels, are considered in more detail in Section 4.

1.3.2 Environment Agency Requirements

The Environment Agency is 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;
- Management Control systems.

A tiered framework should be adopted in assessing environmental risks. 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 Control and Trigger Levels for the landfill that will indicate, with confidence, when the landfill is not performing as expected or designed, and when remedial action is necessary.

1.4 The Risk Assessment Process and Structure of this Guidance

Risk assessment should be a structured, transparent and practical process that aids decision-making. The Government's recommended framework for environmental risk assessment and management is described in DETR (2000) and in the *H1 Guidance: Annex (j) Groundwater* (Environment Agency, 2010b), as illustrated in Figure 1.3. 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.

The approach described in this guidance also emphasises:

- The importance of developing a robust conceptual site 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,
- The iterative nature of the process, with Control and Trigger levels and reviews of monitoring data being an integral part of that process.

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

- Developing the conceptual model and risk screening (Section 2)
- Carrying out detailed risk assessments (Section 3)
- The derivation and use of Control criteria and use of Trigger levels (Section 4)
- Reporting requirements (Section 5)

Figure 1.2 is currently being updated. This relates to Figure 1.1 ‘The interrelationship between this document and related guidance’ in the 2003 version.

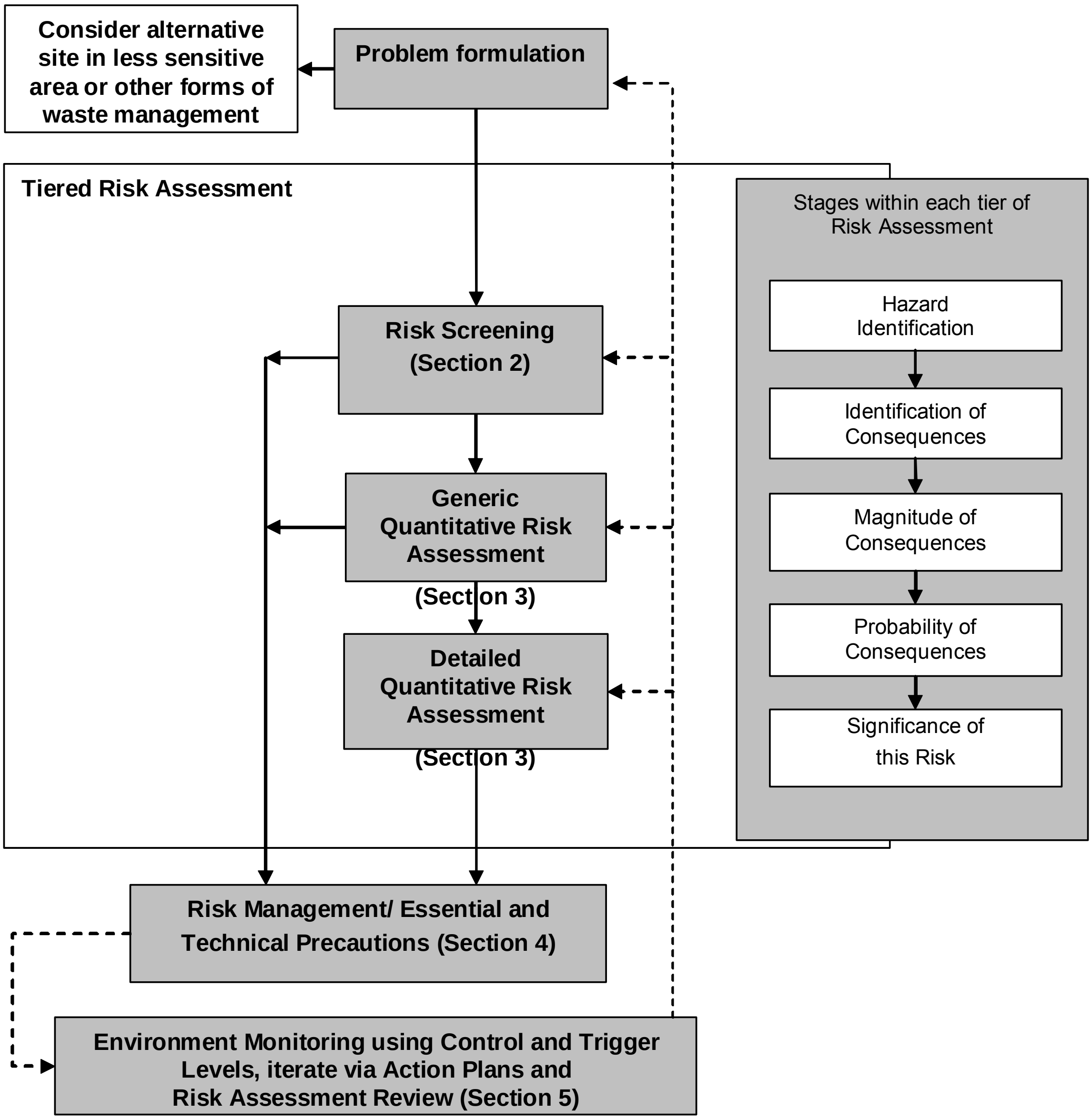


Figure 1.3 Framework for a Tiered Approach to Risk Assessment

2 Risk Screening and Conceptual Model Development

2.1 Introduction

This section describes the development of an understanding of a landfill site in its surroundings and the initial consideration of the risks from a landfill. These two elements are respectively known as developing the conceptual model and risk screening. Development of the conceptual site model involves defining the nature of the proposed landfill and its hydrogeological setting. More specifically, it should describe the design, construction and operation of a landfill, 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 linkages.

2.2 Risk Screening

Risk screening is the process used to determine whether the landfill development represents, or potentially represents, a hazard to ground and surface water resources. This process typically involves identification of possible source-pathway-receptor (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), 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 the Environment Agency along with the initial conceptual model, to be agreed to ensure that it is clear and documented where the subsequent risk assessment effort should be directed.

2.2.1 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 (2006/118/EC) and EPR (2010).
- Determine whether leachate needs to be collected, in accordance with Annex I (2) of the LFD enforced through EPR (2007, Schedule 10). That is, to assess on the basis of the wastes to be taken and the location of the site, whether the site is likely to require a liner.
- Determine whether a natural geological barrier is present and to make an initial assessment of the likely attenuation that this geological barrier could provide.
- Determine the status of the landfill development with respect to the Agency's landfill location and impact assessment position statement (Environment Agency, 2006a).
- 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

- 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.

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

- Identification of site-specific compliance points;

- Determination of the most appropriate Environmental Assessment Levels;

- Derivation of site-specific Trigger levels.

2.3 Developing the Conceptual Site 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 site model may not be required for the planning application stage but will be required at the environmental permitting stage, to allow robust understanding of relevant processes acting on contaminating substances, and in most cases their simulation by quantitative modelling.

The preparation of a robust conceptual model is a critical element in successfully evaluating environmental risks. Its development underpins each stage of risk assessment, such that its development and refinement is an iterative process within each level of risk assessment. Guidance on the development of conceptual site models has been published by the Environment Agency (Environment Agency, 2001a).

The conceptual site model should describe potential environmental impacts associated with the site. The development of a conceptual site 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 conceptual site model should include reference to the Environment Agency's Groundwater Protection: Policy and Practice ('GP3' Parts 1 to 4, Environment Agency, 2006-2008), in particular whether or not it complies with the policy on landfill location (Part 4, section 3.2).

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

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

2.3.1 Direct and Indirect Inputs

The conceptual model must explicitly identify whether there is a potential for a direct or indirect input of any hazardous substances or non-hazardous pollutants (see Box 2.1) to groundwater.

A direct input means:

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

and an 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, such as an unsaturated zone, to the water table is an indirect input, whereas seepage directly into groundwater without the benefit of a geological barrier is a direct input. This distinction is important because, except where no pollution or discernible increase in concentration would occur, the direct input of hazardous substances into groundwater, for all practical purposes, cannot be viewed as preventing an input into groundwater and so is prohibited under the GWD (2006/118/EC). Further guidance on preventing or limiting direct and indirect inputs in the context of the GWD (2006/118/EC) is given in WFD Common Implementation Strategy (CIS) Guidance Document No. 17 (EC, 2007).

A key output from the 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 as well as the nature of the landfill development.

Groundwater levels fluctuate, typically as a result of seasonal variations or abstraction. Where this results in the groundwater alternating between levels that lie above and below the base of a site, or where groundwater ingress into the site occurs on a seasonal basis, inputs should be treated for the purposes of the GWD (2006/118/EC) as being potentially direct. 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 there are no accurate data on past rest 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 direct.

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 stability (Environment Agency, 2003b) and landfill gas (Environment Agency, 2004c, CIRIA, 2007) risk assessments.

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

The passage of leachate through a substantial and intact mineral barrier (i.e. 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 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.

Hydraulic conditions may vary around the site and with time, and 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 (i.e. more than a few metres above the base of the cell), then the implications for gas management and stabilisation of the landfill, and the length of the post-closure pre-surrender period, must also be carefully considered. The saturation of the waste may inhibit biodegradation as a result of consequent lower temperatures (for example, groundwater in the UK is typically around 10°C). Any future abstraction of groundwater that would lower the water table is likely to be accompanied by an increase in gas generation.

The completion and surrender of a hydraulically contained landfill may therefore be difficult unless there is careful control over the hydraulic gradient and the volume/depth of leachate that the site will contain in the pre-surrender period. The long-term integrity and effectiveness of engineering and management structures is also more difficult to guarantee since the duration that hazardous substances remain undegraded is increased.

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

Where the potential for a direct discharge is identified in the conceptual model and risk screening stage, the subsequent risk assessment will be correspondingly more detailed (see Section 3.2). Issues such as failure scenarios are considered in more detail in Section 3.5.

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.

2.3.2 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 site model for both the site and its hydrogeological setting. This should include summaries of information such as maps, plans, cross-sections, schematic diagrams etc, which allow an easy understanding of the environmental setting;
- Determine, using the initial conceptual site 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 conceptual site 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 conceptual site model formulation stage. In addition, Appendix 2 sets out the possible sources of information that relate to determination of the potential or actual leachate quality, while Appendix 3 sets out in more detail, the specific information requirements that relate to site geology and hydrogeology. The data collection exercise, and specifically the degree of site-specific data analysis, is likely to reflect the environmental sensitivity of the site and the nature of the hazard posed by the wastes.

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

Adequate leachate characterisation is required for all levels of risk assessment. Appendix 2 presents the potential sources of information that could be used to predict likely leachate chemistry. However, wherever possible, representative samples of leachate from either the landfill or representative analogue sites that take similar waste streams, should be tested.

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

- Obtain feedback relating to the conceptualisation of the site;
- Determine whether assumptions made are consistent with Environment Agency understanding of the local hydrogeology and environmental setting;
- Agree the current uncertainties present within the conceptual site 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 the Environment Agency, 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 illustrate clearly the potential sources, hazards and pathways and drawings showing 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 CONCEPTUAL SITE MODEL

Issues	Information that should be reviewed	Potential sources of information that should be consulted
Site Context	***For all sites*** • *Groundwater Protection: Policy 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 • Likely leachate quality (including whether the site may give rise to the discharge of potential pollutants) (DoE, 1995; Knox *et al*, 2000; Environment Agency, 2004a))	***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) • 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*** • Technical guidance and relevant publications

TABLE 2.1(continued) : ISSUES THAT NEED TO BE CONSIDERED DURING THE DEVELOPMENT OF THE INITIAL CONCEPTUAL SITE MODEL

Issues	Information that should be reviewed	Potential sources of information that should be consulted
	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 conceptual site 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 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 (e.g. EA/BGS Aquifer Properties Manuals) • Geological and hydrogeological data from the British Geological Survey • Information on sites of ecological importance or for nature conservation (Natural England, Countryside Council for Wales and Scottish Natural Heritage)

2.3.3 Site Investigations

The objectives of site investigations are to increase the assessor's 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 conceptual site model, in order to critically test the conceptual site 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 conceptual site 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 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 adopting a robust QA/QC method and audit trail. General guidance on site investigations is available in a number of other documents (British Standards Institute, 1999 & 2001; Environment Agency, 2003a). Some of the potential 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.

2.3.4 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, i.e. to determine the baseline conditions; impacts during landfill operation, and continued performance post-closure. *Guidance on 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 feed back into the risk assessment in an iterative review process (e.g. 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 Trigger levels***);

- As a means of determining whether a landfill meets completion criteria.

With respect to the conceptual model development, monitoring must provide a high level of confidence in the baseline conditions at the landfill, and additional data to test and revise the assumptions incorporated within the conceptual model. Monitoring data collected for other purposes (e.g. landfill gas monitoring), should be reviewed and used where appropriate.

2.3.5 Permanently Unsuitable

Reference to groundwater that is "permanently unsuitable for other uses" in the original Groundwater Directive (80/68/EEC) is not brought forward into EPR 2010. EPR 2010 does however implement the exemption within the WFD (2000/60/EC) that allows direct inputs of substances from certain groundwater activities (e.g. related to mining, oil exploration and storage of LPG) 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.

2.4 Risk Screening Criteria

2.4.1 Screening based on (Size and) Quality of Discharge

The GWD (2006/118/EC) and paragraph 3 of Schedule 22 of EPR (2010) note 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. The Environment Agency 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.

If the actual or predicted leachate volume and chemistry are likely to exceed the thresholds of quantity and concentration noted above, then the discharge requires a permit under the Regulations, and the subsequent assessment (prior examination) must demonstrate that the geological, engineering and operational controls are adequate to meet the requirements of the Regulations.

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 (see Box 2.1) rather than their volume or the assumed characteristics of an unsaturated zone. The volume of discharge will invariably be significant and the unquantified effect of an unsaturated zone cannot be relied upon other than to provide a degree of confidence where the decision is marginal.

For hazardous substances, an analytical framework for screening leachates has been developed to assess whether these are likely to be present in the leachate (see Appendix 5). Where concentrations of the core determinands exceeds the minimum reporting value (MRV, see Appendix A2 of our H1 Guidance: Annex (j) Groundwater, Environment Agency, 2010b) 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.

Box 2.1 **Hazardous Substances and Non-Hazardous Pollutants**
The old 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 its daughter Groundwater 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 (2010) 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***" The Environmental Permitting Regulations (2010) only specify 'hazardous substances' as being toxic, persistent and liable to bioaccumulate. 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 also 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. For an up to date list of hazardous substances and non-hazardous pollutants refer to the Environment Agency's web site www.environment-agency.gov.uk

The majority of leachates from landfill sites have the potential to contain both hazardous substances and non-hazardous pollutants. Inert landfills will 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 due to the accidental acceptance of contaminated material would be required. Regardless of whether the GWD applies or not, the disposal activity must still comply with the requirements of the LFD and Control and Trigger levels must be set and environmental monitoring will be required.

As a consequence of the requirements of the LFD (e.g. 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, 2004).

2.4.2 Screening Based on the Collection of Leachate

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 (2) of the LFD)). The Environment Agency is 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 (i.e. there is no need for an artificial sealing liner) 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, 2008, 2009a, 2009b).

Leachate chemistry should be compared to water quality standards (see Appendix 9) to provide an assessment of its potential hazard. Only where the actual or predicted leachate quality presents a low 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.

2.4.3 Screening Based on Nature of Geological Barrier

The need for a geological barrier is an absolute requirement in the LFD. It must provide sufficient attenuation between the landfill source and any potential groundwater receptor in order to ensure compliance with the GWD.

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

Provision exists within Annex I (3)(3.2) of the LFD to artificially complete and reinforce the geological barrier. However, in certain sensitive hydrogeological situations (see Environment Agency, 2006a), the Environment Agency is unlikely to accept artificial enhancement of the geological barrier.

The existence and extent of any natural geological barrier is therefore an important consideration at the risk screening stage. This consideration should include the potential presence of discontinuities and other natural variations in the geological barrier. As outlined above, the assessment of the attenuation that the natural or artificial geological barrier would provide is a vital consideration. This assessment of attenuation is the same as the consideration of the purifying powers of the soil and sub-soil to ensure that the attenuation capacity is sufficient to prevent a risk to groundwater i.e. 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.

2.4.4 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, 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 the Environment Agency's landfill location policy (Environment Agency, 2006a). 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.

2.4.5 Further Risk Screening Requirements

One output from the risk screening process should be a recommendation of the appropriate level of further risk assessment work. Section 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.

2.5 Compliance Points

A principal requirement of the EPR (2010) is to assess the actual or potential impact of the discharge on groundwater in the vicinity of the site (i.e. 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 Limits (EALs) are set in order to ensure that relevant environmental standards will be met at all the receptors at risk.

General guidance on compliance points is provided in Section 4.2 and Appendix 1 of our *H1 Guidance: Annex (j) Groundwater* (Environment Agency, 2010b), text from which is included as Appendix 10.

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

- The water table (not readily monitored beneath a landfill therefore theoretical) - for calculated concentrations of hazardous substances to check whether the entry of hazardous substances to groundwater will be avoided;
- A point (for example, a borehole or spring suitable for monitoring) at the down-gradient edge of the landfill to check that:
    - o Monitored concentrations of hazardous substances are acceptable in terms of the “prevent” objective ;
    - o Calculated and monitored concentrations of non-hazardous pollutants will not cause pollution.
- An off-site receptor (for example, abstraction borehole, spring, wetland, stream or river).

Illustration of the selection of compliance points is given in Figure 2.1.

2.5.1 Compliance Points for Hazardous Substances

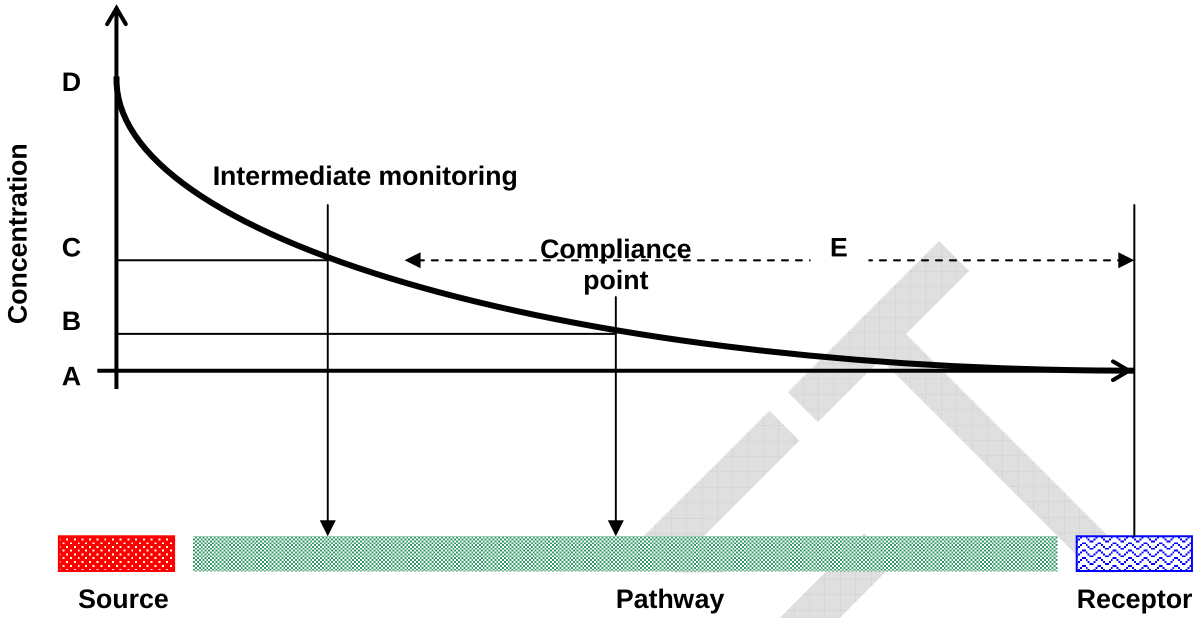
EPR 2010 requires that the input of hazardous substances to groundwater must be prevented. An input is considered to have been prevented if the substance concerned is not discernible in the groundwater above natural background concentrations or a relevant minimum reporting value (MRV) after the immediate dilution as the discharge enters the groundwater (the interpretation of ‘prevent’ is further discussed in our *H1 Annex (j) Groundwater* Guidance). Effectively the receptor at risk from hazardous substances is the groundwater immediately surrounding the area of discharge.

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 and Trigger levels is 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.

2.5.2 Compliance Points for Non-Hazardous Pollutants

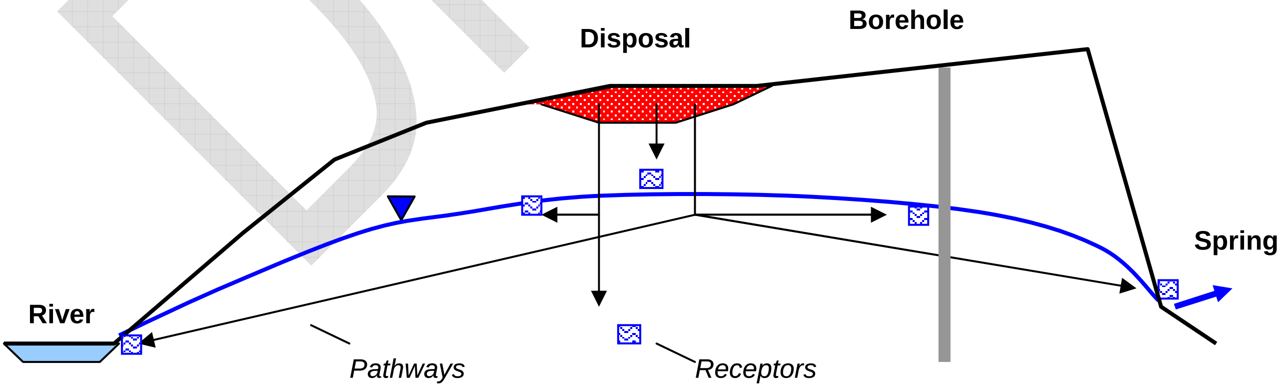
Inputs of non-hazardous pollutants should be limited so as to avoid pollution of groundwater. In most instances the compliance point for non-hazardous pollutants will be monitoring boreholes adjacent to the landfill. In some instances, where groundwater has no current or potential future resource value, boreholes further from the site may be appropriate or the compliance point could be a surface water feature in the vicinity of the landfill. The selection of a compliance point other than at the perimeter of the site would have to consider the sensitivity of the landfill's location. Factors such as the status of the site under the Environment Agency's guidance on the location and impact assessment of landfill sites (which considers the vulnerability of groundwater) and our aspirations for the receiving groundwater should also be considered. The selection of a surface water feature as a compliance point is only likely to be acceptable where the consideration of all the source-pathway-receptor linkages has identified the surface water as the highest priority risk, and where the Environment Agency agrees that it represents the most significant (water) receptor for any contamination from the landfill (i.e. where groundwater is not a useable resource). The risk screening and prioritisation process is fundamental in determining the appropriate point of compliance for each individual landfill.

Figure 2.1 Compliance Point Selection



A = Environmental standard necessary to protect the **receptor**.
B = Compliance value at a **compliance point**, set to ensure the environmental standard at the receptor is/will be met (may be physical, i.e. an actual **monitoring point** or virtual, i.e. 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.

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



2.6 The Selection of Environmental Assessment Limits (EALs)

The conceptual site model and risk screening should identify the most appropriate water quality standards that apply to the groundwater around the landfill. These quality standards and baseline water chemistry should be used to derive Environmental Assessment Limits, or EALs, for the potentially polluting substances that might be present within the landfill leachate, in order to make decision whether the impact of the landfill on water quality is acceptable. All current and future potential uses of the groundwater would need to be considered for this purpose including receptors, such as surface watercourses and ecologically sensitive features (see Section 3.4 of H1 Annex (j) Groundwater, Environment Agency, 2010b). It is key that water quality standards and compliance points are considered in tandem. The identification of the location(s) (in 3 dimensions) where a standard applies is an integral part of the determination of an appropriate water quality standard.

Some of the standards that should be considered in developing the most appropriate EALs for groundwater are presented within Appendix A3 of our *H1 Guidance Annex (j) Groundwater* (Environment Agency, 2010b). Whatever water quality standards are applicable to a particular site, the appropriate EAL should be the most stringent applicable standard available for the considered contaminants, which will provide, therefore, 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 and Trigger levels 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, e.g. 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 at 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 (e.g. baseline ~50mg/l, DWS 250mg/l) and some metals, where there are no discharges to surface waters. For example, both copper and zinc are present as trace elements in groundwater but have DWSs of 2000 and 5000μg/l respectively. EQSs for copper (1 - 28μg/l) and zinc (8 - 500μg/l) are considerably lower.

In many cases the EAL for groundwater in Principal and Secondary Aquifers will be derived from either the Drinking Water Standard (DWS) or the Environmental Quality Standard (EQS), 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 ensures long term compliance with the DWS at the tap. So a safety factor may need to be applied to derive the compliance value at the receptor.

In the case of low permeability formations that do not represent a groundwater resource locally (or a potential groundwater resource), the EAL may be applied at the point at which groundwater enters other water receptors. For example, the EAL may be selected to ensure there is no deterioration in river water quality, or harm to an ecosystem. In adopting this approach, assessors must ensure that it will not result in pollution of water. An acceptable concentration at the landfill site can then be back-calculated using methods set out in the *Remedial Targets Methodology* (Environment Agency, 2006). The most stringent, relevant EAL for the receptor should be used as the basis for the calculations. This recognises that, in these circumstances, the low permeability formation is not in itself a current or potential future water resource but that it may still support important water resources or features such as wetlands or surface watercourses. Typically, baseflow into the nearest surface water body should be protected to ensure no deterioration against baseline quality, or where baseline quality is currently impaired, baseflow into the surface water should not exceed the relevant Environmental Quality Standards[1].

Assessors should confirm with the Environment Agency that low permeability formations, such as some unproductive strata, have no water resource value, or potential resource value. Some unproductive strata 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.

Trigger levels at *inert sites* should be derived based on baseline groundwater quality. By definition, inert landfills should not produce leachate containing significant pollutant concentrations and so deterioration in groundwater quality, attributable to the landfill, would require contingency actions to be undertaken.

2.7 Necessary Technical Precautions

In the context of the Environmental Permitting Regulations (2010), 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

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

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 (e.g. 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, 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 2.3.1), 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.

3 Quantitative Risk Assessment

3.1 Introduction

Following the formulation of a robust conceptual site model and risk screening, subsequent hydrogeological risk assessment comprises a more detailed (quantitative) risk assessment. This 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 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 not sufficient 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 site's geology and hydrogeology, as well as whether the formations are a water resource locally, or support secondary receptors (e.g. wetlands, surface water bodies) 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 i.e. the disposal of wastes into the landfill will not result in a discernible input of hazardous substances into groundwater and will not cause 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 source-pathway-receptor 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 source-pathway-receptor linkages over the short and long-term;
- Develop indicative completion criteria with respect to groundwater.

3.2 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.

Generic quantitative risk assessments should consist of simple quantitative calculations, typically analytical solutions solved in a deterministic fashion using conservative input parameters, assumptions and methods. The use of conservative (worst case) assumptions results in a generic assessment. Generic quantitative 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 source-pathway-receptor linkages are identified, or in preparation for conducting a more complex assessment, and where either:

- It is clear from the conceptual model and the risk screening that the hazards are relatively low and the environmental setting is sufficiently insensitive to negate the possibility of significant impacts (e.g. 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, e.g. 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. If the site poses a long-term pollution threat, it will be important to identify if there is a geological barrier between the site and sensitive waters. In such cases, 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.

In all cases 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.

Detailed quantitative risk assessments should be carried out in a quantitative manner using stochastic, i.e. probabilistic, techniques to analytical solutions, or mathematical solutions. The use of more site characterisation data is key 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 source-pathway-receptor terms are present and where either:

- The site setting is sufficiently sensitive to warrant detailed assessment e.g. on permeable strata (e.g. Principal Aquifer); within a Source Protection Zone; or close to surface water bodies;
- There is uncertainty relating to any of the source, pathway or receptor terms e.g. variable leachate quality, undefined groundwater flow pattern, which cannot be overcome by the adoption of conservative inputs or assumptions.

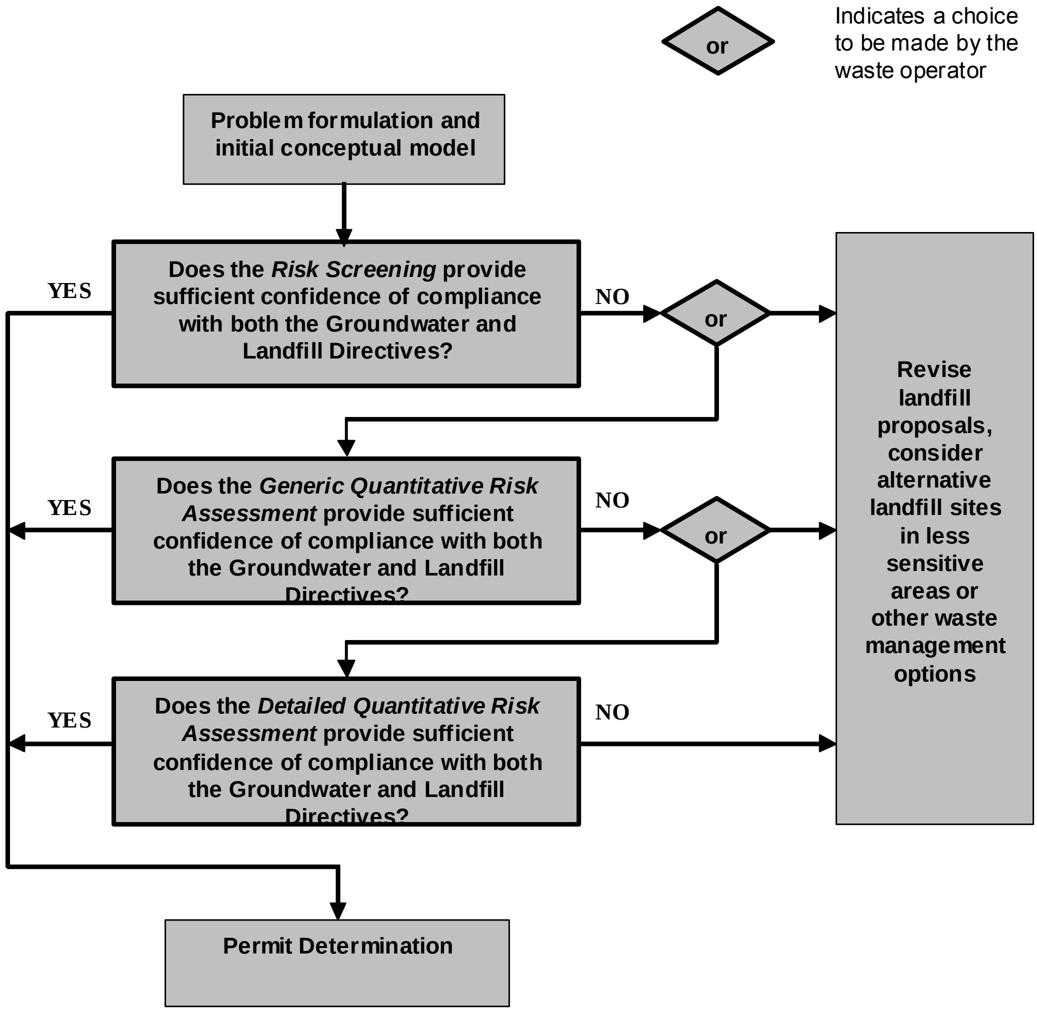
Worked examples of generic and detailed quantitative risk assessments are presented in Appendix 8.

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 (e.g. Unproductive Strata)			
No surface water or other receptors (e.g. springs or abstractions)	RS	RS/G	G/D
Surface water, springs, abstractions etc present or significant uncertainty	RS/G	G/D	D
Below the water table	RS/G	G/D	D
Moderate permeability strata (e.g. Secondary Aquifer)			
Outside SPZ, no surface water receptors, above the water table	RS	G	G/D
Outside SPZ, no surface water receptors, below the water table	RS	G/D	D
Outside SPZ, surface water receptors, below the water table or uncertainties	RS/G	D	D
Within SPZ II or III no surface water receptors, above the water table	RS/G	D	D
Within SPZ II or III, no surface water receptors, below the water table	RS/G	D	D
Within SPZ II or III, surface water receptors, below the water table or uncertainties	G	D	D
Highly permeable strata (e.g. Principal-Aquifer)			
no surface water receptors, above the water table	RS/G	D	D
no surface water receptors, below the water table	G	D	D
surface water receptors, below the water table or uncertainties	G	D	D
Within SPZ II or III	G	D	D

Note:
1) RS – Risk Screening; G- Generic quantitative risk assessment; D- 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: Policy and Practice ('GP3').

FIGURE 3.1: ILLUSTRATIVE RISK ASSESSMENT FRAMEWORK



3.3 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.

3.3.1 Emissions to Groundwater

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 i.e. 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 landfill's life.

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 5, 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 for the substance in clean water (see Appendix A2 of our H1 Guidance: Annex (j) Groundwater, Environment Agency, 2010b) 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.

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). The Environment Agency 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 e.g. 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; and
- The predicted time at which active management of the landfill will cease (e.g. extraction of leachate and maintenance of leachate collection systems).

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.

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. The Environment Agency can only authorise activities where it is shown, by *[prior] examination*, (i.e. risk assessment) that there will not be any pollution, or other unacceptable risks. In making this judgement we will consider the robustness of the conceptual model and risk assessment method used, the data reliability and the treatment of uncertainty.

The risk assessment process is not an abstract exercise but must be closely linked to the actual landfill design and operations, i.e. the necessary technical precautions. 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.

Degradation of engineering and management systems

The risk assessments must be carried out for the whole lifecycle of the landfill, that is to say, from the start of the operational phase until the point at which the landfill is no longer capable of posing an unacceptable environmental risk. This means that the changes in leachate quality with time must form part of the evaluation of the likely pollutant concentrations. The risk assessment must consider the changes in leachate quality over time, (inevitable) degradation or removal of management systems and the ability of the geological barrier to provide long-term environmental protection. Any models used will need to be able to reflect the different phases of the landfill's lifecycle. The risk assessment must explicitly identify and document the different assumptions used to simulate the lifecycle of the landfill. A simple example would be three stages: operational phase with all management systems working as designed; post closure with a capping system working as designed but with some degradation of leachate collection systems, and long-term (just prior to completion) post closure with degradation of management systems, including artificial lining systems 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 as described in Section 3.5, and 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 below:

Geomembrane liners (e.g. 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 (e.g. 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 (e.g. 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 only while financial provision is available to remedy any blockages. After this period, it is assumed that no management or institutional control will be available to maintain the drainage system and so it will become clogged very quickly (effectively instantly) due to biological, chemical and physical reactions. It will subsequently have a permeability equal to that of the overlying waste.

Cap:
All capping systems are assumed to allow their design infiltration after they are installed. Geomembrane caps will then degrade in a linear fashion over a long time period (hundreds of years) due to oxidation, with the final recharge being equal to the effective rainfall on a grassed site (assuming final restoration is to grassland). Clay or GCL caps are expected to continue to perform to their design specification without degradation.

3.3.2 Priority Contaminants to be Modelled

Hazardous substances and non-hazardous pollutants have been discussed in Section 2.4.1 and Box 2.1 with further discussion on their likely presence in landfill leachate provided in Appendix 2. 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 5. Where the screening procedure identifies elevated concentrations of hazardous substances (thresholds are given in Appendix 5), 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 2. 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.

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

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 3.2.

Table 3.2 - Examples of Chemical Species that may be Appropriate for Modelling Typical Domestic (non-hazardous) Landfills

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

3.3.3 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 an assessor 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 (e.g. 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 (i.e. reasonable "worst-case", as agreed by all parties) are suitable. The assumptions behind these conditions should be made clear and provided as evidence within the risk assessment process.

Due regard should be given to an assessor's experience and knowledge of the processes being simulated in any model, i.e. 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 (e.g. for attenuation properties or groundwater levels) 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 (i.e. to 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 the *Groundwater Protection: Policy and Practice* ('GP3', Environment Agency, 2006a).

3.4 Risk Assessment Tools

A number of assessment tools, including computer models can aid the hydrogeological risk assessment process. Table 3.3 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 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 Agency's preferred model for assessing the risks to groundwater from landfill sites.

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 a site's life 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, cap, leachate management systems and changes in the leachate quality). A variety of scenarios should be developed to reflect different phases of the landfill's life.

Parameter values should, as far as possible, be based on site-specific data. Use of literature or default values should only be undertaken 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** (e.g. soil-water partition coefficients, K_d) and, ideally, **contaminant degradation rates**.

TABLE 3.3: 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 (e.g. 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			√

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 the Environment Agency in an electronic format. If the models have been constructed by the assessors and have not been independently verified, then the models need to be supplied with the appropriate quality assurance information to allow their verification prior to the risk assessment outputs being reviewed.

3.5 Accidents and Possible Failure Scenarios

The inevitable degradation, over time, of engineered and management systems should form part of the normal risk assessment process, as described in Section 3.3.1. This 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 or leachate collection systems should be considered in assessing the long-term flux of pollutants discharged from the landfill.

The risks associated with accidents and their consequences must be considered separately from the risks arising from normal operations. Accidents are considered to be unintentional incidents that could reasonably occur, which are unforeseeable 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 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 (e.g. 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 pipework, 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.

3.6 Completion

Landfill completion requires a consideration of whether the site, as a result of the disposal of controlled wastes, is likely or unlikely to cause pollution of the environment or harm to human health. This determination needs to take into account all of the potential hazards and risks associated with the site and guidance is being prepared on this matter (Environment Agency, 2009c). 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 (i.e. the geological barrier) to provide long-term environmental protection. Landfills with a declining source term will eventually reach a stage where the quality and quantity of the leachate can be attenuated by the geological barrier and active management of the landfill is no longer required.

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

4 Use of Control and Trigger Levels

4.1 Introduction

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

- Allows for validation of the risk assessment;
- Can confirm whether risk management options are meeting their desired aims;
- Provides a warning mechanism if adverse impacts are found.

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

Control levels are specific assessment criteria, as defined by Environment Agency (2003a), relating to groundwater or other relevant parameters, which are used to determine whether a landfill is performing as designed. They are levels that are intended to draw the attention of site management and the Agency to the development of adverse, or unexpected, trends in the monitoring data. Such trends may results from failure of site engineering or management, or from variations between actual conditions and those assumed within the conceptual model. Control levels should be treated primarily as an early warning system to enable appropriate investigative or corrective measures to be implemented, particularly where there is potential for a Trigger level to be breached.

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

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

Trigger levels are specific compliance levels, or regulatory standards, as defined by Environment Agency (2003a), the nature of which should be stipulated within an environmental permit. They are defined as criteria at which significant adverse environmental effects and/or breaches of legislation have occurred. Such effects would be consistent with the groundwater having been polluted.

4.2 Control Levels

4.2.1 Aims of Control Levels

Control levels should:

- highlight variations between the conceptual model (i.e. 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);
- give sufficient time to take corrective or remedial action **before** Trigger levels are breached.

4.2.2 Deriving Control Levels

Control levels must be set for all landfills. 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 Trigger level has been set (see Section 2.6), 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 Environment Agency to identify, at an early stage, whether the landfill's performance is deviating from its design performance, as assumed within the conceptual model. They should give an early warning that allows action to be taken by the operator to avoid 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.

Hazardous substances. The GWD requires that entry of hazardous substances into groundwater is prevented, which means that any increase in their concentration in groundwater should not be discernible. Since the Trigger levels 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 that, 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 conceptual model for the site and the outcome of the risk assessment process. In particular, the results of a sensitivity analysis on the predictive modelling of the landfill are likely to be important in identifying those parameters that are likely to have the greatest impact on the rate at which contaminant mass is released from the landfill.

Control levels should be set for relevant parameters at a point that is a significant deviation from the assumed values incorporated within the conceptual model. For example, if leachate is assumed to have a concentration of a hazardous substance no greater than 250μg/l, it would be appropriate to set Control levels (applied to leachate monitoring data) at, say, 250μg/l plus 10%, 20% and 50% (i.e. 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 conceptual model.

Similarly, if leachate head is a sensitive parameter in the risk assessment and it is assumed within the conceptual model that leachate head will not exceed, say, two metres above the base of the site, then a 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.[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 of those waters. 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 (i.e. the risk assessment output based on the conceptual model) and the Trigger level, as illustrated in Figure 4.1.

For example, if, on the basis of a robust risk assessment model it is predicted that the maximum concentration of ammonium, NH_4^+, in groundwater at the site boundary will be 0.2mg/l and the Trigger level is set at 0.5mg/l, then Control levels at 0.25 and 0.35mg/l could be appropriate. i.e.

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

25% above predicted maximum and half-way between predicted concentration and the Trigger level. Simultaneously, the trends in pollutant concentrations in the groundwater should be reviewed to check whether there are unexpected trends, and whether Control and Trigger levels are likely to be breached in the near future.

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

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). Trend analysis for groundwater quality data is the subject of a separate guidance document (Environment Agency, 2002c).

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

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

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

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

4.2.3 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 Trigger levels being breached, or when there is a rapidly rising trend towards this point. When an adverse trend or breach of a Control level is indicated by the monitoring results, contingency actions should be implemented, within pre-specified response times, as agreed with the Environment Agency.

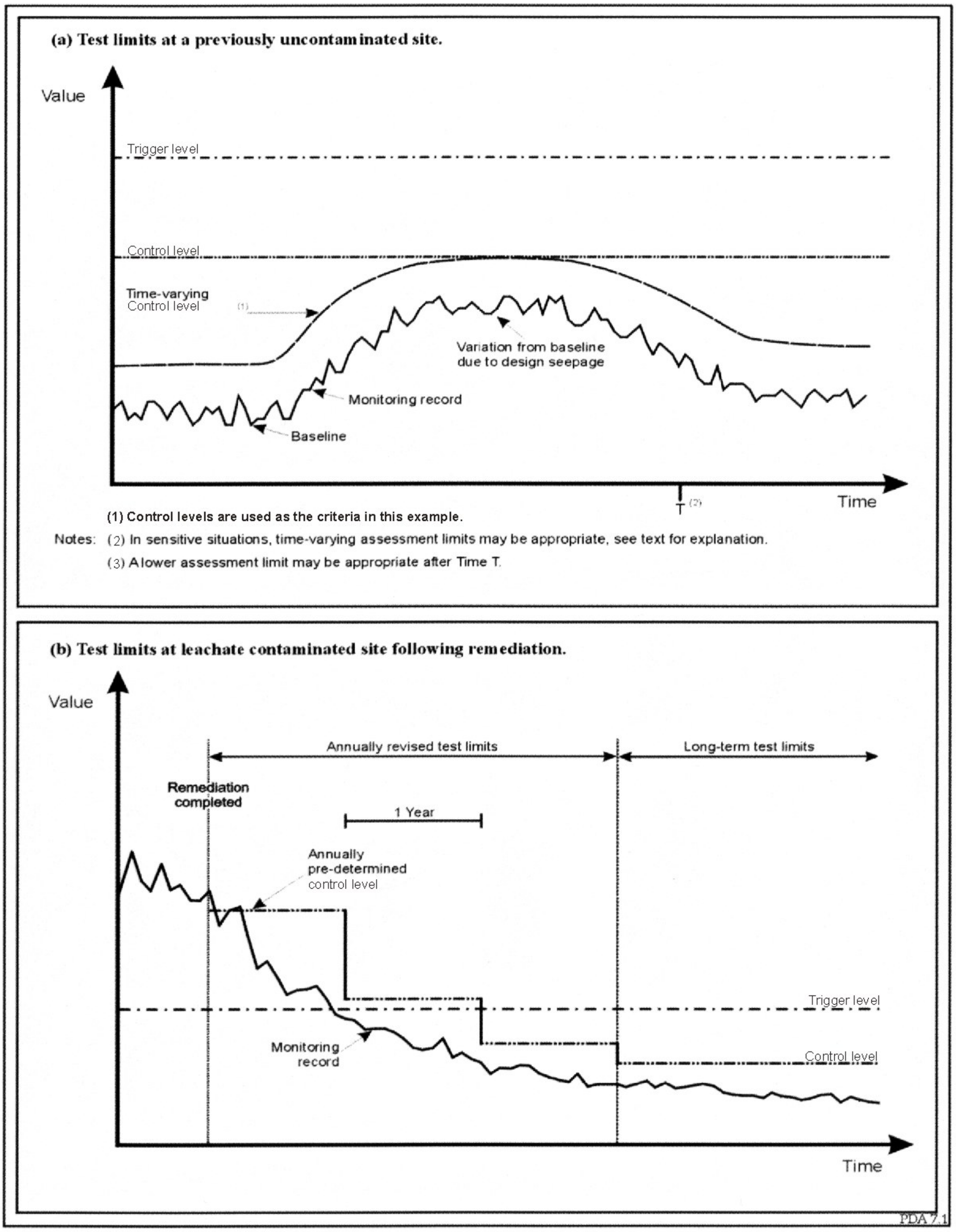


FIGURE 4.1: ILLUSTRATION OF GENERAL PRINCIPLES OF CONTROL AND TRIGGER LEVELS (after Environment Agency, 2003a)

4.3 Trigger Levels

4.3.1 Derivation of Trigger levels

Trigger levels for potentially polluting substances are to be set at the point where pollution can be said to have occurred and can be detected by monitoring i.e. Trigger levels represent the level of contamination that constitutes pollution. This means that a change in water quality to a concentration below the Trigger levels would be acceptable, but a concentration at or above the Trigger level would be unacceptable, subject to the usual caution that should be used when dealing with the numbers generated by a quantitative assessment.

There are three main considerations in setting Trigger levels.

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

4.3.2 Selection of Substances for which Trigger Levels are Required

Trigger levels have a role both as a performance standard for monitoring and as the success criteria for the risk assessment. The selection of substances should reflect this dual role. The 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 Trigger levels within the monitoring regime of the landfill, make reference to our guidance on landfill monitoring (Environment Agency, 2003a). Section 4 deals in more detail with the relationship between Trigger and Control levels and site monitoring.

Trigger levels should be set for the same substances that are considered in the risk assessment, particularly where those substances are present in the highest concentrations in leachate and are most mobile in the subsurface. This will be a site-specific determination depending upon the proposed waste types and the baseline water quality but Section 3.3.3 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, Trigger levels should be set for at least 3, but no more than 10 substances. In addition, they should not be set for substances where resultant (following development of the landfill) levels within groundwater would be at, or below, normal levels of detection.

4.3.3 Selection of Concentration Limits for Trigger Levels

For *hazardous substances*, Trigger levels should be set at a value that represents a concentration of the substance above which it would be considered discernible in groundwater (i.e. 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 (see Appendix 2 of our *H1 Guidance: Annex (j) Groundwater*, Environment Agency, 2010) should be used as the Trigger level for hazardous substances, applied at the closest monitoring points to the waste body, unless baseline groundwater chemistry exceeds these levels.

The Trigger levels should be set:

- At the MRV for hazardous indicator substances that are predicted to be present or detected in the leachate, but not present in the baseline water chemistry;
- At the concentration of the current baseline water quality, on an agreed statistical basis, i.e. 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 e.g. Environment Agency, 2002c. Where a declining historical source is affecting baseline water quality the Trigger levels should be set at reduced levels in the future to ensure the permitted landfill cannot inhibit any improvement in water quality. This could be in the form of a table with Trigger levels specified for discrete time periods.

Trigger levels for *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/Trigger levels that may have either increased or decreased.

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

Where the compliance points for non-hazardous pollutants are remote from the landfill, the Trigger level should be set for on-site monitoring boreholes at a level back-calculated from the selected EAL at the compliance point. This means that where a remote receptor is selected as a compliance point a calculation would be required to produce a Trigger level for a perimeter monitoring borehole. The calculation would have to determine the Trigger level at the perimeter borehole, which would mean the EAL should not be exceeded at the more remote receptor. In practice this means that a higher level of contamination would be acceptable at the monitoring borehole 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 Trigger level for a non-hazardous pollutants 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 (i.e. to ensure that the landfill does not cause additional/future pollution), but the Trigger level will normally take account of the other pollutant inputs (and thereby be a higher concentration). This is necessary to ensure that compliance against the Trigger level can be assessed practically.

4.3.4 The Intervals Between Trigger Level Reviews

The frequency of Trigger level reviews (i.e. to determine whether a Trigger level 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. Notwithstanding this, the Control level reviews, which should be carried out each time new groundwater monitoring data are obtained, will also constitute an informal Trigger levels review.

The regular intervals specified within the 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 Trigger level in the near future). The waste operator should then continue to analyse Trigger level conditions to obtain landfill management information.

If there are breaches of Trigger levels, then the operator should notify the Environment Agency at the earliest opportunity (typically within 5 working days of receipt of the monitoring data). Notification of non-compliance with a Trigger level should **not** be left until the annual reporting round.

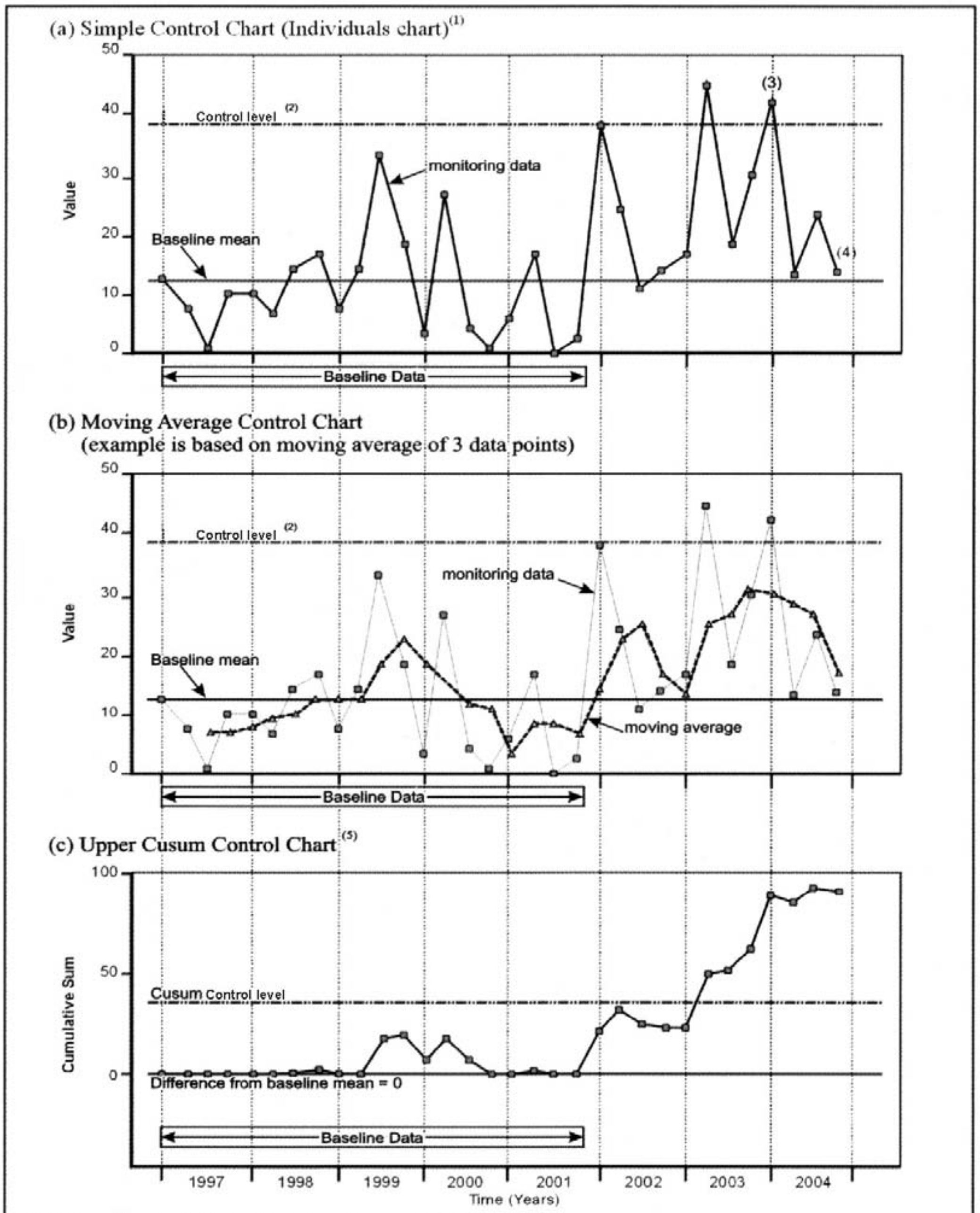
4.3.5 The Period of Monitoring Used for the Analysis

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

4.3.6 The Inclusion of Trigger Levels in the Environmental Permit

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

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



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

FIGURE 4.2 EXAMPLES OF USE OF CONTROL CHARTS TO INTERPRET TRENDS IN MONITORING DATA (after Environment Agency 2003a)

4.4 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 (i.e. the Environment Agency) and must follow the decision of the 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 and Trigger levels should be specified clearly and each action should have an agreed response time. In all cases, where breaches are confirmed as being due to leachate contamination, 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, (e.g. changes to up-gradient groundwater chemistry), and the risk is proven to be small, Control and Trigger levels may be re-evaluated in consultation between the site operator and the Agency.

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

If a breach of a Trigger level occurs as a result of migration of substances from the landfill, this indicates non-compliance with both the LFD and the GWD, and 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 should form part of an action plan, developed in consultation with the Environment Agency, which should include a higher frequency of groundwater monitoring, both in the vicinity of the site and upstream, and a review of the essential and technical precautions required by the environmental permit. If the assessment confirms that the landfill is the likely 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 (e.g. reducing leachate heads) others can be very costly and technically complex (e.g. *in-situ* groundwater remediation). The need for remediation should be balanced against the risk posed to groundwater and surface water receptors and the environmental benefits gained by remediation. However, further pollution must be avoided. In complex cases, specialist advice should be taken and remedial actions and their objectives agreed in consultations between the site operator and the Environment Agency. Not withstanding the above the Environment Agency has 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 in consultation with the Environment Agency as 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	Trigger Level
Advise site management	√	√
Advise environmental manager of landfill operating company	√	√
Advise Environment Agency	√	√
Confirm by repeat sampling and analysis	√	√
Review existing monitoring information	√	√
Review site management and operations, and implement actions to prevent future failure of a Trigger level	√	
Review the assumptions incorporated into the conceptual site model	√	√
Review existing hydrogeological risk assessment, Control and Trigger levels[3]	√	√
If risks are unacceptable set in place procedures for implementing corrective measures in consultation with or required by the Agency		√

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

5 Reporting

5.1 Introduction

Hydrogeological risk assessment may be undertaken as part of the planning process as well as the permitting process. An Environmental Impact Assessment 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 IPC, Landfill and Groundwater Directives, implemented through EPR (2007 and 2010), that must be addressed at the permit stage and this Section will deal specifically with the permit requirements.

It is anticipated that the main use of this guidance will be in preparing and supplementing Part B of 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 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.

5.2 Environmental Permit Pre-application

It is recommended that as part of the pre-application stage the conceptual model and risk screening assessment should be submitted to the Environment Agency. 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.

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

We recommend that a dialogue is maintained with the Environment Agency during the pre-application period in order to discuss and provisionally agree the following elements:

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

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

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

In addition to the written submissions to the Environment Agency (and the Planning Authority), verbal presentation with visual aids following report submission can be useful to assist in communicating the main points of an investigation, especially where information is extensive or issues are particularly complex.

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.

5.3 The Environmental Permit Application

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

- rejection of the landfill application because it poses an unacceptable environmental risk over its lifecycle;
- acceptance of the current landfill application as the risks and corrective measures are acceptable; and
- 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, e.g. upgrading the lining system or improving the leachate management system.

For assessments that indicate the risks are unacceptable at the simple level, (i.e. 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. As stated above, the risk assessment process should ensure that the development complies with both the GWD and the LFD.

The more sensitive the environment surrounding a landfill site and the greater the hazard presented by the waste deposited, the 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. The Environment Agency’s policies and guidance on groundwater protection and landfill location 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 the Environment Agency’s 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;
- it encourages communication between the risk assessor and the Environment Agency and ensures that all relevant matters are discussed at the appropriate stages.

The following sections provide some recommendations on the contents of submitted risk assessment reports. Further advice is presented in Environment Agency (2001d and 2003a).

5.3.1 Emissions to Groundwater

Section B - Hydrogeological Risk Assessment Report of Part B of the Application Form for the Landfill Sector deals specifically with the EPR (2010) Schedule 21, 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 conceptual site model should be reviewed and refined as additional information becomes available or as the understanding of the system is improved throughout the risk assessment process. The refined conceptual site model should be presented within the hydrogeological risk assessment document.

Appendix 7 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 target 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***, e.g. of the "purifying powers" of the soils and sub-soils (Appendix 6) and any mineral component of the engineered lining systems (if used within assessment) i.e. the attenuation capacity of the geological barrier;
- ***Technical precautions***, such as engineering and operational controls, post closure controls;
- The ***risk assessment carried out and the use of numerical models'***
- ***Requisite surveillance, such as the risk-based monitoring scheme***; and
- ***The acceptability of the input of polluting substances to the environment*** i.e. 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 through its life span.

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

5.3.2 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 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 (see Section 3.5 of this guidance). 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 (see Section 4.4).

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

5.3.3 Completion

Site closure, after-care and completion need to be considered as part of the 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;
- A series of performance criteria throughout the life of the landfill that can be used to validate issues such as the declining source term (see Section 5.4 below on the review of the risk assessment).

5.4 Monitoring, Validation and Review

5.4.1 Review of the Risk Assessment

EPR (2010) requires that all environmental permits must be reviewed by the end of 2012, although this will not include any new environmental permit issued under the 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 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 (e.g. 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's 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 instance 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 obvious example where monitoring results can be related to risk assessment assumptions. Meteorological monitoring will also be relevant. The overall review plan must link the initial assumptions made with the sensitivity and importance of those assumptions in the model output. This review plan must essentially identify 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 the Environment Agency's guidance on landfill monitoring (Environment Agency 2003a) and must therefore be based on the understanding of the source-pathway-receptor linkages. The monitoring must take place in each identified groundwater receptor and pathway.

As set out within the worked examples (Appendix 8), Trigger levels should be set for each of the down-gradient, or potentially downgradient, monitoring points that are included in the overall groundwater monitoring programme. This could include both monitoring wells and relevant groundwater resurgences (e.g. springs). Since the Trigger levels represent the point at which pollution can be said to have occurred, the levels will normally be the same for each monitoring point in the same water body. Only where baseline quality or an EAL relevant to a remote receptor (which varies in distance from the monitoring boreholes) form the basis for the Trigger level should individual boreholes be allocated specific (different) Trigger levels.

The following is a checklist of issues for review.

- ***The conceptual site model*** (for example, groundwater level monitoring may indicate a possible change in the hydrogeological regime);
- ***Essential and technical precautions*** (for example, are the risk management measures, such as leachate management systems, performing as predicted?);
- ***Risk Assessment inputs and assumptions*** (for example, is the leachate quality as predicted?);
- ***Sampling and analysis plan and data quality*** (for example, are monitoring points correctly located and designed to provide the information required? Are enough samples being taken and are the appropriate determinands being analysed? Are the objectives of the monitoring plan being met?);
- ***Laboratory analysis quality assurance and quality control*** (for example, are the laboratory analyses reported with sufficient accuracy and precision? Are the reporting limits adequate to assess compliance against Control and Trigger levels?);
- ***Baseline groundwater quality*** (for example, could the groundwater that is flowing below the site have naturally elevated concentrations of contaminants that could influence the results of the monitoring on the down gradient side of the site?);
- ***Landfill operations and destruction of monitoring installations*** (for example, during routine operations a groundwater monitoring well may be destroyed. In this situation a replacement well will normally have to be installed, 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***; and
- ***The requirements for increased frequency of monitoring***.

5.4.2 Monitoring Reporting

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

- **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 the Agency on request. This documentation should be up-dated following each monitoring event and should conclude with statements regarding:
  - whether any breaches in Control or Trigger levels have been noted;
  - whether any adverse trends are apparent;
  - any significant changes in the rate of change of concentrations of constituents;
  - proposals for varying the frequency and range of monitoring.

- **Notification Reports** should be seen as the prime means of disseminating information for which action is required by site management and/or the Agency. Notification reports should be issued when breaches in Control or Trigger levels have occurred. These reports should

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

- **Review or Compliance Reports** should be prepared at least annually as required by the LFD and the environmental permit. They should summarise the monitoring data collected at the site with respect to compliance with the Control and Trigger values set for the site. The main purpose of this report is to inform site management and the Agency 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 discussed with the Environment Agency.

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Glossary

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

Absorption	The incorporation of a chemical within a solid or liquid.
Adsorption	The attachment of a chemical to the surface of a solid.
Abstraction	Removal of water from surface water or groundwater, usually by pumping.
Advection	Mass transport in response to a pressure gradient caused by the bulk movement of flowing groundwater.
Aquifer	A subsurface layer of layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater. [Water Framework Directive (2000/60/EC)] See also *Groundwater system.*
Aquifer classification	Classification given to water-bearing strata by the Environment Agency and published in groundwater protection policy documents (e.g. Principal and Secondary Aquifers or Unproductive Strata).
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 point	Compliance points are used to determine whether a discharge is acceptable and that identified receptors are adequately protected by setting assessment criteria or compliance values at these locations.
Compliance value	The compliance value at a receptor is the relevant minimum reporting value, water quality standard or background concentration that needs to be achieved to prevent pollution of that receptor. Compliance values at compliance points between the landfill and the receptor should ensure that the receptor is protected to the

	same extent.
Conceptual model	A simplified representation or working description of how the real (hydrogeological) system is believed to behave based on qualitative analysis of field data. A quantitative conceptual model includes preliminary calculations for the key processes.
Consented discharge	A *discharge* of effluent formerly controlled by a discharge consent or Groundwater Regulations (1998) authorisation issued by the Agency.
Conservative contaminants	*Contaminants* which can move readily through a permeable medium with little or no reaction and which are unaffected by biodegradation (e.g. chloride).
Contamination / contaminant	The introduction of any substance to water at a concentration exceeding the *baseline* concentration. A contaminant is any such substance.
Contingency action	A predetermined plan of action to respond to a breach of a *Control* and/or a *Trigger level*.
Control (Assessment)	The process of evaluating the significance of a departure from baseline groundwater quality conditions by reference to an adverse trend in data, the breach of a specified limit or some other *Control level*.
Control 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.
Discernible Discharge	The GWD states that all measures necessary to prevent the input of any hazardous substance into groundwater must be taken. "Prevent" means that the substance being discharged must not be discernible in comparison to either the natural background concentration of groundwater or a minimum reporting value (usually the limit of detection or other value prescribed by legislation) 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 (i.e. in groundwater this is following the hydraulic gradient).
Environmental Assessment Level (EAL)	A water quality standard that is defined by either UK Regulations (e.g. Water Supply (Water Quality) Regulations 1989), EU Directives (e.g. Drinking Water Directive (80/778/EEC) or another relevant source (e.g. non-statutory Environmental Quality Standards).
Environmental Quality Standard (EQS)	A water quality and biological standard for a surface watercourse.
Ground waters	Any water contained in underground strata (in both the saturated and unsaturated zones). Defined in s104, Water Resources Act 1991.
Groundwater	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 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 also "permeability").
Hydraulic gradient	The change in total head (of water) with distance in a given direction. The direction is that which yields a maximum rate of decrease in head.
Indirect Input	The introduction of a pollutant into groundwater after percolation through soil or subsoil.
Landfill	Site used for waste disposal into or onto land.

Leachate	Liquor formed by the interaction of water with wastes.
List I and II Substances	As defined by EC Groundwater Directive (80/68/EC) – now superseded by the terms hazardous substances and non-hazardous pollutants.
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 whereas before it was not a listed substance.
Pathway	The route alone which a particle of water, substance or contaminant moves through the environment e.g. the route contaminants are transported between the source of landfill leachate and a water receptor.
Perched water	This is a layer of saturated soil formed above the main water table due to a layer of low permeability material intercepting water moving downwards through the unsaturated zone.
Permeability	A measure of the rate at which a fluid will move through a medium. The permeability of a medium is independent of the properties of the fluid. See also "hydraulic conductivity".
Pollutant	Water Framework Directive: "any substance liable to cause pollution, in particular those listed in Annex VIII [of the WFD]".
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."
Pollution Prevention and Control (PPC)	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).
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).
Receptor	An entity/organism or a controlled water that is being or could be harmed by a potential pollutant, such as groundwater or surface water resource, amenity or abstraction point.
Recharge	The amount of water added to the groundwater system by natural or artificial processes.
Remediation	The process of improving the quality of a polluted body of water or an area of land, either by carrying out works on the pollutant source or by 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	Defined as levels at which significant (adverse) environmental effects have occurred. For non-hazardous pollutants, such effects would be consistent with the most stringent *Environmental Assessment Limit (EAL)* for a groundwater receptor being breached, while for hazardous substances concentrations would need to be discernible. A Trigger level specifically relates to groundwater and is directly comparable to a compliance value.
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. Also called the

vadose zone.

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

Up-gradient	In the direction of increasing *hydraulic head* (i.e. in groundwater this is moving up the *hydraulic gradient*).
Water balance	An evaluation of all the sources of supply, storage and corresponding discharges of water - for example within a landfill site or an entire surface water catchment area.

Appendix 1 – Hazardous substances and non-hazardous pollutants

Hazardous substances and non-hazardous pollutants

A **hazardous substance** is any substance or group of substances that are toxic, persistent and liable to bio-accumulate. This includes in particular the following substances listed where they fulfil these criteria:

(a) organohalogen compounds and substances which may form such compounds in the aquatic environment;

(b) organophosphorous compounds;

(c) organotin compounds;

(d) 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;

(e) persistent hydrocarbons and persistent and bioaccumulable organic toxic substances;

(f) cyanides;

(g) metals (in particular cadmium and mercury) and their compounds;

(h) arsenic and its compounds;

(i) biocides and plant protection products

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 and radioactive substances are hazardous substances. Information on these substances combined with our criteria for determining toxicity, persistence and bioaccumulation can be found on our web site www.environment-agency.gov.uk.

A **non-hazardous pollutant** is any pollutant other than a hazardous substance

Appendix 2 – 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[4] ▪ 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, representiveness, precision, accuracy)[5] ▪ 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)

[4] Potential sources of information include:

- Department of the Environment, 1995. A Review of the Composition of Leachate from Domestic Wastes in Landfill Sites, CWM/072/95.
- Knox K *et al*, 2000. The occurrence of trace organic components in landfill leachates and their removal during on-site treatment. 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.

[5] 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.

Appendix 2 – 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) (Cont.)	• 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[6], 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 conceptual site model (see section 3). 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 the Environment Agency is consulting during the specification of the leaching test methodology and determinands in order to ensure that valid and relevant information is collected.

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

Appendix 2 – Potential Sources of Information on Leachate Quality

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 (Annex 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 3 – 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, 2010a). 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 the Agency's guidance on the location and impact assessment of landfills (Environment Agency, 2006a).

(a) Saturated zones

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 i.e.
  - 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) e.g. river base-flow, spring discharge, wetland, pumped abstraction, artesian discharge, drains/soughs/adits, mine systems;
  - phreatic and piezometric levels including any variations (e.g. seasonal);

influence of former, current or proposed developments (e.g. 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, e.g. 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);

Appendix 3 – Geological and Hydrogeological Information Requirements

- 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, e.g. carbonate content, clay content, CEC and foc values etc.

Where the "purifying powers of the soils and sub-soils" (i.e. attenuation properties) are being considered, these must be fully justified and based upon actual test results of the soils and sub-soils (as appropriate) collected from the location of the site. Site-specific testing must be carried out if attenuation (such as cation exchange capacity) is relied upon within the Groundwater Risk Assessment. Although theoretical assumptions or literature data[7] 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[8] for the key parameters. Appendix 6 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:-
current licensed/exempt abstractions of water and the nature of its use e.g. domestic, agricultural, industrial or other:

- existing natural/induced discharges (e.g. springs, wetlands.);
- 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.

7 Environment Agency, 2001, *Determination of cation exchange capacity in selected lithologies from England, Wales and Scotland*. R&D Technical Report P435.
8 Environment Agency, 2000, *CEC and Kd Determination in Landfill Performance. Evaluation: A Review of methodologies and preparation of standard materials for laboratory analysis*. R&D Technical Report P340.

Appendix 4 – Potential Site Investigations

Conceptual Site 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 e.g. the observation of perched leachate escaping over outer bunds, the surface run-off of recirculated leachate that has failed in infiltrate into the waste mass.
	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.
	Laboratory Testing of Soils and Rocks	• This may include 1. Partition coefficients (Kd) – 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
	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

[9] Environment Agency, 2000, CEC and Kd Determination in Landfill Performance. Evaluation: A Review of methodologies and preparation of standard materials for laboratory analysis. R&D Technical Report P340, prepared by British Geological Survey

Appendix 4 – Potential Site Investigations

Conceptual Site Model Issue	Potential Site Investigations	Additional Comments
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. 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. 4. 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. 5. 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.

Appendix 4 – Potential Site Investigations

Conceptual Site Model Issue	Potential Site Investigations	Additional Comments
The Definition of the Source, Pathway and Receptor Terms and The Establishment of the Baseline Conditions (Cont.)	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
	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
	Laboratory testing of soil and rock materials	• To potentially include properties such as: Partition coefficients (K_d) – to determine the degree specific contaminants are retarded within the tested materials[10] Particle size analysis – to characterise the materials and provide approximate estimations of permeability for certain materials Undisturbed permeability of clays Cation exchange capacity (CEC) – to characterise the ability of the materials to attenuate cationic contaminants such as ammonium[10] Fraction of Organic Carbon (foc) – to characterise the general ability of the material to retard organic contaminants
	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.

Appendix 4 – Potential Site Investigations

Conceptual Site Model Issue	Potential Site Investigations	Additional Comments
The Definition of the Source, Pathway and Receptor Terms and The Establishment of the Baseline Conditions (Cont.)	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.

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

Appendix 5 – Analytical Framework for Screening Landfill Leachates

The Analytical Framework for Screening Landfill Leachates appendix is currently being updated.

Appendix 6 – 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 and the EPR2010, 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 (e.g. NH_4^+, Cd^{2+} etc.), the test methods and manner in which the values are used should be agreed in advance with the Agency and further technical guidance on this matter has been prepared.[11].

[11] 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, 2001, *Guidance on the Assessment and Monitoring of Natural Attenuation of Contaminants in Groundwater*' R&D Publication 95

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 EA and the formulation of an Agency 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 (Yes/No/See 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 presence 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 (2010) 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, 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 geological barrier. Stratigraphic, structural and topographic controls, influence of preferential flow via fissures, drainage systems, 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			

Appendix 7 – Groundwater Risk Assessment Checklist

Site:_______________________________ **Sheet 2 of 4**

Does the report adequately address the following aspects? Please tick columns (Yes/No/See 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 groundwaters and estimates of flow taking account of structural, stratigraphic or abstraction influences.			
	Purifying powers of subsoil	Attenuation characteristics of site liners and underlying saturated and unsaturated geology supported as relevant by experimental data.			
	Baseline quality and suitability for use	Historical and baseline groundwater analyses to establish natural quality and current pollution impacts. Assessment in context of suitability for use and potential for impact on other aquatic environments.			
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 (e.g. 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.			

Appendix 7 – Groundwater Risk Assessment Checklist

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 Agency specialists)			
		Justification for using particular computer models			
		Model selection and suitability to represent conceptual model including hydrogeological conditions (e.g. below WT) and engineering design			
		Identification of receptors, compliance criteria and calibration			
	Application	Realistic use of conservative parameters and plausible worst case, adequate calibration.			
		Schematic diagrams showing relationship of conceptual model to computer model inputs			
		Use of multiple model runs to simulate different phases (time) and justified range of input parameter values.			
		Justification for field measurement and model defaults			
	Output	Numbers consistent with conceptual model, e.g. • 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 and Trigger Levels	Groundwater Control and Trigger Levels 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 most stringent 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.			

Appendix 7 – Groundwater Risk Assessment Checklist

	Direct inputs	Particular attention paid to risk assessments where potential exists for direct input of pollutants to groundwater (e.g. 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 – Worked Examples

Example I – Initial Conceptual Model

It is proposed to develop a new non-hazardous waste landfill. On the basis of the likely waste materials to be deposited it has been established that Site A falls within the scope of the Groundwater Directive, (i.e. that leachate is likely to contain pollutants).

The preferred site is located on an outcrop of a thick sequence of clay strata, with subordinate inter-bedded limestone horizons. The Groundwater Vulnerability map indicates that this geological formation is classed as unproductive strata by the Environment Agency, and consideration of the Groundwater Protection: Policy and Practice (‘GP3’) and guidance on landfill location identifies no policy objections on the grounds of general environmental setting.

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

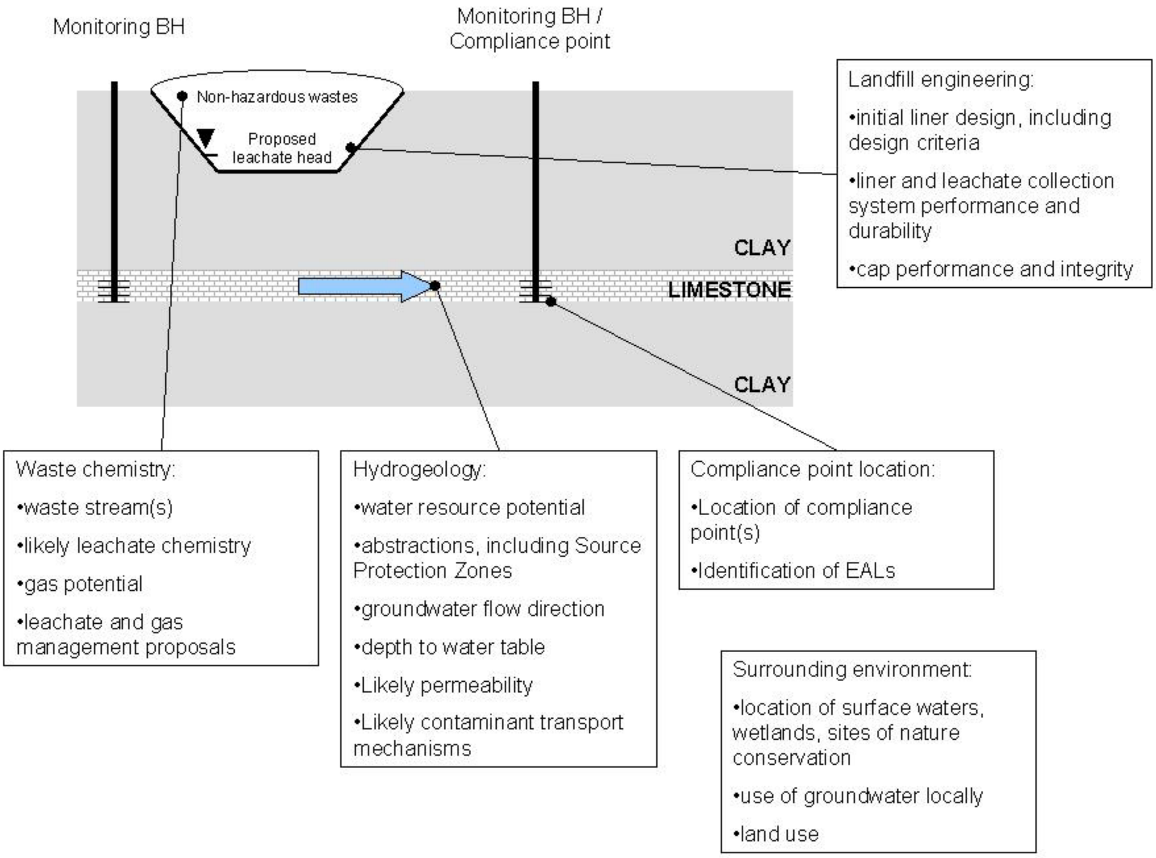


Figure A11-1. Typical issues to be covered by landfill conceptual model

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

Example II - Risk Screening

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

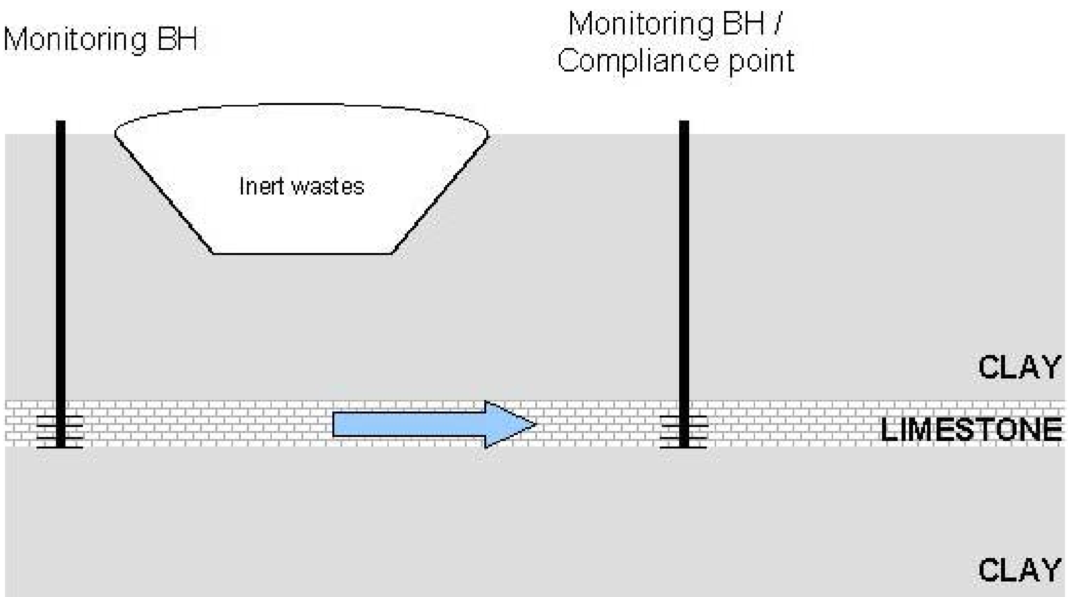


Figure A11-2. Schematic cross-section of inert landfill considered by risk-screening

Following an initial assessment of the hazard posed by the site, it is decided that the risk of groundwater pollution is minimal and that quantitative risk assessment (such as simulation of contaminant transport processes in the subsurface) is unnecessary. It is identified that, in this instance, establishment of, and compliance with, robust waste acceptance criteria is key to ensuring that the wastes pose no significant risk to groundwater. Further, it is established that on the basis of anticipated leachate chemistry there is no requirement (in terms of Annex I(2) of the LFD) to collect and manage leachate.

It should be noted that risks to other receptors (e.g. landfill stability assessment and impact on nearby structures) may be a higher priority than the risk to groundwater and consequently require more detailed assessment.

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

DETERMINATION OF ENVIRONMENTAL ASSESSMENT LIMITS (Section 2.5)	**GROUNDWATER IN UNDERLYING LIMESTONE BAND**			
	Determinand	Maximum background conc. in limestone groundwater (mg/l)	Drinking Water Standards (mg/l)	Selected EAL (mg/l)
	ammonium (as NH_4^+)	<0.2	0.5	0.5
	chloride	78	250	250
	magnesium	23	50	50
	Note: 1. EU and UK Drinking Water Standards taken to be most stringent applicable EAL 2. Determinands in groundwater chosen after review of indicator species in potential leachate			

Appendix 8 – Worked Examples

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

SETTING OF CONTROL AND TRIGGER LEVELS (Section 4)

CONTROL LEVELS FOR SELECTED POLLUTANTS (Section 4.2.2)

Hazardous Substances
- No GW control levels set for Hazardous substances: No expectations of wastes containing Hazardous substances.

Non-hazardous pollutants

- Trend of increasing and adverse concentrations in target compounds: Three consecutive samples with increasing concentrations between background concentration and Trigger Levels. Test applied to:
  - ammonium
  - chloride
  - magnesium

<u>AN ASSESSMENT FOR EACH OF THE MONITORED SUBSTANCES (Sections 4.2 & 4.3)</u>
- Control level reviews to be conducted each time monitoring data are obtained
- Formal annual review and report

APPROPRIATE RESPONSE TIME
- Control level reviews to be completed within one month of sampling event

TRIGGER LEVELS FOR SELECTED SUBSTANCES

Groundwater Trigger Levels are set for two down-gradient monitoring boreholes at concentrations equal to the EAL. Background (up-gradient) water quality should be reviewed if a Trigger Level is breached to ascertain that it is not due to other anthropogenic sources.

CONTINGENCY ACTIONS

ACTION	Control Level Breach	Trigger Level Breach
Issue notification report - advise site operator - advise Agency	*	*
Conduct confirmatory sampling	*	*
Determine degree of risk presented by breach	*	*
Review conceptual model, control and trigger levels	*	*
Agree any corrective/remedial measures with Agency		*

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

<u>Example III: Generic Quantitative Risk Assessment</u>

A third landfill, Site C, is proposed. A non-hazardous waste facility is proposed for a sensitive principal aquifer, but non-SPZ, location. The operator notes the Agency's position documented in the Groundwater Protection: Policy and Practice ('GP3') and guidance on landfill location, but decides to proceed with a design that accelerates waste stabilisation and therefore aims to avoid long-term reliance of engineered pollution prevention measures.

Appendix 8 – Worked Examples

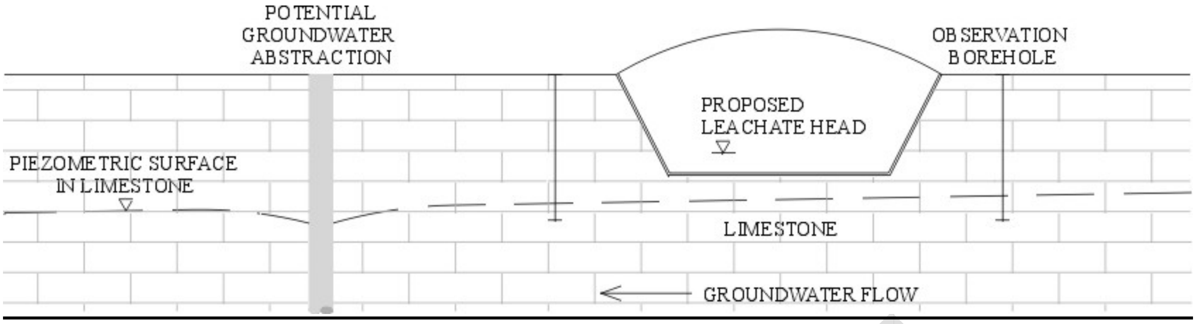


Figure A11-3. Schematic of landfill proposed in principal aquifer

Following development of an initial conceptual model and screening of risks it is recognised by the operator that the site is in a very sensitive location with respect to groundwater. It is recognised that for Environment Agency acceptance of such a proposal a detailed quantitative risk assessment will be necessary because of the potential environmental impacts should pollution occur. Nevertheless, the operator chooses to perform a generic quantitative risk assessment initially to help decide whether the additional expenditure of comprehensive site characterisation and complex modelling is warranted.

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

DETERMINATION OF ENVIRONMENTAL ASSESSMENT LIMITS	PRIMARY RECEPTOR IDENTIFIED AS GROUNDWATER IN AQUIFER						
	Determinand (selected from more extensive list)	Maximum recorded GW concentration from Baseline Monitoring (mg/l)	Typical leachate chemistry (mg/l)	DWS (mg/l)	EQS (mg/l)	Selected EAL (mg/l)	Leachate chemistry: EAL ratio (AF_U)
	ammonium	<0.1	4000	0.5	-	0.5	8000
	chloride	28	8000	250	250	40	200
	mecoprop	<0.00004	0.2	0.001	0.02	0.00004*	5000
	toluene	<0.004	200	-	50	0.004*	50000

* Hazardous substances. EALs selected on basis of Minimum Reporting Value (see Appendix 2 of H1 Annex (J) Groundwater, Environment Agency, 2010a), noting that background groundwater quality is below these limits.

The operator notes than in order to achieve Groundwater Directive / EPR (2010) compliance at this site, an unsaturated zone attenuation factor (AF_U) in excess of 5×10^5 will be necessary. AF_U describes the necessary concentration reduction due to degradation, sorption, diffusion and dispersion processes within the landfill liner and in the unsaturated zone.

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

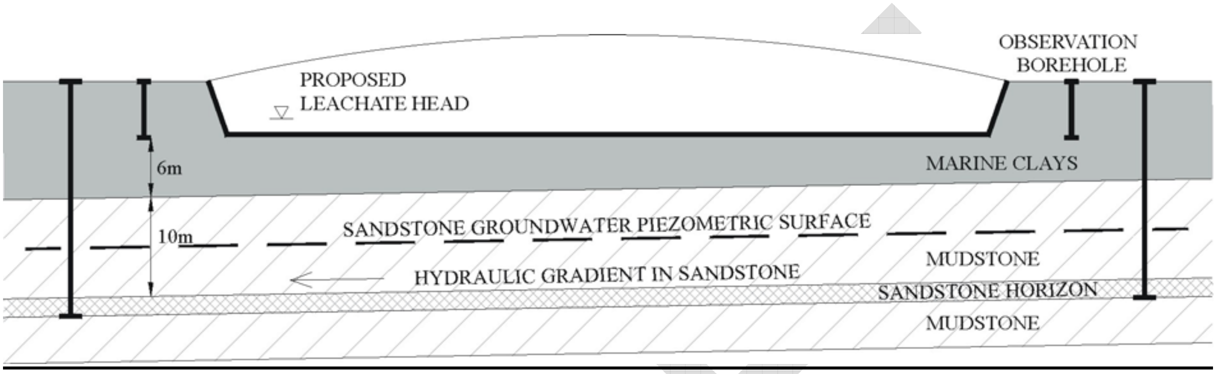
Example IV: Generic Quantitative Risk Assessment

Site D. Following development of an initial conceptual model and risk screening, it is decided that assessment is needed for Groundwater Directive purposes, and that the appropriate level of assessment for a non-hazardous waste landfill on a sequence of clay strata should be a Generic Quantitative Risk Assessment. This approach relies on generic (conservative) assumptions and data

Appendix 8 – Worked Examples

in the absence of detailed site-specific data. The general location of the site, which is part of the basic conceptual model, is depicted below.

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



It is decided that the groundwater receptor at this site is groundwater within the sandstone horizon(s). Compliance for hazardous substances must be considered at the point below the landfill at which those substances enter the sandstone, but taking into account whether their concentrations would be discernible in groundwater, while the likely impact of non-hazardous pollutants (and other potential pollutants) are considered at a monitoring borehole on the down-gradient site boundary.

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

	PRIMARY RECEPTOR IDENTIFIED AS GROUNDWATER IN SANDSTONE HORIZON						
	Determinand (selected from more extensive list)	Typical leachate chemistry (mg/l)	Maximum recorded GW concentration from Baseline Monitoring (mg/l)	DWS (mg/l)	EQS (mg/l)	MRV for clean water (Hazardous substances only) (mg/l)	SelectedEAL (mg/l)
DETERMINATION OF ENVIRONMENTAL ASSESSMENT LIMITS	ammonium	2000	1.2	0.5	-	-	1.5
	Chloride	4500	350	250	250	-	400
	potassium	540	8	10	-	-	10
	Copper	750	1	2	0.028	-	1
	Phenol	50	<0.005	0.0005	0.03	-	0.0005
	Toluene	80	<0.004	-	50	0.004	0.004
	Note: 1. EAL for NH_4^+, Cl^- and Cu^{2+} selected on basis of GW monitoring data that exceed water quality standards. 2. EAL for K^+ and phenol reflective of respective DWS (lowest relevant water quality standard) 3. EAL for toluene (List I substance) reflective of minimum reporting value in GW (i.e. discernibility)						

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

Appendix 8 – Worked Examples

RISK ASSESSMENT (Section 3)	**GENERIC QUANTITATIVE RISK ASSESSMENT** –CALCULATIONS USING LARGELY GENERIC (CONSERVATIVE) ASSUMPTIONS TO ASSESS RISK TO GROUNDWATER			
	Factor	**Nature of Input Values**	**Resultant Calculation (maximum concentration after 100,000 years)**	
	Potential rate of leachate leakage	Adequate characterisation data from existing landfill liner and geology Assumed (conservative) hydrogeological data detailing hydraulic conductivity, gradient and attenuation processes Leachate source characterisation data from nearby site	61 l/day	
	Unretarded travel time for leachate to reach groundwater		4,452 years	
	Potential concentration of hazardous substances in porewater immediately prior to discharge to groundwater		toluene	<0.001ug/l
	Potential concentration of non-hazardous pollutants in groundwater at down -stream site boundary		ammonium	0.1 mg/l
			chloride	57 mg/l
			potassium	4 mg/l
			copper	0.08 mg/l
			phenol	$<1\times10^{-9}$mg/l
	Potential attenuation of ammonium within mineral portion of liner		Retarded plug flow time 9,978 years	
	SUMMARY OF RESULTS Proposed development compliant with Landfill Directive Proposed development compliant with Groundwater Directive			

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

DERIVATION OF CONTROL AND TRIGGER LEVELS (Section 4)	IDENTIFICATION OF CONTROL AND TRIGGER LEVEL ASSESSMENT POINTS (Sections 2.6.3, 4.2 and 4.3) Four down-gradient groundwater monitoring boreholes (in the sandstone horizon) located on predicted 'plume' centreline
	THE TRIGGER LEVELS FOR EACH POTENTIAL POLLUTANT (Sections 2.6.1, 4.2 and 4.3) Hazardous substances –samples with concentrations above minimum reporting values for water sampled from designated monitoring boreholes Hazardous pollutants -concentrations in groundwater at designated boreholes greater than: ammonium 1.5 mg/l chloride 400 mg/l potassium 10 mg/l copper 1 mg/l
	CONTROL LEVELS FOR EACH POTENTIAL POLLUTANT (Section 4.2) Hazardous Substances Concentrations in leachate exceed max predicted concentration in leachate by factor of 2 (e.g. 160 mg/l for toluene) Non-hazardous Pollutants - Trend of increasing and adverse concentrations in target substances and - Three[1] (or more) consecutive groundwater samples exceed the 75%ile of the baseline groundwater quality, which is: ammonium 0.8 mg/l chloride 275 mg/l potassium[2] none set copper 0.6 mg/l

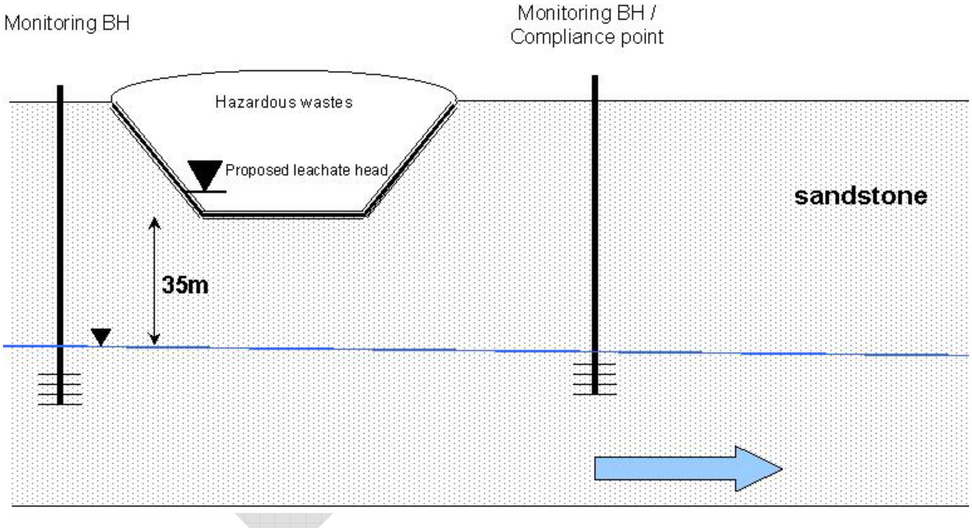
Appendix 8 – Worked Examples

	Notes [1] This aims to ensure that occasional "spikes" (natural noise) in groundwater quality data do not routinely cause control level exceedence. [2] No Control Level set for potassium: 75%ile of background groundwater quality (5mg/l) is so close to the predicted potassium concentration (4mg/l) that it is considered inappropriate to set a control level for potassium. An alternative determinand could be selected in place.
	AN ASSESSMENT TEST FOR EACH OF THE MONITORED CHEMICALS OF CONCERN (Section 4.2.2 and Section 5.4.2) - Control level reviews to be conducted each time monitoring data are obtained - Formal annual review and reporting

Example V: Detailed Quantitative Risk Assessment

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

Recognising the significant hazard that the hazardous waste represents and the potential resource value of the sandstone aquifer in this location it is decided that a Detailed Quantitative Risk Assessment is most appropriate, using site-specific data and detailed assessment techniques. Comprehensive site characterisation has been undertaken to develop and refine the initial conceptual model of the landfill and hydrogeological processes around the site. Site specific data on groundwater levels and flow; geochemical properties that control retardation of key pollutants, and waste characterisation has been undertaken over a period of 2 years to allow adequate data to construct a groundwater flow model, if that is necessary.



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

Appendix 8 – Worked Examples

POTENTIAL LEACHATE COMPOSITION

Hazardous Substances

Determinand	Max predicted concentration in leachate (µg/l)	Minimum Reporting Value (µg/l)	Max background groundwater chemistry (µg/l)	Selected EAL (µg/l)
mecoprop	50	0.04	<0.04	0.04
benzene	200	1	<1	1
cadmium	3000	0.1	4	5*
Toluene	50	4	3	4

Non-hazardous

Determinand	Max concentration in Leachate (mg/l)	Max background groundwater chemistry (mg/l)	DWS (mg/l)	EQS (mg/l)	EAL (mg/l)
ammonium	750	0.8	0.5	-	1*
Chloride	15000	180	250	250	250
potassium	7000	4	10	-	10
Lead	10000	0.003	10	4	4
Nickel	7000	0.006	20	50	20

* EAL for cadmium (hazardous substance) and ammonium (non-hazardous pollutant) selected as background concentration +25% to take account of natural background concentration, where this exceeds water quality standards.

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

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

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

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

Appendix 8 – Worked Examples

RISK ASSESSMENT: PREDICTED CONTAMINANT CONCENTRATION FROM DETAILED MODELLING	Substance	EAL	units	50%ile of contaminant concentration	95%ile of contaminant concentration
	mecoprop	0.04	µg/l	1×10^{-5}	3×10^{-4}
	benzene	1	µg/l	3×10^{-8}	3×10^{-6}
	cadmium	5	µg/l	0.3	0.46
	toluene	4	µg/l	1×10^{-8}	1×10^{-6}
	ammonium	1	mg/l	0.18	0.27
	chloride	250	mg/l	177	238
	potassium	10	mg/l	3.8	7.5
	lead	4	mg/l	0.31	0.39
	nickel	20	mg/l	11	16

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

Appendix 8 – Worked Examples

<table>
<tr><td rowspan="10">DERIVATION OF TRIGGER LEVELS</td><td colspan="3"><u>THE TRIGGER LEVELS FOR EACH POTENTIAL POLLUTANT</u>

Hazardous substances:
cadmium – concentrations above 5 μg/l (after EAL that takes natural water chemistry into account)

Non-hazardous Pollutants – Concentrations greater than:
ammonium 1 mg/l
chloride 250 mg/l
potassium 10 mg/l
lead 4 mg/l
nickel 20 mg/l</td></tr>
<tr><td colspan="3"><u>CONTROL LEVELS FOR EACH POTENTIAL POLLUTANT</u>

Hazardous substances
- Concentrations in leachate above 2 × predicted concentration in leachate (e.g. 100 μg/l for mecoprop)

Non-hazardous Pollutants
- 75%ile of risk assessment resultant concentrations:
ammonium 0.85[1] mg/l
chloride 178 mg/l
Potassium 5.6 mg/l
lead 3 mg/l
nickel 15mg/l

Notes [1] ammonium control level set at 0.85 mg/l on basis of background monitoring data and EAL</td></tr>
<tr><td colspan="3"><u>AN ASSESSMENT TEST FOR EACH OF THE MONITORED SUBSTANCES OF CONCERN (Sections 4.2 and 4.3)</u>
- Control level reviews to be conducted each time monitoring data are obtained
- Formal annual review and reporting</td></tr>
<tr><td colspan="3"><u>APPROPRIATE RESPONSE TIME</u>
- Control level reviews to be completed within one month of sampling event</td></tr>
<tr><td>ACTION</td><td>Control Level Breach</td><td>Trigger Level Breach</td></tr>
<tr><td>Issue notification report
- advise site operator
- advise Agency</td><td>*</td><td>*</td></tr>
<tr><td>Conduct confirmatory sampling</td><td>*</td><td>*</td></tr>
<tr><td>Determine degree of risk presented by breach</td><td>*</td><td>*</td></tr>
<tr><td>Review existing hydrogeological risk assessment, control and trigger levels</td><td>*</td><td>*</td></tr>
<tr><td>Agree any corrective/remedial measures with Agency</td><td></td><td>*</td></tr>
</table>

Appendix 9 – Selected Water Quality Standards for Use in Assessing the Presence of Pollution in Controlled Waters

Appendix 9 – Selected Water Quality Standards for Use in Assessing the Presence of Pollution in Controlled Waters

NOTE: The tables attached are for general guidance and care should be exercised when applying these for specific purposes. The information given here is of necessity summarised. It may be necessary to refer back to the original source of the data for qualifying/clarifying information.

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

KEY TO STANDARDS REFERENCED

1) Figures for Environmental Quality Standards (EQS) are Annual Average Concentrations with Maximum Allowable Concentrations in round brackets and 95th percentile in square brackets. Standards taken from:

   - Directive 2008/105/EC European Parliament and of the Council on environmental quality standards in the field of water policy
   - UKTAG UK Environmental Standards and Conditions (phase 1). Final report April 2008 (SR1 – 2006).
   - UKTAG Proposals for Environmental Quality Standards for Annex VIII Substances. June 2008 (SR1 – 2007).
   - Environment Agency Statutory Environmental Quality Standards (where more recent standards are proposed under the Water Framework Directive these later values are given).
   - Environment Agency Non Statutory Environmental Quality Standards (where more recent standards are proposed under the Water Framework Directive these later values are given).

   Where a range of EQS for freshwater is given it is usually dependent on the hardness of the water. Further advice from the Environment Agency should be sought.

2) World Health Organisation (WHO) Guidelines for Drinking Water Quality, 2004.

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

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

4) UK Drinking Water Standards taken from:

- Water Supply (Water Quality) Regulations 2 (3184) (as amended)
- The Water Supply (Water Quality) (Amendment) Regulations 2001

Appendix 9 – Selected Water Quality Standards for Use in Assessing the Presence of Pollution in Controlled Waters

Contaminant	units		EQS freshwater (1)	EQS saltwater (1)	WHO Health (2)	EU Drinking Water Standards (3)	UK Drinking Water Standards (4)
Acrylamide	ug/l				0.5	0.1	0.1
Alachlor	ug/l	PS	0.3 (0.7)	0.3 (0.7)	20	0.1	0.1
Aldicarb	ug/l				10	0.1	0.1
Aldrin	ug/l	OP	0.01[a]	0.005[a]	0.03	0.03	0.03
Aluminium	ug/l					200	200
Ammonia unionised (NH_3 as N)	mg/l	SP	0.021[b]	0.021			
Total ammonia	mg/l		0.2 – 2.5[c]				
Ammonium (as NH_4^+)	mg/l					0.5	0.5
Anthracene	ug/l	PS	0.1 (0.4)	0.1 (0.4)			
Antimony	ug/l				20	5	5
Arsenic	ug/l	SP	50	25	10[d]	10	10
Atrazine	ug/l	PS	0.6 (2)	0.6 (2)	2	0.1	0.1
Azinphos-methyl	ug/l	EQ	0.01	0.01		0.1	0.1
Barium	mg/l				0.7		
Bentazone	ug/l	EQ	500	500		0.1	0.1
Benzene	ug/l	PS	10 (50)	8 (50)	10	1	1
Benzo [a] pyrene	ug/l	PS	0.05 (0.1)	0.05 (0.1)	0.7	0.01	0.01

Appendix 9 – Selected Water Quality Standards for Use in Assessing the Presence of Pollution in Controlled Waters

Contaminant	units		EQS freshwater (1)	EQS saltwater (1)	WHO Health (2)	EU Drinking Water Standards (3)	UK Drinking Water Standards (4)
Benzo(b)fluoranthene + Benzo(k)fluoranthene	ug/l	PS	0.03	0.03			
Benzo(g,h,i)perylene + Indeno(1,2,3-cd)pyrene	ug/l	PS	0.002	0.002			
Biphenyl	ug/l	EQ	25	25			
Boron	mg/l	EQ	2	7	0.5[d]	1	1
Bromate	ug/l				10[d]	10	10
Bromodichloromethane	mg/l				0.06	f	f
Bromoform	mg/l				0.1	f	f
Bromoxynil	ug/l	NEQ	100 (1000)	100 (1000)		0.1	0.1
C10-13 Chloroalkanes	ug/l	PS	0.4 (1.4)	0.4 (1.4)			
Cadmium	ug/l	PS	0.08-0.25 (0.45-1.5)[e]	0.2 (<0.45-1.5)[e]	3	5	5
Carbofuran	ug/l				7	0.1	0.1
Chlordane (all isomers)	ug/l				0.2	0.1	0.1
Chlorfenvinphos	ug/l	PS	0.1 (0.3)	0.1 (0.3)		0.1	0.1
Chloride	mg/l	NEQ	250			250	250
Chloroform	ug/l	EQ	12	12	300	f	f
2-Chlorophenol	ug/l	EQ	50	50			
4-Chloro-3-methylphenol	ug/l	EQ	40	40			
Chloronitrotoluenes	ug/l	EQ	10	10			
Chlorothalonil	ug/l	NEQ	0.1	0.1		0.1	0.1

Appendix 9 – Selected Water Quality Standards for Use in Assessing the Presence of Pollution in Controlled Waters

Contaminant	units		EQS freshwater (1)	EQS saltwater (1)	WHO Health (2)	EU Drinking Water Standards (3)	UK Drinking Water Standards (4)
Chlorotoluron	ug/l	NEQ	2	2	30	0.1	0.1
Chlorphenylid	ug/l					0.1	0.1
Chlorpropham	ug/l	NEQ	10	10		0.1	0.1
Chlorpyrifos	ug/l	PS	0.03 (0.1)	0.03 (0.1)			
Chromium	ug/l	SP	Cr (VI) 3.4 Cr (III) 4.7 [32]	Cr (VI) 0.6 [32]	50[d]	50	50
Copper	ug/l	SP	1 – 28[e]	5	2000	2000	2000
Coumaphos	ug/l	NEQ	0.03 (0.1)	0.03 (0.1)		0.1	0.1
Cyanazine	mg/l				0.0006		
Cyfluthrin	ug/l	EQ	[0.001]	[0.001]		0.1	0.1
Cypermethrin	ug/l	SP	0.1 [0.4]	0.1 [0.4]			
DDT Total	ug/l	OP	0.025	0.025			
Demetons	ug/l	EQ	0.5	0.5		0.1	0.1
1,1-Dichloroethene (1,1-DCE)	ug/l				30		
1,2-dibromo-3-chloropropane	ug/l				1	0.1	0.1
1,2-Dibromoethane	mg/l				0.0004[d]		
1,2-Dichlorobenzene	ug/l				1000[g]		
1,2-Dichloroethane (1,2-DCA)	ug/l	PS	10	10		3	3
1,2-Dichloroethene (1,2-DCE)	ug/l				50		
1,2-Dichloropropane	ug/l				40[d]	0.1	0.1

Appendix 9 – Selected Water Quality Standards for Use in Assessing the Presence of Pollution in Controlled Waters

Contaminant	units		EQS freshwater (1)	EQS saltwater (1)	WHO Health (2)	EU Drinking Water Standards (3)	UK Drinking Water Standards (4)
1,3-Dichloropropene	ug/l				20	0.1	0.1
1,4-Dichlorobenzene	ug/l				300[g]		
2,4-DB (4-(2,4-Dichlorophenoxy)butyric Acid)	mg/l				0.09		
2,4-Dichlorophenol	ug/l	SP	20	20			
2,4-dichlorophenoxyacetic acid (2,4-D), (ester form)	ug/l	SP	0.3 [1.3]	0.3 [1.3]	30	0.1	0.1
Di(2-ethlyhexyl)pthalate	ug/l	PS	1.3	1.3	8		
Diazinon	ug/l	SP	0.01 [0.02]	0.01 [0.1]		0.1	0.1
Dibromochloromethane	mg/l				0.1	f	f
Dichlorodiphenyltrichloroethane (all isomers)	ug/l	EQ	0.025	0.025			
Dichloromethane	ug/l	PS	20	20	20		
Dichlorprop (DCPP)	ug/l				100	0.1	0.1
Dichlorvos	ug/l	EQ	0.001	0.040 (0.6)		0.1	0.1
Dieldrin	ug/l	OP	0.01[a]	0.005[a]	0.03	0.03	0.03
Dimethoate	ug/l	SP	0.48 (4.0)	0.48 (4.0)	6	0.1	0.1
Diuron	ug/l	PS	0.2 (1.8)	0.2 (1.8)			
Drins (total)	ug/l	EQ	0.03	0.03		0.1	0.1
Edetic Acid (EDTA)	ug/l	NEQ	400 (4000)	400 (4000)	600		
Endosulfan	ug/l	PS	0.005 (0.01)	0.0005 (0.004)		0.1	0.1
Endrin	ug/l	OP	0.01[a]	0.005[a]	0.6	0.1	0.1
Epichlorohydrin	ug/l				0.4[d]	0.1	0.1

Appendix 9 – Selected Water Quality Standards for Use in Assessing the Presence of Pollution in Controlled Waters

Contaminant	units		EQS freshwater (1)	EQS saltwater (1)	WHO Health (2)	EU Drinking Water Standards (3)	UK Drinking Water Standards (4)
Ethylbenzene	ug/l				300[g]		
Fenchlorphos	ug/l	NEQ	0.03 (0.1)	0.03 (0.1)		0.1	0.1
Fenitrothion	ug/l	SP	0.01	0.01		0.1	100
Fenoprop	ug/l				9	0.1	0.1
Flucofuron	ug/l	EQ	[1]	[1]		0.1	0.1
Fluoranthene	ug/l	PS	0.1 (1.0)	0.1 (1.0)			
Fluoride	ug/l	NEQ	1000-5000[e]	5000	1500	1500	1500
Formaldehyde	ug/l	NEQ	5 (50)			0.1	0.1
Free Cyanide	ug/l	SP	1 [5]	1 [5]	70	50	50
Heptachlor	ug/l					0.03	0.03
Heptachlor epoxide	ug/l					0.03	0.03
Hexachlorobenzene	ug/l	PS	0.01 (0.05)	0.01 (0.05)		0.1	0.1
Hexachlorobutadiene	ug/l	PS	0.1 (0.6)	0.1 (0.6)	0.6		
Hexachlorocyclohexane (lindane)	ug/l	PS	0.02 (0.04)	0.002 (0.02)	2	0.1	0.1
Hydrogen Sulphide	ug/l	NEQ	0.25 (1)	(10)			
Hydrogen sulphide (H_2S as S)	ug/l	EQ	0.25 (1.0)	10			
Ioxynil	ug/l	NEQ	10 (100)	10 (100)		0.1	0.1
Iron	mg/l	SP	1	1		0.2	0.2
Isodrin	ug/l	OP	0.01[a]	0.005[a]		0.1	0.1
Isoproturon	ug/l	PS	0.3 (1.0)	0.3 (1.0)	9	0.1	0.1

Appendix 9 – Selected Water Quality Standards for Use in Assessing the Presence of Pollution in Controlled Waters

Contaminant	units		EQS freshwater (1)	EQS saltwater (1)	WHO Health (2)	EU Drinking Water Standards (3)	UK Drinking Water Standards (4)
Lead (inorganic - dissolved)	ug/l	PS	7.2	7.2	10	10	25 (reducing to 10)
Linuron	ug/l	SP	0.5 [0.9]	0.5 [0.9]		0.1	0.1
Malathion	ug/l	EQ	0.01	0.02		0.1	0.1
Manganese	ug/l				400[g]	50	50
MCPA	ug/l	NEQ	12-80 (120-800)[h]	80 (800)	2	0.1	0.1
Mecoprop (MCPP)	ug/l	SP	18 [187]	18 [187]	10	0.1	0.1
Mercury	ug/l	PS	0.05 (0.07)	0.05 (0.07)	6	1	1
Methoxychlor	ug/l				20	0.1	0.1
Methylbenzene	ug/l	EQ	50	40			
Metolachlor	ug/l				10	0.1	0.1
Molinate	ug/l				6	0.1	0.1
Molybdenum	ug/l				70		
Naphthalene	ug/l	PS	2.4	1.2			
Nickel	ug/l	PS	20	20	70	20	20
Nitrate (as NO_3)	mg/l				50	50	50
Nitriloacetic acid	mg/l	NEQ	1 (10)	3 (30)	0.2		
Nitrite (as NO_2)	ug/l				0.2	500	100
Nonylphenol	ug/l	PS	0.3 (2.0)	0.3 (2.0)			
Octylphenol	ug/l	PS	0.1	0.01			
Omethoate	ug/l	EQ	0.01			0.1	0.1

Appendix 9 – Selected Water Quality Standards for Use in Assessing the Presence of Pollution in Controlled Waters

Contaminant	units		EQS freshwater (1)	EQS saltwater (1)	WHO Health (2)	EU Drinking Water Standards (3)	UK Drinking Water Standards (4)
Para, para-DDT	ug/l	OP	0.01	0.01	1	0.1	0.1
Pendimethalin	ug/l	NEQ	1.5 (6)	1.5 (6)	20	0.1	0.1
Pentabromodiphenylether	ug/l	PS	0.0005	0.0002			
Pentachlorobenzene	ug/l	PS	0.007	0.0007			
Pentachlorophenol	ug/l	PS	0.4 (1)	0.4 (1)	9[d]	0.1	0.1
Permethrin	ug/l	SP	[0.01]	[0.01]	20	0.1	0.1
Pesticides (individual species, unless specified)	ug/l					0.1	0.1
Pesticides (total)	ug/l					0.5	0.5
Phenol	ug/l	SP	7.7 [46]	7.7 [46]			
Phosphorous	ug/l						
Pirimicarb	ug/l	NEQ	1 (5)	1 (5)		0.1	0.1
Polycyclic Aromatic Hydrocarbons (PAH)	ug/l					0.1[i]	0.1[i]
Propanil	ug/l					0.1	0.1
Propetamphos	ug/l	NEQ	0.03 (0.1)	0.03 (0.1)		0.1	0.1
Pryridate	ug/l					0.1	0.1
Selenium	ug/l				10	10	10
Silver	ug/l	NEQ	0.05 (0.1)	0.5 (1)			
Simazine	ug/l	PS	1 (4)	1 (4)	2	0.1	0.1
Sodium	mg/l					200	200
Styrene	ug/l	NEQ	50 (500)	50 (500)	20[g]		

Appendix 9 – Selected Water Quality Standards for Use in Assessing the Presence of Pollution in Controlled Waters

Contaminant	units		EQS freshwater (1)	EQS saltwater (1)	WHO Health (2)	EU Drinking Water Standards (3)	UK Drinking Water Standards (4)
Sulcofuron	ug/l	EQ	[25]	[25]		0.1	0.1
Sulphate	mg/l	NEQ	400	250		250	250
Tecnazene	ug/l	NEQ	1 (10)	1 (10)			
Terbuthylazine	mg/l				0.007		
Tetrachloroethene (PCE)	ug/l	OP	10	10	40	10 (with TCE)	10 (with TCE)
Tetrachloromethane (PCM, carbon tetrachloride)	ug/l	OP	12	12	4		3
Thiabendazole	ug/l	NEQ	5 (50)	5 (50)		0.1	0.1
Tin (inorganic)	ug/l	NEQ	25	10			
Toluene	ug/l	SP	50 [380]	40 [370]	700[g]		
Triazophos	ug/l	EQ	0.005	0.005		0.1	0.1
Tributyltin compounds	ug/l	PS	0.0002 (0.0015)	0.0002 (0.0015)			
Trichlorobenzenes (total)	ug/l	PS	0.4	0.4			
1,1,1-Trichloroethane (1,1,1-TCA)	ug/l	EQ	100	100			
1,1,2-Trichloroethane (1,1,2-TCA)	ug/l	EQ	400	300			
Trichloroethene (TCE)	ug/l	OP	10	10	20[d]	10 (with PCE)	10 (with PCE)
2,4,5-trichlorophenoxyacetic acid (2,4,5-T)	ug/l				9	0.1	0.1
2,4,6-Trichlorophenol	ug/l				200 [g]		
Trifluralin	ug/l	PS	0.03	0.03	20	0.1	0.1
Trihalomethanes (total)	ug/l	PS	2.5	2.5		100	100
Triphenyltin	ug/l	EQ	0.02	0.008			

Appendix 9 – Selected Water Quality Standards for Use in Assessing the Presence of Pollution in Controlled Waters

Contaminant	units		EQS freshwater (1)	EQS saltwater (1)	WHO Health (2)	EU Drinking Water Standards (3)	UK Drinking Water Standards (4)
Uranium	mg/l				0.015[d]		
Vanadium	ug/l	EQ	20 – 60[e]	100			
Vinyl chloride (chloroethene)	ug/l				0.3	0.5	0.5
Xylene	ug/l	EQ	30	30	500 [g]		
Zinc	ug/l	SP	8 – 125 (total)[e]	40 (dissolved)			

Appendix 10 – Compliance Point Guidance

Compliance Points (extracts from H1 Guidance Annex (j) Groundwater (Environment Agency, 2009b))

Importance for Risk Assessment

Choosing compliance points and agreeing these with us is an important part of the risk assessment process and can significantly affect the effort and costs involved (See Section 4.1.4).

Compliance Values and Limit Values

'*Compliance values****' and '****limit values****' are outputs from your risk assessment, in that the risk assessment should work out for example what the concentration of a substance should be in the discharge (the limit value) and in a borehole at the down-gradient edge of your activity (a compliance value) to ensure the risks to the identified receptors are acceptable.***
The compliance value at a receptor is the relevant minimum reporting value, water quality standard or background concentration that needs to be achieved to prevent pollution of that receptor. Compliance values at compliance points between your activity's source and the receptor should ensure that the receptor is protected to the same extent.
A '*limit value****' is a compliance value specifically set in your activity's discharge such that if it is exceeded, the receptor will be at risk of being polluted.***
Further guidance on compliance and limit values is provided in Appendix X and the European Commission's Common Implementation Strategy (CIS) for the Water Framework Directive Guidance Document No 17 (EC 2007).
Due to costs, installing boreholes to investigate the processes[12] that could occur in the deeper soils and substrata beneath your activity's discharge will not always be feasible. This means the chosen compliance point for your activity may need to be at a point beneath your site where you or we can easily check properties of e.g. soil layers. This will make the risk assessment cheaper but more conservative, and if its outcome is unacceptable, we won't be able to grant you a permit without submission of further information and risk assessment based on site investigation data.

Location of Compliance Points

'*Compliance points****' can be located at a number of different points between your activity's discharge and the identified receptor(s). Their purpose is to define a (modelled or real monitoring) point where, if a compliance value is achieved, the receptor(s) will be protected. Where the compliance point is set between the receptor and the activity's discharge, compliance values are based on the justified and predicted effects of dilution and attenuation/degradation downstream at the receptor. The compliance point could even be the discharge itself and in this case the compliance value is referred to as the limit value. Where the compliance point is the receptor, the compliance values will be the water quality targets set out in Section 4.1.2.***
Further discussion on compliance points is provided in The European Commission's Common Implementation Strategy (CIS) for the Water Framework Directive Guidance Document No 17 (EC 2007) and in Appendix A1.

Typical Compliance Points

For most activities, the following compliance points (theoretical and suitable for monitoring) should be considered:

[12] that you could use to justify a compliance value higher than the receptor water quality target concentration.

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- *Your activity's discharge (suitable for monitoring);*
- *The water table (not readily monitored and so theoretical) for calculated concentrations of hazardous substances to check whether the entry of hazardous substances to groundwater will be avoided;*
- *A point (e.g. borehole or spring suitable for monitoring) at the downgradient edge of your activity to check that:*
  - o *monitored concentrations of hazardous substances are acceptable in terms of the "prevent" objective and will not cause pollution;*
  - o *calculated and monitored concentrations of non-hazardous pollutants will not cause pollution.*
- *An off site receptor (e.g. abstraction borehole, spring, wetland, stream or river).*

Distance to Downgradient Compliance Point / Receptor

If groundwater beneath your site is judged to be a valuable current or future resource, then this groundwater is your receptor and a point immediately down-gradient of your discharge may be one of your compliance points. However, if a monitoring borehole is placed too close to your activity's discharge it may provide an additional pathway to groundwater. We therefore recommend locating down-gradient compliance boreholes at sufficient distance from your activity's discharge to avoid this risk, but within 50 m of the downgradient edge of the discharge.

The 50 m distance may be extended where there is credible information to demonstrate a significant physical constraint on the ability to use the groundwater resource. Box 4.2 identifies the physical constraints which may apply.

Box 4.2 Physical Constraints that may affect Distance to Downgradient Receptor

The following physical constraints to the development of groundwater should be considered when setting compliance points in terms of a downgradient groundwater receptor:

- ***Topography****. Steep or inaccessible land or areas with unsuitable access may reasonably influence the identification of where groundwater might be developed or the feasibility of installing a monitoring borehole.*
- ***Natural conditions****. Constraints on the future development of groundwater may also exist due to the limitations of the groundwater resource (e.g. potential low yield) or the natural groundwater quality.*
- ***Existing and future land use*****. For example, an area designated for use as domestic housing with mains supplies might reasonably be regarded as a constraint to develop the groundwater resource.*
- ***Land ownership*****. There may be factors governing the long-term control of land or access to adjacent land that constrain the potential for future water abstraction, e.g. private estates, park land, major infrastructure development, extensive industrial complexes, and .*

Note: *It is important when considering these constraints that the full lifetime of your activity and its potential effect on groundwater is recognised. Some activities may continue to affect groundwater quality for decades or centuries after they have ceased operating and these constraints may change in that time.
Source: Remedial Targets Methodology: Hydrogeological Risk Assessment for Land Contamination: Consultation Draft Appendix G: Supplementary Guidance on Compliance Criteria for a Level 3 Risk Assessment.

In these cases, receptors other than the resource potential of the groundwater are likely to be the primary drivers in for your risk assessment. We would however consider a maximum default compliance position of 250m reasonable in aquifers with local groundwater potential.

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