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SAFEGROUNDS

Guide to the comparison of contaminated land management options

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SAFEGROUNDS Guide to the comparison of contaminated land management options

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Summary

The SAFEGROUNDS Learning Network uses participatory approaches to develop and disseminate good practice guidance for the management of contaminated land on nuclear-licensed and defence sites in the UK. It is a large and well-established network strongly supported by a wide range of participating groups.

A central theme of SAFEGROUNDS guidance is the need for the systematic comparison of management options for contaminated land, in terms of the factors important to site owners/operators and other stakeholders, to inform decision making.

This document provides guidance on comparing contaminated land management options. It does not consider the decision making step, which is covered in the main SAFEGROUNDS guidance.

As well as explaining the general approach, the guide presents selected methods and discusses how to choose the most appropriate one for a given contaminated land situation. As different situations demand differing levels of rigour, detail and stakeholder involvement, the methods presented cover situations from the simple (eg a small patch of well defined contamination on an operating site) to the complex (eg a restoration strategy for a complex site). Properly applied, all methods will fulfil the SAFEGROUNDS key principles and are consistent with the SAFEGROUNDS *Good practice guidance for the management of contaminated land on nuclear-licensed and defence sites* (Hill *et al*, 2009) and relevant regulatory requirements. Worked examples are included to show how the methods can be applied.

The guide is primarily aimed at those with responsibility for developing and applying a process for comparing options for managing contaminated land on nuclear-licensed and defence sites. However, it recognises a wider audience where possible, including those who may be involved in the options comparison process, and those who have an interest in the outcome.

Although it is part of the SAFEGROUNDS suite of documents, the guide can be used as a stand-alone document provided its context is appreciated.

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Authors

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Project Steering Group

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1 Introduction

1.1 Background

The SAFEGROUNDS Learning Network <www.safegrounds.com> uses participatory approaches to develop and disseminate good practice guidance for the ***management of contaminated land***[1] on ***nuclear-licensed sites*** and ***defence sites*** in the UK. It is a large and well-established network strongly supported by a wide range of participating groups.

The main SAFEGROUNDS document provides good practice guidance for the management of contaminated land on nuclear-licensed and defence sites (Hill *et al*, 2002) and is known as the *Land management guidance* or LMG. It is a framework for contaminated land management and is built on five ***key principles*** that were debated and agreed through independently assisted workshops. The LMG is kept under review so that experience and developments can be reflected. The second version (LMGv2) was issued in 2009.

LMGv2 is supported by other documents providing information on related issues such as the regulations that apply and methods for characterising contaminated sites.

A central theme of LMGv2 is options appraisal – the systematic comparison of a suitable range of management *options* for contaminated land, in terms of the factors important to site ***owners/operators*** and other ***stakeholders***, to inform ***decision making*** on its management. Options appraisal or options comparison, options assessment and optioneering – is accepted as a central element of safety and environmental decision making in relation to radioactively and non-radioactively contaminated land. A range of relevant regulatory guidance (described in Section 1.3) requires options appraisal.

This supporting document gives practical guidance on methods for options appraisal.

1.2 Purpose and scope

This guide presents procedure for, and guidance on, comparing contaminated land management options with a view to identifying a ***preferred option*** for a particular contaminated land situation. It focuses on processes for comparing options, however it does not cover the stage when the owner/operator decides on the option to be used.

This decision will depend on issues specific to the particular situation, and will be an outcome of the proper application of options comparison and stakeholder involvement. This is a separate responsibility of the site owner/operator and represents a later stage in the SAFEGROUNDS process. These steps are discussed in LMGv2.

A broad approach to options comparison is presented, which is consistent with the SAFEGROUNDS principles and guidance. Specific methods are also described, as well as how to select the most appropriate approach for a given contaminated land

1 ***Bold italics*** are used to indicate the first instance of a word or phrase that has a specific meaning in SAFEGROUNDS, which is defined in the Glossary.

situation. The guide recognises that different situations demand differing levels of rigour, detail and stakeholder involvement. The methods presented cover situations ranging from the simple (eg a small patch of well defined contamination on an operating site) to the complex (eg a comprehensive strategy for a complex site). The methods are representative of the spectrum of approaches that could be used, and others may be adopted if appropriate. The guide should not be taken to be prescriptive.

The guide is primarily for those responsible for developing and applying a process that compares options for managing contaminated land on nuclear-licensed and defence sites. Consistent with LMGv2, this group is referred to as site owner/operators. It recognises a wider audience where possible, including those who may be involved in the options comparison process, and those who have an interest in the outcome.

The guide reflects established options comparison methods, current regulatory guidance, and experience of comparing options for the management of contaminated land on nuclear and defence sites. Although it supports LMGv2, and assumes that the reader is familiar with it, the guide can be used alone provided its context is appreciated.

1.3 Context

1.3.1 Policy, regulations and regulatory guidance

Different regulatory regimes apply to different types of site, and different regulatory requirements apply at different stages in the management of contaminated land. An information paper has been prepared for SAFEGROUNDS that provides a summary of regulations relating to contaminated land (Hill, 2007).

There are formal requirements to consider options for managing contaminated land in the following instances:

- for a nuclear-licensed site, government policy requires owners/operators to determine a strategy for the end state of site decommissioning (which may largely be determined by the presence of ***radioactively contaminated land)*** that represents the Best Practicable Environmental Option (BPEO) (DTI, 2004)
- for radioactively contaminated land on nuclear-licensed sites, regulatory guidance (HSE, 2002a and HSE, 2002b and HSE, 2006) under the Nuclear Installations Act 1965 (as amended) requires site owners/operators to determine and evaluate possible remediation options, justifying the preferred option
- radioactively contaminated land on defence and other sites in England and Wales are undergoing a change, now included in Planning Policy Statement 23 (CLG, 2004), which requires the options to be appraised sufficiently to identify a viable remediation scheme that will reduce the risks to acceptable levels
- radioactively contaminated land on defence or other sites regulated under the Part 2A regime (EA, 2007a) should adhere to the regulatory guidance that recommends a broad comparison of remediation options is carried out (EA, 2004), and the identification of the BPEO (EA, 2002)
- for ***non-radioactively contaminated land***, the Contaminated Land (England) Regulations 2000 require the enforcing authority to take into account the best practicable technique for remediation and in all cases the remediation selected should be reasonable
- for non-radioactively contaminated land, regulatory guidance requires the appraisal

of options (EA, 2004), if necessary, in relation to the planning regime for the development of any contaminated land in England (CLG, 2004).

These regulations and guidance have been taken into consideration in developing this guide, and the methods presented are capable of satisfying them. Generally, EA (2004) and the other guidance is not prescriptive and will be satisfied by the application of the SAFEGROUNDS approach. In several instances, however, guidance indicates that the comparison of options should conform to the principles of the BPEO method (RCEP, 1988).

1.3.2 Management of nuclear and defence sites

Owners/operators of nuclear-licensed sites owned by the Nuclear Decommissioning Authority (NDA) are required to develop strategies and plans for the work to operate and decommission the site that require periodic review (lifetime plans). This will include a contaminated land management strategy that should demonstrate a solid approach, and will contribute to the achievement of the site end state. The strategy should also take account of NDA's requirements for an integrated waste strategy and prioritisation. The SAFEGROUNDS approach incorporates the development and documentation of a land quality management Strategy. The strategy is reviewed and refined throughout the process of managing contaminated land. The outcome of options comparison represents an important contribution to the land quality management strategy.

At nuclear-licensed sites owned by the MoD and non-nuclear defence sites such strategies and plans will be part of corporate management procedures. They should contribute to the suitable management of the asset, within the context of the policy and regulations described in the preceding section.

1.4 Relationship to the SAFEGROUNDS key principles and guidance

1.4.1 SAFEGROUNDS key principles

The options comparison guide is founded on the SAFEGROUNDS key principles. These are presented in an order agreed by consultation and are addressed as follows:

- Principle 1: Protection of people and the environment – the guide states that the protection of people and the environment, now and in the future should always be considered as a factor when comparing options.
- Principle 2: Stakeholder involvement – the guide describes how stakeholders can be involved in the comparison of options, taking account of the nature of the contaminated land and stage of its management.
- Principle 3: Identifying the preferred land management option – the guide provides practical guidance on comparing options with a view to identifying a preference.
- Principle 4: Immediate action – this principle is primarily addressed in LMGv2 and is not relevant to this guide.
- Principle 5: Record keeping – the methods described in the guide will provide important information on the comparison of options for the contaminated land, which will support the final decision.

1.4.2 Land management guidance

LMGv2 presents SAFEGROUNDS guidance within the overall framework recommended by the Environment Agency *Model procedures for the management of land contamination* (CLR11) (EA, 2004). This is an established methodology that is familiar to many practitioners. It is a suitable vehicle for introducing the specific activities that are needed to satisfy the SAFEGROUNDS key principles. Where appropriate, the terminology in Figure 1.1, from CLR11, has been used for consistency.

Options appraisal is the second stage of the CLR11 process. It is used if risk assessment demonstrates that unacceptable risks are associated with a site and that they need to be managed. It is assumed in this document that earlier stages of the process have been undertaken as described in LMGv2, eg that the site has been characterised sufficiently and has been subject to risk assessment.

This document gives specific advice in relation to the process of systematically comparing options in the process (Elements 22 to 27 in Figure 1.1). It does not cover the process of making decisions on the option to be used (Elements 28–30), referred to by EA (2004) as the development and identification of the remediation strategy[2]. Decision making is informed by the options comparison process described in this document, but it also involves the consideration of other factors such as the implications of the decision beyond the site. SAFEGROUNDS does not give generic guidance on the decision making process, as it will be specific to each situation.

1.4.3 Other SAFEGROUNDS documents

This guide is linked to other SAFEGROUNDS documents that support LMGv2.

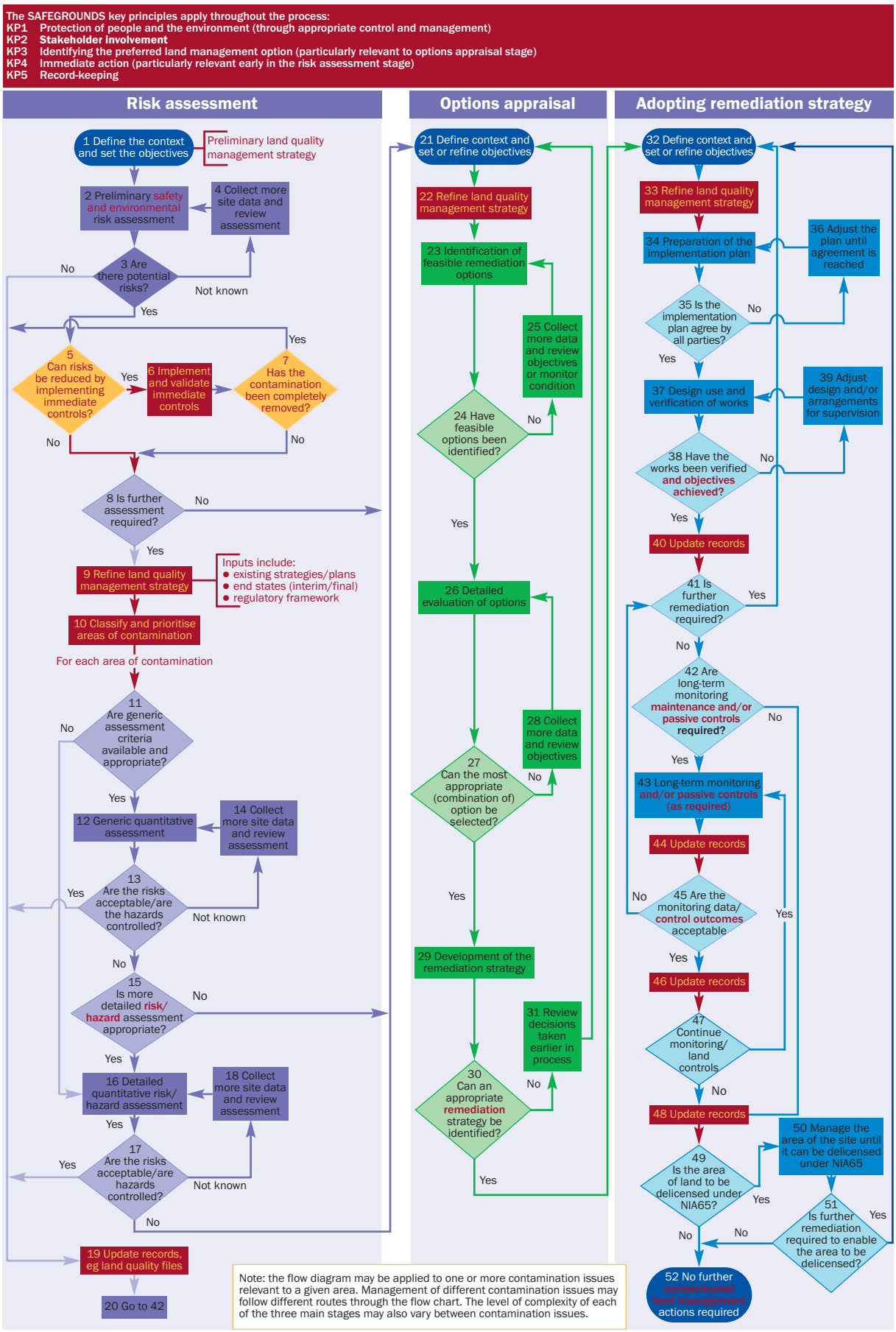
- options comparison will make use of information about the extent and character of the contamination, and its context in the terms of the site. Gathering this information is described in the *Good practice guidance for site characterisation* (Baker *et al*, 2007)
- options comparison needs to take account of stakeholder views. Important issues and methods of involvement are described in the SAFEGROUNDS *Community stakeholder involvement* document (Collier, 2005a)
- an important consideration for any contaminated land management option is the potential human health and environmental risks[3] associated with it. Guidance on *Assessments of health and environmental risks of management options for contaminated land* (Smith, 2007) describes how such risks can be quantified
- it will be important to maintain a record of the contaminated land management actions and the reasons for their selection. The *Good practice guidance for land quality records management for nuclear-licensed and defence sites* (Cruickshank and George, 2007) describes how information from options comparison can be maintained.

Other documents have been developed for SAFEGROUNDS that are relevant, and are available at: <www.safegrounds.com>. In particular, this guide is informed by regulatory policy and requirements described in *The UK Regulatory Framework for contaminated land on nuclear-licensed and defence sites* (Hill, 2007).

Points of interaction with these documents are noted throughout this guide, where appropriate referring the relevant element of Figure 1.1.

2 Remediation strategy is used for consistency with CLR11 to refer to the option that has been selected for managing contaminated land, following options comparison. Otherwise, the term *strategy* refers to a broad plan for the management of all the contaminated land on a site.

3 There are important uncertainties concerning the relationship between radiation exposure and human health risks. There is consequently an ongoing debate concerning the definition and application of standards to provide an appropriate degree of protection of people and the environment. This issue is outside the scope of the options comparison document and is dealt with elsewhere in SAFEGROUNDS.



Note: the modifications to the CLR 11 decision flow diagram for SAFEGROUNDS are highlighted in dark red boxes with tan lettering

Figure 1.1 ***Decision flow diagram for management of contaminated land according to SAFEGROUNDS***

1.5 Document status

This is the first version of the options comparison guide. It is a live document that is intended to be revised at intervals in the future in the light of experience in using it and in response to policy, regulatory and other changes.

Previously, guidance on options comparison was presented in version 1 of the LMG. This new guide expands on previous guidance. There are no major areas of difference, but more information and detail is presented on the various methods available and their applicability to different contaminated land situations.

The guidance is not binding on site owners/operators and has no legal standing. It represents good practice in accordance with regulatory requirements. However, site specific requirements should always be discussed and negotiated with the appropriate regulators.

1.6 Structure

The guide has been ordered as follows:

Chapter 2 presents guidelines for options comparison in the context of the management of contaminated land on nuclear-licensed and defence sites.

Chapter 3 describes a general approach to options comparison that uses the guidelines, and presents guidance for its use in practice.

Chapter 4 describes the range of practical methods that can be used and provides guidance on selecting one suitable for a particular contaminated land situation.

Supplementary information is provided in appendices:

Appendix A1 provides further details of the selection of methods for options comparison considered in Chapter 4.

Appendix A2 provides worked examples of use of the methods presented in Chapter 4.

2 Elements for the comparison of options for the management of contaminated land

This section presents a set of elements for comparing contaminated land management options. These are not prescriptive, but will help to ensure that:

- SAFEGROUNDS key principles are put into practice during options comparison
- options comparison is undertaken in a reasonable and proportionate manner
- options comparison methods apply good practice.

There are five elements, which are defined in the following paragraphs.

Element A: Comparison of contaminated land management options should be undertaken in a structured, systematic and transparent manner with the involvement of stakeholders

This element emphasises the need for the options comparison process to be undertaken in an open and logical way that is accessible to all. It uses SAFEGROUNDS Key Principle 3 in relation to options comparison with the involvement of stakeholders (Key Principle 2). It also reflects the requirements of regulations and associated guidance in relation to options comparison.

Element B: Stakeholder involvement is an integral and defining part of options comparison. The extent of stakeholder involvement depends on the technical and societal significance of the contaminated land issue.

This element recognises that stakeholder involvement must always be considered, and the extent and nature of involvement is related to the situation under consideration. The element uses SAFEGROUNDS Key Principle 2 in relation to the options comparison. The element is consistent with good practice (eg Dodgson *et al*, 2000).

Element C: The level of detail in which the options are compared should be commensurate with the size of the contaminated land issue, whether it is strategic or specific, and its potential impact on people or the environment. A comprehensive list of options should be assessed.

There is a variety of methods for comparing options that involve differing levels of detail. This element emphasises that the options comparison process needs to be proportionate to the contaminated land situation. The main factors that determine the significance of a given situation include the size and nature of the area of contamination, how far its management strategy has been developed, and the range of stakeholders with an interest. Nevertheless, an options comparison is generally only meaningful if the range of options considered is comprehensive. The options should range from the minimum effort required to manage the contaminated land to the maximum that can be done, unless there are fundamental constraints that limit what options can be considered.

The element is not derived from a SAFEGROUNDS key principle, but it reflects the

need for completeness, but with proportionality. It also represents good practice in options comparison methods, expressed, for example, in regulatory guidance (EA and SEPA, 2004).

Element D: The options comparison process will require information and data, which should be at an appropriate level of detail for the study. Uncertainties should be identified and taken account of in the options comparison.

This element identifies the importance of using factual information in the options comparison process, but also recognises that the level of detail required is related to the significance of the contaminated land situation. Many aspects may be subject to uncertainty because of incomplete information, and this element requires this to be taken into consideration. The outcomes of the options comparison exercise should be reviewed if more information becomes available, or if the situation changes (as indicated in Elements 24 and 27 in Figure 1.1). The element is not derived from a SAFEGROUNDS key principle, but it represents good practice in options comparison (eg Dodgson *et al*, 2000).

Element E: The output of the options comparison should be a clear record of the information considered, the assessment of options, the views expressed, and the conclusions reached. Unless issues of national security dictate, it should be available to anyone interested.

This element requires the options comparison process, and the context in which it was undertaken, to be clearly documented in a manner that can be scrutinised, for example as part of the land quality management strategy document. It emphasises the need for transparency, and recognises that a wide range of information is likely to have been considered which is useful to record, in particular the rationale for the preferred option(s). So it uses SAFEGROUNDS Key Principle 5 (record-keeping) in relation to options comparison.

3 Methods for comparing options for the management of contaminated land

3.1 General approach

3.1.1 Main steps

A systematic and transparent method for options comparison, which is compatible with the guidelines presented in Chapter 2, involves several steps[4]:

- a statement of the issue, defining the ***objectives, assumptions*** and ***constraints***, and establishing the scope and context of the assessment
- identification of all relevant options (and, if necessary, ***screening*** to identify those that are practicable)
- definition of criteria that reflect the factors that are important to stakeholders (sometimes referred to as attributes)
- assessment of the options in terms of criteria, on the basis of appropriately detailed factual information
- compare the options with a view to identifying a preferred[5] option (or options), appropriately informed by stakeholders' views. This may include applying sets of weights to criteria to represent their relative importance to stakeholders.

Taking account of established guidance on options comparison (eg Dodgson *et al*, 2000), a generalised sequence of steps can be defined (see Figure 3.1). These map to the key main elements of LMGv2 and the options appraisal stage presented in CLR11 (EA, 2004). This guide expands on CLR11, mainly to provide more detailed discussion of the methods for comparing options (evaluating options in CLR11 terminology). It also gives greater consideration to options comparison methods that permit stakeholder involvement. The approaches described in this guide are not inconsistent with CLR11, but permit a broader and more flexible approach to options comparison which is needed to satisfy the SAFEGROUNDS key principles.

It is important to recognise that this does not imply that the process is necessarily onerous or complicated. Appendix A1 presents methods for options comparison that follow this general approach and which could take no more than an hour or two to complete, or might take months. The methods are representative of the spectrum of approaches that could be used, and others may be adopted if appropriate, and the guide should not be taken to be prescriptive in this respect.

At the heart of the general approach to options comparison is the concept of a matrix. The performance of options for each criterion of interest is quantified, as far as possible, using objective and factual information. This is the general approach to the detailed evaluation of options (Element 25 of Figure 1.1). Numerical ***scores***, ranks or simply words can be added to each element of this performance matrix (see Figure

4 Terms defined in the Glossary are italicised on their first use.

5 The preferred option is not necessarily that which will be implemented. It is an input to the development of the remediation strategy, Element 28 of Figure 1.1, that is the responsibility of the site owner/operator, as discussed in the LMG.

3.2). Completion of the matrix then allows the pros and cons of each option to be identified and compared. A simple inspection may be sufficient to determine a preferred option for a simple contaminated land situation. However, more detailed analysis methods can be applied if the situation demands. These generally use the concept of weighting criteria relative to one another to reflect stakeholder's views of their relative importance. The preferred option or options then form an input to the development of the remediation strategy.

This form of approach is typically referred to as a multi criteria technique. There is a wide variety of approaches ranging from sophisticated mathematical techniques to simple rating systems (eg Dodgson *et al*, 2000). A selection of multi criteria techniques suitable for use in comparing contaminated land management options is presented in Appendix A1. Their relevance to different types of contaminated land situations is considered in Chapter 4.

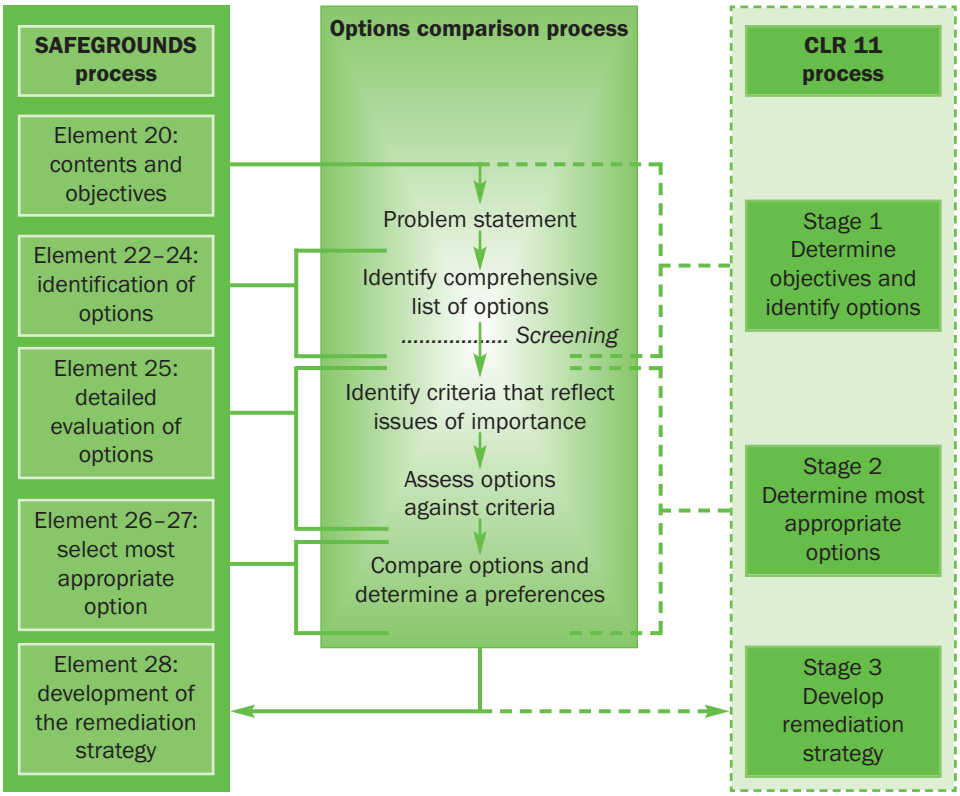


Figure 3.1 ***General steps in structured approach to options comparison***

	Option 1	Option 2	Option 3
Criterion 1	1	2	3
Criterion 2	3	1	2
Criterion 3	2	1	3

	Option 1	Option 2	Option 3
Criterion 1	50	85	100
Criterion 2	60	55	60
Criterion 3	15	10	50

	Option 1	Option 2	Option 3
Criterion 1	Typical performance	The option...	Very good
Criterion 2	The option...	Similar but worse	Reasonable Adequate
Criterion 3	Marginally better	Very poor	Adequate option

Figure 3.2 ***Examples of performance matrices with different methods of assessing option performance***

Whichever approach is adopted, it is necessary to apply the multi criteria techniques with a degree of care and recognise potential limitations. A poorly expressed scope can lead to problems defining options and criteria that are genuinely comparable. For example, genuinely alternative options should be capable of reaching the same end point and/or cover the same times. Also, in some circumstances there may be basic requirements that play a major role in determining suitable options. For example, geological or hydrogeological issues may preclude a whole range of options or result in very specific requirements that should be met by all (for example, engineered structures might be required to withstand the effects of climate change over thousands of years). So the application of multi criteria techniques needs to be flexible with respect to the choice of options – if a set is identified as being incomplete or to include inappropriate options, it should be changed.

3.1.2 Tiered approach

A contaminated site needs to be managed as a single entity, even if there are a range of separate areas of contamination. However, it may not be possible or appropriate to determine a complete remediation strategy for a particular contaminated land situation with just one application of the options comparison process. A tiered approach may be needed, in which the range of possible solutions is systematically narrowed down through several stages of options comparison. This may be necessary if the situation is complex, eg:

- contamination is of substantial size (in terms of hazard and/or area)
- there is a range of different areas of contamination
- a significant number of management options or technologies (that could perhaps be used in combination) are relevant.

Figure 3.3 illustrates one way that a tiered approach can be applied. In this example, there are three stages of options comparison:

Stage 1 Identify a general strategy for managing the contaminated land, which will enable the land quality management strategy to be refined. The strategic options study is high-level, concentrating on broad themes for the management of the contaminated land. The outcome of a strategic options study can clarify the specific objectives and requirements to be considered in the next stage. This stage may not be necessary if there is an established plan, or the contaminated land is limited in scale and significance.

Stage 2 An analysis of general categories of options (eg capping, excavation, immobilisation). This stage refers to groups of options with particular characteristics that can be defined in some detail.

Stage 3 Focused on evaluating specific remediation options on specific areas of contaminated land. This considers distinct issues associated with the practical application of contaminated land management option(s).

The second and third stages may be combined providing this does not lead to a long list of options that proves impractical to evaluate. It may be useful to undertake an initial scoping study, preceding a more detailed assessment, to understand the nature and significance of the issue. A scoping study should not result in options being discounted without a suitable level of stakeholder involvement. So it is essential that any scoping study undertaken is transparent, takes due account of the guidelines and general process described here, and is fully recorded.

The outcome of a scoping study would indicate whether a tiered approach is necessary,

or if a single stage of options comparison is sufficient. If a tiered approach is applied it is equivalent to a series of iterations through Elements 20–27 of Figure 1.1.

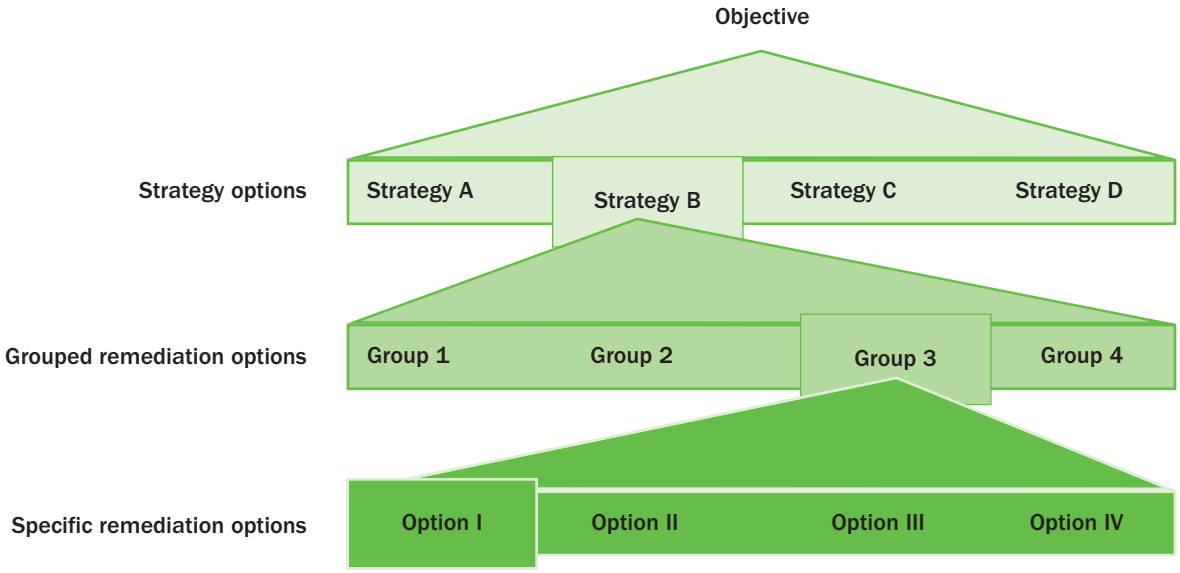


Figure 3.3 ***Sequentially identifying a specific option for managing contaminated land***

Finally, it is often of value to review the options comparison periodically, particularly if the preferred strategy has yet to be carried out and new information is available.

3.1.3 Main advantages

The advantages of using a structured multi criteria technique instead of informal judgment are that (Dodgson *et al*, 2000):

- it is open and transparent
- the choice of objectives and criteria that any decision making group may make are open to analysis and to change if they are considered inappropriate
- the assessment of options is explicit and structured
- the objective assessment of the performance of options can be subcontracted to experts
- it can provide an important means of communication, within the decision making body and the wider community
- it provides a rigorous audit trail.

These features enable multi criteria techniques, properly applied, to fulfil the guidelines presented in Chapter 2.

3.2 Description of the main steps in the options comparison process

3.2.1 Problem statement

The initial stage involves setting out the problem statement. This indicates the scope, context and basic expectations for the options comparison study. It draws on Elements 20 and 21 of the SAFEGROUNDS process shown in Figure 1.1 and described in LMGv2.

As a starting point for the options comparison process, it is necessary for the contaminated land situation to be described, with an indication of its significance. Reference should also be made to the context of the contaminated land in terms of the whole site, eg whether there is an existing strategy for contaminated land.

A contaminated land situation should always be considered in totality at the outset. It is not acceptable to deal with a contaminated site as several small issues (or salami-slicing) without first establishing an overarching strategy. So the problem statement should indicate whether the study is part of a tiered options comparison process as illustrated in Figure 3.3. It may be relevant to describe regulatory regimes that apply. The extent and character of stakeholder interest should be indicated.

The overall objectives for contaminated land management should be defined from the start of the contaminated land management process (Element 1), then incorporated into the land quality management strategy, and reviewed and updated (Elements 7 and 18). However, specific objectives for the options comparison will need to be defined in the problem statement, which draws on Elements 20 and 21, at the start of the options appraisal stage. Hypothetical examples of specific objectives could be initial framing of a contaminated land situation, or identification of a management option that can implement the end state in less than five years. Specific objectives will typically be defined by the owner/operator, but may also be imposed by regulators, or represent other stakeholders' aims.

Factors that are external to the options comparison process, but limit the breadth of options that can be considered feasible, should be documented as constraints[6]. The number of constraints should be minimised as far as possible, consistent with the overall objectives and scope of the assessment. Constraints are likely to be practical considerations, but might also include factors associated with regulations or policy. Examples could be a requirement for the contaminated land management to be completed within a specified time, limits related to waste management routes or discharges, or restrictions on the types of remediation activity that can be undertaken because of other activities on a site. Constraints can always be applied following options comparison as part of the later preferred option decision making stage. However, some constraints may be fundamental to the management of the contaminated land management. For example wider strategic objectives such as sale of land, site redevelopment and construction of new facilities can limit the range of options. Note that for most decommissioning nuclear sites the declared ultimate aim is delicensing, which requires a demonstration of no danger from future use of the land (HSE, 2002b).

Assumptions are likely to be needed to address important areas of uncertainty that apply to all (or several) options. For example, assumptions may be made concerning the availability of facilities and resources that enable certain technologies to be used, or concerning the level of detail available on the extent of contamination.

It is good practice to publish the problem statement, although for very simple cases with no significant stakeholder interest this may not be necessary. In other circumstances, for example when defining the strategy for clean-up of a nuclear-licensed site, the problem statement may be expressed in the land quality management strategy.

6 CLR 11 indicates that constraints should be identified at the beginning of the options identification stage, however in practice this follows on from the determination of objectives and context, and therefore there is no fundamental difference in approach.

For simple situations, the objectives, assumptions and constraints will be evident to owners/operators. Nevertheless there is value in documenting them to provide others with a clear picture of the scope of the options comparison. This might require a few paragraphs, with reference, where appropriate, to other documents that define the situation and its scope (eg site characterisation information).

For complicated situations, it is likely that more effort will be needed. The problem statement will provide a main point of reference for the development of the approach for managing the contaminated land. It will frame the options comparison process and so may be of interest to a wide range of stakeholders. In such situations, the problem statement should be defined in the land quality management Strategy.

If there is a significant degree of stakeholder interest in the situation, then it may be appropriate to offer stakeholders the chance to comment on the problem statement, perhaps expressing their own views on the objectives and scope of the work.

3.2.2 Identify options

The next step relates to the SAFEGROUNDS process (Elements 22–24 of Figure 1.1). A broad range of options should be identified. They should range from the minimum effort required to manage the contaminated land to the maximum that can be done, unless there are fundamental constraints that limit what can be considered. Options should be distinct, either in what they aim to achieve (strategic) or how they are going to achieve the strategic objective (technique and use), and care should be taken not to mix the strategic and technical/implementation options.

An initial list of options is likely to be most effectively identified by those familiar with the situation, principally the owner/operator. CLR11 recommends identifying options specific to each relevant pollutant link, however it may be appropriate to consider the issues more holistically. The list of options can be developed by using the knowledge and experience of suitable experts, or by a survey examining available technologies or similar situations elsewhere. It can be difficult to develop a comprehensive, consistent and practicable options list, especially when there are many potential variants of options that can apply, or options related to different times. Such issues need to be recognised from the start, and may indicate the need for several stages of analysis (an initial assessment of broad options, followed by a more detailed assessment of the sub-options).

The list of proposed options should always be reviewed. For detailed technical options, peer review by technical specialists may be useful. For strategic options, input from stakeholders, including the local community can be valuable.

If a wide range of options is identified it may be appropriate to screen the options. This is referred to as the identification of feasible options in the SAFEGROUNDS process (Element 23 of Figure 1.1). Screening should be undertaken on the basis of clearly defined factors. Screening factors are likely to cover issues of legality, technical practicability/relevance to the situation, and gross disproportion (providing this is not a proxy for screening out options on the basis of cost alone). The basis for screening options should be clearly stated and open to scrutiny. The screened options that are taken forward to detailed assessment should all be capable of being put into practice within an appropriate time.

In determining an overall contaminated land management strategy it will generally be important to determine a selection of strategic options that covers the whole range of practical possibilities. As strategies are often broad, and overlap, the options will need

to be very clearly defined. Strategic studies are likely to have a broad level of stakeholder interest, so stakeholders could also be invited to submit ideas.

Provided that the overall contaminated land management objectives (including future uses) are clear, remediation options should be reasonably evident. The following categories cover the main types of technology options (some will only be interim solutions):

- in situ options for partial or complete removal of contamination associated with soil (eg electro-remediation, soil vapour extraction)
- ex situ options for partial or complete removal of contamination associated with soil[7] (eg, soil washing, bioremediation using windrows, direct disposal)
- options for immobilisation or stabilisation of contaminated soil (eg solidification/stabilisation, surface amendment to immobilise contaminants, vitrification)
- in situ isolation and containment of the contaminated ground (eg capping, in-ground barriers, cryogenic barriers, hydraulic containment)
- contaminated groundwater management options (eg pumping with physical, chemical or biological treatments, permeable reactive barrier)
- contaminated soil gas management options (eg passive and active systems).

During the identification of options it is important to develop unambiguous descriptions so that all participants in the process have a clear understanding of each option. Differences in the perception of options could cause problems in later stages of analysis. Detailed characterisation of the option (eg in terms of assessment criteria) is not necessarily needed at this stage, although an evaluation of the options in relation to any screening factors may be required (Element 24 of Figure 1.1). Important uncertainties should also be identified.

3.2.3 Assessment criteria

The detailed evaluation of options (Element 25 of Figure 1.1) begins with the selection of assessment criteria. Criteria should be defined in a manner that reflects the objectives and ensures that the main issues of interest to stakeholders will be considered in the assessment, even if the stakeholders are not represented in person as part of the options evaluation process. It is essential that the list is comprehensive. This is because the validity of a multi criteria approach relies on all issues of concern being captured by the criteria. If an issue is not taken into account, options will not be assessed against it. The evaluation criteria should also be independent, to avoid bias and double-counting, and defined at similar levels of detail.

The range and character of criteria to be considered often depends on the degree of stakeholder interest in the situation. The type of criteria considered will also depend on the stage that has been reached in deciding how to manage the contaminated land. At the stage of developing a strategy there is likely to be significant emphasis on social and macro-economic factors. There is likely to be more emphasis on practicability and cost issues when decisions concerning specific remediation options are under consideration.

For simple studies, it can be appropriate to consider the basic criteria groups directly and determine the benefits and costs of options for each. However in most instances a more detailed set of specific criteria may be needed. A very long list of criteria can be

7 These may be the only options under consideration if a strategic decision has already been taken to excavate the contamination.

impractical and can make the process of weighting more complicated. Experience has shown that about 20 criteria are a manageable number that permits a considerable amount of detail in the assessment.

There is no fixed method for determining specific criteria, as the assessment process will largely depend on the situation under consideration and the issues of importance to stakeholders. The most common approach that has been applied is for either the owner/operator or an independent body to define and justify a list of criteria, which is then exposed to scrutiny by stakeholders. Reference can be made to published lists of criteria that have been used or recommended for similar problems (eg EA and SEPA, 2004 and Phillips *et al*, 2006). If this is done, care should be taken to ensure any selected criteria are relevant to the contaminated land situation under consideration. Also, the chosen criteria should always avoid representing other aspects of the options comparison process. Stakeholder acceptability should not be a criterion, but the issues of concern to stakeholders should be represented by criteria.

Criteria should be described, with the selection of each criterion justified as appropriate, and reviewed by stakeholders. It may be necessary to define a performance scale to compare options against. This can be easily achieved by defining, in terms relevant to the criterion, what is considered to be the best and worst possible performance of an option. The definition of a performance scale can be very important as it directly influences how options are rated and compared. Consideration should be given to obtaining the views of stakeholders in more detailed studies.

3.2.4 Assess options

The assessment (or structured analysis in CLR 11 (EA, 2004)) of options involves making an objective assessment of each option's performance against each criterion. These scores should be sufficient to form a basis for the analysis.

There are two basic methods of quantitatively assessing options. Scores can be assigned in **relative** terms (ranking options, from best to worst) or **absolute** terms (rating options against a scale that defines the best and worst expectations of performance). In both approaches, a scoring scale should be used where each increment has an equal value.

Relative scoring

Relative scores are generally easier to apply (especially by non-specialists). However important information can be lost on how options rate against an objective measure of performance, as this approach simply indicates how the options fare against one another. Also, scoring increments may not be of equal value. This can lead to problems in interpretation if the range in the performance of options is very large in relation to one criterion, and very small in respect of another.

Absolute scoring

This approach involves determining scores by comparing options against a scale that is defined at the same time as the criteria are identified, before the scoring process. Generally, two or more points are needed to define the scale, for example by indicating the worst performance that can be tolerated (the bottom end of the scale) and the best performance that is necessary (the top end). Alternatively, a central point of reference can be defined that represents the existing situation. In the latter case, scores can then be assigned on the basis of how much better or worse an option performs than the existing situation.

In either case the scoring is linked to an absolute measure of the performance of options against an external point of reference. So this approach has the benefit of preserving more information about the performance of individual options in relation to a criterion, rather than simply against one another. For example, it may be found that, within the reasonable bounds of uncertainty, all options fare equally badly or equally well. In such a situation, the criterion does not help to differentiate between options, but information may be gained about whether there is a limit to what can be expected of any option for the management of contaminated land in respect of that criterion. Whichever approach is adopted, it should be used for all criteria.

Generally, the range that is used for scoring should reflect the quality of information the scores are based on. If there is detailed information being used in the assessment then it may be appropriate to use a finely graded scale (eg 0–100). If information is limited, or there is significant uncertainty, then a coarser scale may be appropriate (it may not be numeric – a simple qualitative description of the option's performance could be included). In some cases, however, a finely graded scale may be needed to capture large differences in the performance of options. In choosing a scoring scale it is also important to consider how understandable it is to stakeholders. For ease of communication, it can sometimes be useful to express scores in different ways (eg using colours, words, number of stars).

Scores can be assigned in various ways. The simplest method is for one or more experts to collectively examine each criterion and agree scores for the options under consideration. More detailed assessments should make use of a compilation of factual information to inform the assignment of scores (eg an evidence pack). The assessment of certain criteria (eg costs, radiation risk, waste volume) can potentially be quantified directly. For those criteria that cannot be quantified directly, either an indirect measure could be sought, or a score assigned directly, supported with a description of the basis for assigning the score. It is also very useful to explicitly record uncertainties in scores.

Scores should always be reviewed. In many instances stakeholders have important knowledge that can contribute to the options assessment process. For situations with a significant degree of stakeholder interest, comments can be invited on the scores, and stakeholders could be involved in the options assessment process. However it should be clear that the aim is always to assign scores in an objective manner based on factual information. Solid arguments would be needed to modify scores. Also, it should be clear that the primary mechanism the stakeholder views are captured is the assignment of weights and not scores. During the scoring process it should be remembered that scores do not determine the preferred option, but **inform** those involved in its selection.

3.2.5 Compare options

The final stage of the process is to use information on the performance of options to determine their various merits and drawbacks, and to compare these in a structured way. The SAFEGROUNDS process, and this guide, expands significantly on the CLR11 process (EA, 2004) at this stage (Element 26 in Figure 1.1). Greater consideration is given to the involvement of stakeholders in the selection of a preferred option. This stage will generally involve stakeholders as the aim is to identify, if possible, an option or options that best satisfy the issues of concern to all stakeholders. So the outcome of the comparison stage should be one or more preferred options, however these would not necessarily define the option that is used. There can be no guarantee that all stakeholders' concerns can be satisfied. Ultimately a preferred option will need to be selected by the owner/operator, who may have to take into account other factors. The final decision is taken in Element 29 of Figure 1.1. This is not covered in the options comparison guide but is described in LMGv2.

Options comparison can be undertaken at varying levels of detail, depending on the significance of the contaminated land management situation. There is a wide variety of options comparison methods that are suitable for contaminated land situations of different levels of complexity and/or stakeholder interest. A selection of methods is presented in Appendix A1 – overall there are two main approaches.

- the first is to examine the main trade-offs between criteria for different options by examining patterns of scores, perhaps seeking large distinctions between option performance, or areas in which one option scores consistently well or poorly. This method is flexible and open to the involvement of stakeholders, but requires a degree of interpretation that should be carefully scrutinised and recorded
- the second approach is to use quantitative information from the option assessment together with stakeholder-assigned numerical weights to determine an aggregate measure of performance. Uncertainty and sensitivity can be explored if scores and/or weights are expressed as probability distribution functions, or what if calculations can be undertaken with alternative scores or weights. However, care should be exercised as an understanding of the main features of options (where they perform well or poorly) can become lost in a result that is presented as a single aggregate score for each option.

Although methods differ, a common feature of many of them is the assignment of weighting factors as an indication of the importance of criteria (and also, in some cases, the range of performance of options). For example, each increment in the scoring scale for a criterion assigned a weight of 100 is considered to be ten times the importance to the overall performance of an option as that associated with a criterion assigned a weight of 10. The detailed meaning of the weight differs, however, according to the methodology using it in the options comparison process. Whichever approach is applied, weights should be based on the elicited views of stakeholders regarding the situation under consideration.

The options comparison stage can be led by a person independent from the stakeholders (including owners/operators), although this is generally only warranted for more significant issues. More complex options comparison exercises will involve a greater degree of stakeholder involvement, and/or a greater degree of analysis of the options assessment (eg Monte-Carlo analysis to determine the importance of uncertainties and the sensitivity of the outcome to different sets of weights).

The concluding step is to document what has been revealed by the options comparison process, in clear terms. As a minimum, the land quality management strategy should be updated (eg at Element 32 of Figure 1.1). This provides a logical argument for the preferred option and makes reference to stakeholders views as expressed in the comparison of options. For more complicated situations, a specific options comparison report is likely to be required.

3.3 Issues to consider in the options comparison process

This section discusses issues to consider ensuring that the general approach described in Section 3.2 is properly applied and will satisfy the guidelines specified in Chapter 2. The issues discussed below are based on relevant guidance (eg Dodgson *et al*, 2000, EA and SEPA, 2004 and EA, 2004) and practical experience in the application of options comparison methods to contaminated land situations on nuclear-licensed and defence sites.

3.3.1 Defining a problem statement

A problem statement defines the scope and context of an options comparison study by giving the objectives, constraints and assumptions that apply.

The objectives should be defined from the start

The overall objectives for the management of the contaminated land will be defined at the start of the SAFEGROUNDS process (Element 1 of Figure 1.1), incorporated in the land quality management strategy (Element 7) and reviewed and updated as information is gained (Element 18). These should be echoed and (if necessary) refined and added to at the start of the options comparison process (see Elements 20 and 21 in Figure 1.1). Extra specific objectives should be explained. Depending on the significance of the contaminated land situation, it may be appropriate to invite stakeholders to comment on the objectives.

It is particularly important that the physical and temporal scope of the study is clearly defined. The physical scope should describe the area under consideration and provide clear links to the wider context of the area (for example, any overall site management strategy). The temporal scope should be clear over what period the option should apply (for example, whether the requirement is for an interim management of the land, or a complete and final solution).

Constraints should be identified

There may be factors that are beyond the control of those accountable for the options comparison, which constrain the breadth of the options comparison process. An example could be a regulatory imperative for risk reduction. These constraints should be clearly documented and applied equally to all options.

Assumptions should be made for important uncertainties

Some important aspects of the contaminated land situation may be unclear, in which case assumptions need to be made. Assumptions should be documented clearly and be applied equally to all options. As far as possible, assumptions should be acceptable to all stakeholders.

3.3.2 Identifying options

A wide range of options should be considered

The options comparison process should always consider a comprehensive list of options – at least initially. The initial list of options should range from the minimum to the maximum amount of effort to deal with the contaminated land. It is often useful to include an option that represents the status quo, because it provides an absolute indicator of the potential for improvement offered by alternatives. The extent of stakeholder involvement in defining options depends on the situation. However, stakeholders should be able to suggest options if they wish.

Impracticable options can be screened out

If there is good evidence that an option is not practicable, it need not be considered in detail. The reasons for screening out options should be clearly recorded. Options may be considered to be impracticable and screened out if they:

- are not effective or relevant to the contaminated land situation
- are not legal
- cannot be applied in the required time (eg because the technology is insufficiently developed)
- are or grossly disproportionate in terms of benefits and detriments (providing this is not used as a proxy to screen out options on the basis of cost alone).

Other problem-specific reasons for screening options may be determined. The extent of stakeholder involvement depends on the situation, however, stakeholders should be able to comment on the screening of options if they wish.

A manageable number of options should be considered

It can be difficult to compare a large number of options consistently and transparently. Practical experience indicates that typically about five to 10 is a good number. If a very large number of options are identified then it may be appropriate to adopt a tiered approach to options comparison as described in Section 3.1.2.

3.3.3 Assessment criteria

Criteria should reflect issues of importance

Criteria for the assessment of options should be chosen to reflect the objectives for managing the contaminated land and the issues of importance to stakeholders. Criteria from the following subject areas should always be considered:

- health and safety
- environmental
- technical
- social and economic
- costs.

These criterion groups should be broken down into specific criteria that reflect the issues of concern. For example, important factors that should usually be included are waste management issues (probably within the technical and cost groups) and sustainability (within the social and economic group). The technical group can also include a criterion relating to the ease that regulatory requirements can be satisfied. At a minimum each should be broken down into benefits and costs. Criteria should be included that address issues related to protecting people and the environment, such as sustainability, precautionary action, avoidance of irreversible effects and environmental justice. Stakeholders should be able to comment on the criteria if they wish, and in more detailed studies may be involved in the identification and definition of criteria.

Care should be exercised in identifying criteria, because if an important issue is not covered it can be missed in the options comparison. However, while it is important to consider a very wide range of attributes, there may be a case for only using those that can reasonably be expected to discriminate between options.

Criteria should be independent and at a similar level of detail

Each criterion should be independent of others to avoid double-counting, which could unduly bias the assessment of options. For the same reason, criteria should reflect issues

at similar levels of detail or should be organised into appropriate hierarchies.

Criteria should be measurable

Criteria should be objectively measurable for the identified options, even if only in qualitative terms.

3.3.4 Assessing options

The assessment should objectively determine pros and cons

The main pros and cons of each option should be determined by assessing options against each criterion and recording the outcome in a performance matrix. The performance of options can be rated in various ways, depending on the specific options comparison method adopted. Uncertainties and limitations in the quality of information available are important and should be reflected in the options assessment.

Objective and factual information should be used as evidence

The options assessment should make use of available factual information or, failing that, the informed judgement of specialists. The level of detail with which evidence is developed and presented should be commensurate with the scope of the study and the level of uncertainty that can be tolerated. The assessment should always be reviewed.

3.3.5 Comparing options

Options comparison should take account of different views

In the context of the significance of the contaminated land situation, stakeholders should have the opportunity to provide their views on the options that best satisfy their priorities. So the options comparison method needs to incorporate an appropriate degree of stakeholder involvement. The information gained should be used to determine the preferences of stakeholders. If weights are elicited, the sets of weights proposed by stakeholders should be considered in the assessment.

Options can be compared at differing levels of detail

Comparing options is rarely as simple as identifying the best aggregate score, summed over criteria, since good performance in respect of one criterion does not necessarily directly offset poor performance in respect of a different criterion. A structured analysis of the options evaluation is needed to reveal the important messages and issues that will inform the consideration of trade-offs between options. Options comparison methods, which are suitable for differing levels of detail of analysis, are described in Appendix A1.

Uncertainties should be assessed

Inherent uncertainties in the performance of options against particular criteria may be sufficiently important to directly affect the perceived relative merits of the options. Assumptions, made because of uncertainties, may also have a major influence on the outcome of the assessment. So it is important to understand the likely influence of uncertainties on the outcome of the options comparison.

If, within the scope of the options comparison, the uncertainties cannot be reduced, the aim should be to identify and characterise the uncertainties. The sensitivity of the outcome to the uncertainties can then be understood. The results will indicate how robust the preferred option is. It may be that even substantial uncertainties leave the outcome unaffected, or it may be that more work is obviously needed to reduce important uncertainties and inform the decision.

Approaches to sensitivity analysis are varied but include examining:

- the effects of alternative scores, to capture uncertainties in the score (either by deterministic or probabilistic methods)
- examining the significance of particular attributes by removing them from the analysis
- examining the effects of alternative assumptions and constraints.

The outcome of the options comparison process is not a decision

The outcome of the options comparison provides information on the development of a remediation strategy by the owner/operator (Elements 28–30 of Figure 1.1). These stages are not covered in this guide but are discussed in LMGv2.

4 Selecting a comparison method

This section is intended to indicate which of the available options comparison methods is most appropriate for a given contaminated land situation. It also provides guidance on the level of stakeholder involvement that may be required. This is done by rating the suitability of options comparison methods in relation to the main features of a given situation. The section also discusses typical applications of the methods, and the involvement of stakeholders.

4.1 Method of selecting an options comparison method

Appendix A1 presents a range of options comparison methods that can be applied consistent with the discussion in Chapter 3. All methods are capable of fulfilling relevant regulatory guidance and requirements, eg CLR11 (EA, 2004) for defence sites and guidance such as that relating to the demonstration that risks are as low as is reasonably practicable on nuclear sites (HSE, 2008). These methods, and their names, are based on a multi criteria analysis manual developed for Government (Dodgson, 2000) and a review of options comparison methods (Karaback, 2007). The selected range is not comprehensive, and other methods can be used if they are appropriate. However, this set represents the broad spectrum of approaches, and is considered in this section.

Each method has different strengths and weaknesses. The main characteristics of the selected option comparison methods are summarised in Table 4.1, which are ordered according to typical complexity of the method when it is applied.

Each contaminated land situation is different, so to develop a general basis for determining which options comparison methods are most suitable for a given situation, three main factors are considered:

- the characteristics of the contaminated land (eg size, levels of contamination and assessed risk, location)
- the status of the management of the contaminated land (ie the stage in the process of managing contaminated land – is a strategy being developed or are specific remediation option being considered for a specific area of contamination?)
- the level of stakeholder interest in the issue (local communities, national organisations, regulators, government and industry can all potentially be affected by the outcome).

These factors are not unrelated and it is unlikely that using a management option for a small patch of very low level contamination, eg close to the relevant assessment criteria (EA, 2004) that is on a site with security and access controls already in place would raise interest with external stakeholders. However, each represents a distinct and identifiable feature of any given situation. Considering the situation in terms of the characteristics of the contamination, status and range of stakeholders can provide an indication of which options comparison methods are appropriate.

The following sub-sections consider these factors. An indication of the applicability of the options comparison methods presented in Appendix A1 is given, ranging from very poor (the method is very unlikely to be appropriate to situations with the given

characteristics) to very good (the method is likely to be very suitable for situations with the given characteristics). These ratings are intended to provide a general guide to the applicability of the options for particular contaminated land situations, however, and should not be taken to be a definitive indication on the suitability of a method.

Table 4.1 ***Main characteristics when selecting options comparison methods***

Method	Main characteristics
Direct evaluation	Essentially the simplest application of a multi criteria technique, this involves developing a basic matrix of options and criteria and recording the pros and cons. The preferred option is identified by seeking the option that carries the greatest benefit across the criteria.
Non-compensatory methods[8]	The range of options is tested against a criterion with an associated required level of performance. Only those that meet the criterion are retained. The remaining options are tested against the next criterion. The process continues until a single option remains or all criteria have been applied.
Cost-benefit analysis	The performance of each option against each criterion is valued in monetary terms: benefits in terms of people's willingness to pay for them, and costs in terms of people's willingness to pay to avoid them. The balance of costs and benefits can then be numerically analysed in various ways, such as net present value, benefit-cost ratio and cost-effectiveness.
Trade-off analysis	Options are assessed in terms of a range of criteria using words or generalised scoring scales to rate them, with an accompanying justification for the rating. The resulting performance matrix is then evaluated to determine where the main trade-offs between criteria lie, and/or where options are rated particularly poorly or well, to determine the overall best balance of performance. The analysis may involve consideration of weights that reflect the importance of particular criteria (see Appendix A1). This approach can be most effective when used to determine important issues and differences in view rather than seeking to identify a preferred option.
Linear additive method	Options are assessed and scored quantitatively against a range of criteria. Weights are then determined that reflect the importance of different criteria to particular stakeholder groups (see Appendix A1). For each option, a single weighted aggregate score is calculated using the scores and weights for all criteria. The weighted aggregate scores are used to rank the options. This approach also permits numerical analysis to examine the effects of uncertainties in scores, and/or the sensitivity of the outcome to weightings.
Analytical hierarchy process	The process has the same basic structure as the linear additive method but provides an alterative method of determining weights. It focuses on determining the relative importance of weights in a more systematic way than eliciting a preference and trusting that the response is genuinely representative of the underlying views. Scores and weights are then aggregated and evaluated in the same manner as the linear additive method
Multiple criteria decision analysis	The process has the same basic structure as the linear additive method but involves a more structured approach to weighting, referred to as swing weighting. This aims to take account of the potential for a criterion to actually discriminate between options. Swing weights reflect the overall importance of the criterion, the range in the performance of different options against the criterion, and how much the difference matters.

4.2 Characteristics of the contaminated land

A contaminated land situation can be characterised in terms of:

- the contaminants present and the distribution of concentrations
- the area affected

8 The non-compensatory method described is *elimination by aspects*. a similar and alternative approach, lexographic ordering, is also described in Appendix A1.

- the migration pathways and if it is close to people and/or sensitive environmental receptors.

Characterisation information should be available from an earlier stage in the SAFEGROUNDS process (eg Elements 2, 11 and/or 15 in Figure 1.1). There may be some uncertainties, but it is assumed that the characterisation information is sufficient for the purpose of comparing options. There may be a need for iteration, if the options comparison process identifies a need for further information (Elements 24 and 27 in Figure 1.1).

4.2.1 Level and mixture of contamination

The range of contaminants present, and their concentrations, will be determined by the source of contamination, its history (ie is the contamination fresh or aged, did it occur from a one off incident or leak over many years) and the extent to which contaminants are retained in the ground by natural processes.

The significance of the hazard is related to the types of contaminants present, the total amounts of contaminants, and their concentrations[9]. An indication of the degree of hazard posed by the contamination should be available from the risk assessment(s) and the use of appropriate assessment tools (eg CLEA (DEFRA and EA, 2002), RCLEA (EA, 2006) and RECLAIM (Lennon *et al*, 2006)). These stages precede options appraisal (Element 2, 11 and/or 15 in Figure 1.1).

In general terms, a scale of increasing significance can be considered to be:

- concentrations below generic screening criteria and/or near limits of detection
- concentrations comparable to generic screening criteria
- concentrations of contaminants above generic screening criteria
- concentrations of contaminants further above generic screening criteria.

Guidance on the determination of contaminated land can be used to establish the significance of the contamination (EA, 2004, 2007a and 2007b)[10].

A guide to the applicability of the selected options comparison methods to situations with differing levels of contamination is shown in Table 4.2.

4.2.2 Scale and complexity of contaminated area

The management of large areas of contamination may involve considerable cost, disruption, time, waste/discharge and/or effects on people. Small patches of contamination might be dealt with by a simple and quick solution.

In general terms, a scale of increasing significance can be considered to be:

- a patch of a few m^2 or less
- a region of localised contamination (eg around drains) in an area of a few hundred m^2
- a region of ubiquitous contamination in an area of a few hundred m^2
- a complex pattern of contamination over an area of more than a few hundred m^2.

9 Some risks are dependent upon contaminant concentrations, and some on the total amount of contamination present.

10 This guidance is applicable to the management of contaminated land in England and Wales, except radioactive contamination on nuclear sites.

A guide to the applicability of the selected options comparison methods to situations of differing scale and complexity is shown in Table 4.3.

Table 4.2 ***Applicability of options comparison methods to situations with differing levels of contamination***

Method	Contamination below generic screening criteria and/or near limits of detection	Contamination comparable to generic screening criteria	Contamination above generic screening criteria	Contamination well above generic screening criteria
Direct evaluation	Very good	Poor	Very poor	Very poor
Non-compensatory	Very good	OK	Poor	Very poor
Cost benefit analysis	OK	Good	Poor	Poor
Trade-off analysis	Good	Good	Good	Good
Linear additive	OK	Good	Good	Good
Analytical hierarchy	Very poor*	OK	Good	Good
Multiple criteria decision analysis	Very poor*	OK	Good	Good

Note: *The method is overly complicated for a situation of limited significance.

Table 4.3 ***Applicability of options comparison methods to situations of differing size and complexity***

Method	A few m² or less	Localised contamination on a site	Ubiquitous contamination on a site	Complex pattern of contamination on a site
Direct evaluation	Very good	OK	Poor	Very poor
Non-compensatory	OK	Good	OK	Poor
Cost benefit analysis	Poor*	Good	Poor	Poor
Trade-off analysis	Very poor*	Good	Good	Good
Linear additive	Very poor*	Good	Good	Good
Analytical hierarchy	Very poor*	Poor	OK	Good
Multiple criteria decision analysis	Very poor*	Very poor	OK	Good

Note: *The method is overly complicated for a situation of limited significance.

4.2.3 Pathways and nearness to receptors

Contamination might be immobile and localised in part of a larger area of controlled land, or could be difficult to control, meaning prompt action may be needed.

In general, a scale of increasing significance can be considered to be:

- immobile contamination, isolated from potential receptors
- mobile contamination or contamination close to sensitive receptors (people or the environment).

A guide to the applicability of the selected options comparison methods to situations with differing potential to affect receptors is shown in Table 4.4.

Table 4.4 ***Applicability of options comparison methods to situations with differing pathways to receptors***

Method	Immobile contamination, isolated from receptors	Mobile contamination or contamination close to receptors
Direct evaluation	Good	Poor
Non-compensatory	Good	Poor
Cost benefit analysis	Good	OK
Trade-off analysis	OK	Good
Linear additive	OK	Good
Analytical hierarchy	Poor	Good
Multiple criteria decision analysis	Poor	Good

4.3 Status

A status of a contaminated land situation can be characterised in terms of:

- the stage that has been reached in the overall process of managing the contaminated land
- the extent to which it has been understood and characterised
- the level of regulatory scrutiny that is being applied.

4.3.1 Stage in the contaminated land management process

In the early stages of dealing with a contaminated land situation the focus will be on determining an overall strategy, although the strategy may already exist or be defined elsewhere. For single small patches of contaminated land a strategic vision may be unnecessary. Strategy development will consider broad options and is likely to involve considerable stakeholder involvement. In later stages the emphasis will be on the selection of the most appropriate remediation method for achieving the strategic objectives, and its use. The options will be more specific. Important issues are likely to relate to technical performance and cost, and there will probably be less interest from stakeholders (although there should not be a presumption that stakeholders are not interested, as they may provide important knowledge).

In general, two stages can be identified:

- development of an overall land management strategy
- identification of a remediation strategy

A particular contaminated land situation might not necessarily progress through all these stages separately.

A guide to the applicability of the selected options comparison methods to situations at different stages of managing the contaminated land is shown in Table 4.5.

Table 4.5 ***Applicability of options comparison methods to situations at different stages of management***

Method	Development of an overall strategy	Determination of a remediation strategy
Direct evaluation	Very poor	OK
Non-compensatory	Poor	OK
Cost benefit analysis	Poor	Very good
Trade-off analysis	Very good	OK
Linear additive	Good	Good
Analytical hierarchy	Good	OK
Multiple criteria decision analysis	Good	OK

4.3.2 Available information

The characterisation of contaminated land and risk assessment stages that precede options comparison in the SAFEGROUNDS process (Elements 2, 11 and/or 15 of Figure 1.1), should generate sufficient information for options comparison, although there may be areas of uncertainty. These need to be identified so they can be considered in the options comparison process. Further information may be generated as the management of the contaminated land develops.

The maturity of the information describing the contaminated land can be considered to be:

- limited information, expert judgement
- a broad body of factual information
- specific information on the performance and cost characteristics of options.

It is noted that the maturity and detail of information needed is related to the stage in the contaminated land management process. For example, strategy development tends to deal with broad themes that do not necessarily rely on detailed information. By contrast, the selection of a remediation strategy option may require detailed specifications for options.

A guide to the applicability of the selected options comparison methods to situations with differing levels of available information is shown in Table 4.6.

4.3.3 Regulatory scrutiny

The basic principle of optimization of radiological protection, and the related concepts of ALARA and ALARP, requires options to be compared. Many regulatory regimes also specifically require a systematic options comparison. The SAFEGROUNDS guide on regulatory frameworks (Hill, 2007) describes the requirements and should be consulted.

Table 4.6 ***Applicability of options comparison methods to situations with differing levels of available information***

Method	Limited information	Generic factual information	Information on site-specific application
Direct evaluation	Very good	Very good	OK
Non-compensatory	OK	Good	OK
Cost benefit analysis	Very poor	Poor	Very good
Trade-off analysis	Good	Very good	OK
Linear additive	Poor	OK	Very good
Analytical hierarchy	Poor	OK	Very good
Multiple criteria decision analysis	Poor	Poor	Very good

Generally, regulatory requirements are not prescriptive. In many cases there is a requirement to apply the concept of best practicable environmental option (BPEO) or best practicable means (BPM). The concepts themselves are also not very prescriptive. Guidance on the application of BPEO and BPM has been published, although it is in relation to managing radioactive wastes (BPEO is discussed in a report by EA and SEPA (2004) and BPM in a report by SNIFFER (2005)). Although not aimed specifically at the management of contaminated land on nuclear-licensed and defence sites, these documents provide a useful guide to regulatory requirements, and reflect good practice.

Options studies are also a part of the corporate planning, as they provide a structured basis for determining the optimum management approach for contaminated land. In particular, decommissioning nuclear-licensed sites are required periodically to review elements of their plans that are relevant to the management of contaminated land, such as end state objectives, the lifetime plan and shorter time work plans.

Regulatory and corporate drivers can broadly be categorised as:

- routine corporate planning/review (strategic and/or work plans)
- periodic regulatory review of strategy or plans
- the need to make a formal submission to the regulator(s) in respect of a regulatory requirement, eg to demonstrate BPEO (EA and SEPA, 2004), BPM (SNIFFER, 2005), or ALARP (HSE, 2008).

A guide to applying selected options comparison methods to situations with differing levels of regulatory scrutiny is shown in Table 4.7.

Table 4.7 ***Applicability of options comparison methods to situations with differing levels of regulatory scrutiny****

Method	Corporate planning	Periodic review and development	Regulatory submission
Direct evaluation	Very good	Good	The appropriateness of a method depends on the scale and significance of the situation
Non-compensatory	Good	OK	
Cost benefit analysis	Good	Good	
Trade-off analysis	OK	Good	
Linear additive	OK	Good	
Analytical hierarchy	Poor	OK	
Multiple criteria decision analysis	Poor	OK	

Note: * This table does not imply regulatory acceptance of specific methods in specific circumstances.

4.4 Stakeholder interest

LMGv2 describes the extent to which stakeholders should be involved and notes that it will typically depend on the significance of the contaminated land situation (Chapter 1) and the stage in the contaminated land management process (Section 4.3). There may also be situation-specific factors that determine the level of interest. The topic is included here as an issue to be considered when selecting an options comparison method.

Stakeholders are likely to range from groups within the owner/operator, to regulators (who will apply regulatory requirements and policy), local stakeholders (with an interest in the local effect of options), and potentially national stakeholders (if the contaminated land situation is of national significance and/or may affect other sites). Figure 4.1 shows how the breadth of stakeholder interest can be broadly mapped to the stage in the management of the land and the scale of the contamination. However, while this diagram is illustrative of general trends, site specific circumstances should always be considered.

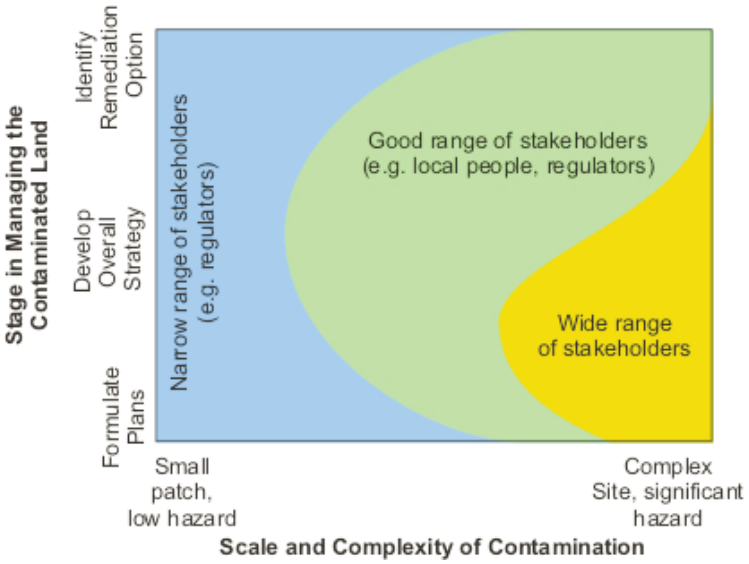


Figure 4.1 ***Illustration of potential breadth of stakeholder involvement, as a function of stage in managing the contamination, and significance of the contamination***

A guide to the applicability of the selected options comparison methods to situations with differing levels of stakeholder interest is shown in Table 4.8. It should be noted that while trade-off analysis, linear additive methods, analytical hierarchy and multiple criteria decision analysis are good at capturing a wide range of views, they can be difficult for the lay person to follow and care is needed to ensure that stakeholders are aided in the process.

Table 4.8 ***Applicability of options comparison methods to situations with differing levels of stakeholder interest***

Method	Narrow range: corporate and regulatory audience	Moderate range: local stakeholders and regulators	Wide range: national stakeholders, regulators etc
Direct evaluation	Good	Poor	Very poor
Non-compensatory	Good	OK	Poor
Cost benefit analysis	Good	Poor	Poor
Trade-off analysis	Good	Very good	Good
Linear additive	Good	Very good	Good
Analytical hierarchy	Poor	OK	Very good
Multiple criteria decision analysis	Poor	OK	Very good

4.5 Typical applications of options comparison methods

The suitability of an options comparison method for a given contaminated land situation depends on the extent to which it has the capability to permit an evaluation to the right level of detail and permit an appropriate level of stakeholder involvement. The choice can be informed by considering the status of the contaminated land, the significance of the contamination, and the extent of stakeholder interest. The discussion in Chapter 1 to 4.4 is intended to provide a guide as to where a particular situation may sit in relation to these aspects.

Different options comparison methods fulfil the potential requirements of the process to differing degrees, as shown in Table 4.9. In general, the most suitable is the one that best fulfils the requirements that are relevant to the particular situation.

Some broad conclusions about the applicability of the example methods can be drawn, as follows:

- direct evaluation is likely to be suitable in situations where there is limited stakeholder interest, and a quick and simple analysis is needed. It has the capability to consider quite a broad range of options or criteria, and outcomes can easily be explained. It is particularly suitable for initial scoping studies. It is also a robust method when one option clearly out-performs others. However, the method is not systematic and will not effectively distinguish between options that are closely matched
- non-compensatory methods have a similar range of applicability to direct evaluation. They offer a structured method of analysis and can be useful if criteria have natural thresholds of acceptability that the performance of options can be gauged against. However, as criteria are examined in sequence rather than

together, the approach risks generating an outcome that is not clearly optimized against all criteria. The method also does not easily incorporate stakeholder involvement

- cost benefit analysis is widely used by government and industry, but is primarily of use where criteria can easily and uncontroversially be expressed in monetary terms. Because of difficulties with justifying discount rates over long periods, options that are carried out over decades may not be analysed. So it is likely to be effective where technologies are defined and there is limited stakeholder interest. It is less suitable for use when options are broad and many of the important issues are difficult to quantify.

Table 4.9 ***Comparison of options comparison methods with potential requirements of the process***

	Direct evaluation	Non-compen-satory method	Cost-benefit analysis	Trade-off analysis	Linear additive	Analytical hierarchy	Multiple criteria decision analysis
Quick, simple	Very good	Very good	Poor	OK	OK	Poor	Poor
Permits detailed analysis	Poor	Poor	OK	Good	Good	Very good	Very good
Can be used for large or complex situations	Very poor	Poor	Poor	Very good	Good	Good	Good
Can be used with limited information	Very good	Very good	Very poor	Good	Poor	Poor	Poor
Can consider broad range of criteria	Good	Very good	Poor	Very good	OK	Very good	Good
Suited to numerical criteria	Poor	OK	Very good	OK	Very good	Very good	Good
Permits numerical analysis of sensitivity and uncertainty	Very poor	OK	Good	OK	Very good	Very good	Very good
Understandable by wide range of stakeholders	Very good	Good	OK	Good	Poor	Poor	Poor
Suited to a limited range of stakeholders	OK	OK	Good	Good	OK	Good	Very good
Allows wide stakeholder involvement	Poor	Poor	Poor	Very good	Good	OK	Very good

- trade-off analysis is quite broadly applicable and is particularly suitable in situations where a wide range of themes need to be considered for options. Stakeholder involvement is easy to incorporate. However, the options comparison stage should be undertaken carefully and is not as mathematically-based as the linear additive methods and its variants. While that means that the approach can better accommodate qualitative and quantitative criteria, it does not enable the method to yield an overall rating for each option
- the linear additive method is well established and widely used. It is systematic and mathematical and permits considerable opportunity for stakeholder involvement. It is suited to situations where a large number of quantitative criteria are considered, eg assessment of remediation options. Its main drawback is that criteria should be carefully defined, and over-emphasis on the aggregate weighted score can risk missing more subtle trade-offs between criteria. The elicitation of weights is also not

structured, opening the potential for weights to be assigned with an inconsistent basis

- the analytical hierarchy process is essentially the same as the linear additive method, but with a more sophisticated approach to eliciting weights. So the approach is particularly suited to situations where there is a need to ensure that weights are assigned in a consistent and representative manner. The process, however, requires help to elicit the weights, which means that a limited number of stakeholders can be directly involved in terms of weighting criteria. It is also not particularly transparent to non-specialists
- like the analytical hierarchy process, multiple criteria decision analysis provides a more systematic approach to determining weights, and requires working with groups of stakeholders to determine the weights. For this approach, the weights themselves are also more sophisticated, representing more than simply a relative preference for different criteria. It is arguably the approach most capable at representing stakeholders' values, but the process is involved, requires specialist help, and the outcomes require careful explanation. So the approach is most suited to particularly complex or important issues where there is the opportunity to work more intensively with small groups of stakeholders.

4.6 Incorporating stakeholder involvement

Whichever options comparison method is selected, it is necessary to consider methods for stakeholder involvement. Guidance on stakeholder involvement is presented in LMGv2 and the community stakeholder involvement document (Collier, 2005a). These documents provide the primary sources of information on this issue in SAFEGROUNDS, however, some specific considerations in relation to options comparison are included in this section.

Continuity and consistency with the whole process

Stakeholder involvement should run through the whole process of land management, and not be restricted to options comparison. So the approach adopted in the options comparison stage should be consistent with the broader approach. The planning for stakeholder involvement, recommended as part of the development of the land quality management strategy (Element 7 in Figure 1.1) should consider the needs for stakeholder involvement in options comparison.

Main areas for stakeholder involvement in options comparison

Whatever the extent of stakeholder involvement in a particular contaminated land situation, the stage that will involve the greatest degree of involvement is the final comparison of options. For more complex situations, stakeholder involvement in the determination of the problem specification, identification of options and selection of criteria may be appropriate.

Nature of stakeholder involvement

A stakeholder involvement plan will have been developed as part of the planning stage of the SAFEGROUNDS process and documented in the land quality management strategy (Element 7 in Figure 1.1). This will list the range of stakeholders with an interest and set out the proposed mode of involvement. The process should always open to stakeholders' involvement.

When stakeholder involvement in the determination of scope, identification of options and criteria can be undertaken by correspondence, the provision of high quality documentation is particularly essential. The emphasis needs to be on making documents clear, readable and succinct. Typically, at least one month is needed for such a form of consultation, and in some cases a statutory consultation period may apply. Written consultations should be addressed to existing lists of stakeholders, where they exist, and also publicised sufficiently widely (eg in local papers).

Workshops are most important in the options comparison stage. It is important to remember that this is not a vote-taking exercise, rather a means to find out the range of views, and clearly and openly identifying the main concerns. Simple situations of limited significance may not require a workshop, but some methods (analytical hierarchy process, multi criteria decision analysis) require a workshop to determine weightings properly. The workshop should nevertheless also be used to review other aspects of the options comparison study such as options and criteria.

Workshop attendees should reflect the range and mix of interests and care should be taken to obtain a balanced and open-ended range of participants. Stakeholders include all those who have an interest in the remediation of the site. It is important to consider capacity-building through local community outreach.

For workshop organisation, a variety of approaches can be taken and this guide does not seek to present detailed information on conducting workshops.

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Glossary

LMGv2 (Hill *et al*, 2009a) contains a glossary of all terms used in the suite of SAFEGROUNDS documents. Terms used in this guide, which are particularly relevant to the options comparison process, are presented in the table below. In the event that a term is unclear and is not defined below, the LMGv2 should be consulted.

Characterise	To investigate and describe properties and qualities, some of which may be distinctive.
Constraint	Any factor that limits the range of options that can be considered in the options comparison, and is outside the control of those with responsibility for making the decision about the management of the contaminated land. Financial issues should not be used as constraints unless all stakeholders agree.
Contaminated land	Any land on or under which there are radioactive or non-radioactive contaminants at levels above the natural and artificial background levels that are typical of where the site is located in the UK.
Context	A definition of the existing situation in which the decisions on the management of the contaminated land need to be taken. The context will include information about the contamination and its status, times, regulatory factors and stakeholders and any issues of particular importance.
Criterion	A property or measure of an option's performance that is relevant to the comparison of options. Criteria should be capable of being objectively quantified for all options under consideration (even if only with a simple scoring or ranking scheme). Criteria should also be unique and independent of one another and be defined at a similar level of detail. Criteria are sometimes referred to as attributes.
Decision making	The process of deciding which option should be used. A major input into decision making is a formal comparison of options. However, other factors may also play a role in determining which option is to be used.
Defence site	In this guidance, these include: non-nuclear sites that have been or are being used for defence activities and nuclear sites that are operated for MoD by contractors and that are licensed and regulated by HSE under the Nuclear Installations Act (nuclear-licensed sites).
Future use	The range of uses the contaminated land can be put to after the selected option has been successful. The range of future uses may be restricted to reduce the potential hazards associated with residual contamination. Alternatively, the site may be made available for any future use, in which case lower levels of residual concentrations of contaminants are likely to be required.
Hazard	A property or situation that in particular circumstances could lead to harm or pollution.

Key principle	A fundamental principle that should be adhered to during land management. Through consultation, SAFEGROUNDS has developed five key principles on the protection of people and the environment, stakeholder involvement, the identification of the preferred land management option, taking immediate action and record keeping.
Management of contaminated land	Aspects of taking of any actions to assess, characterise, control, monitor, remediate or remove (wholly or partially) legacy contamination in, on and under land and all the processes that lead up to decisions to take such actions to protect people and the environment, including, but not limited to, development of a conceptual model and undertaking a risk assessment and structured comparison of potential management options.
Non-radioactively contaminated land	Any land in, on or under which there are non-radioactive contaminants at levels above natural and artificial background levels that are typical of the area of the UK in which the site is located.
Nuclear-licensed site	Sites that are regulated by HSE under the provisions of the Nuclear Installations Act 1965 (as amended) with a nuclear-site licence. The Act applies to fixed sites for the purposes of constructing and operating nuclear reactors and other prescribed nuclear installations. The guidance applies to operating sites and those being decommissioned, whether or not they are to be delicensed.
Objectives	This is what management of contaminated land is intended to achieve. Objectives are set by considering factors such as government policy, corporate/organisational policy and the views of stakeholders. It is recommended that environment and health and safety objectives are established separately from those of a commercial and administrative nature.
Option	Any potential method of managing the contaminated land that is relevant to the objectives. Options can include, but may go further than, some or all of the actions defined as remediation in Part 2A of the Environmental Protection Act 1990. In evaluating options, consideration should always be given to doing nothing more to the contamination and to removing contamination to background levels while ensuring continued control of the existing situation.
Optimization	The form, scale and duration of the intervention (remedial action) that maximises the net benefit. The principle of optimization means that there is no predetermined end point for remediation that is applicable in all circumstances. In the extension to Part 2A, where a remediation scheme addresses significant pollutant linkages, some but not all of which relate to lasting exposure, any intervention should be optimized having regard to their benefit in respect of any remedial treatment actions relating to non-radioactive significant pollutant linkages. Within a radiation protection context optimization is an essential part, and in practice the most important part, of a system of dose limitation because reliance on dose limits is not

	enough to achieve an acceptable level of protection. Safety shall be optimized so that the size of individual doses, the number of people exposed and the likelihood of incurring exposures are all kept as low as reasonably achievable. Economic and social factors are taken into account, within the restriction that the doses to individuals delivered by the source are subject to dose constraints as defined in the Basic safety standards for protection against ionizing radiation and for the safety of radiation sources (Vienna, 1996).
Owner/operator	The organisation with responsibility for the site and any associated contaminated land. At nuclear-licensed sites the operator is the licensee. Owners/operators are responsible for taking final decisions to carry out the proposed option for land management.
Pathway	A route or means by which a contaminant can reach, or be made to affect, a receptor.
Preferred option	An option which, on the basis of the options comparison, represents the best balance of features to achieve the overall objectives for the management of the contaminated land.
Preferred strategy	The strategy that is identified by an owner/operator as their preferred one following a comprehensive, systematic and consultative assessment of potential strategies derived by considering the options for the various areas on a site.
Radioactively contaminated land	Any land in, on or under which there are radioactive contaminants at levels above the natural and artificial background levels that are typical of where the site is located in the UK. The phrase in, on or under includes soils, rocks groundwater and below ground structures but excludes authorised disposals of radioactive and non-radioactive wastes. These definitions are for the purposes of SAFEGROUNDS only. They have been chosen because they best reflect the views of stakeholders on the levels of contamination that the SAFEGROUNDS guidance should be concerned with. The term radioactively contaminated land also has a precise legal definition taken from the EPA 1990 Part 2A.
Score	A numerical value that reflects an option's performance in relation to a particular criterion. Scores should be assigned in a consistent and objective manner, where possible with reference to factual information. Scores can be assigned using an absolute (ie compared with a scale including ideal and unacceptable levels of performance) or relative (ie relative to the performance of other options) measure of performance. The latter approach is sometimes referred to as ranking.
Screening	The process of excluding options from detailed consideration. Screening is usually undertaken with reference to one or more screening criteria that represent basic expectations that should be met by any option. Screening criteria usually reflect the need for legality, technical feasibility, and a measure of proportionality between effort and benefits.
Site	A contiguous area of land on which contamination is known or suspected to be present. In most cases, a site will have a single owner/operator. Sites considered in this guidance are

	further classified as nuclear-licensed sites or defence sites.
Site characterisation	The process of gathering information about a site (or group of sites) and its setting(s) for the purposed of assessing and, where necessary, managing health and environmental risk. Guidance on site characterisation has been developed by SAFEGROUNDS.
Stakeholder	A person or organisation that has an interest in the management of the contaminated land. There are various groups of stakeholders: institutional stakeholders include the owner/operator, regulators, government departments and local authorities. External stakeholders are all those outside the owner/operator organisation. Those stakeholders involved in decisions on the management of contaminated land are participating stakeholders and may include local residents, CBOs and NGOs.
Weight	Weights can be applied to each criterion to reflect their relative importance when comparing options. Weights can be used to reflect stakeholders' views and values, and provide a method for reflecting them in the options comparison. If used, weights need to be systematically derived and justified. Several sets of weighting factors are often needed, so as to reflect the views of various stakeholders.

A1 Selected options comparison methods and their application to the management of contaminated land

A1.1 Introduction

Contaminated land situations can vary in their character and significance, so a range of methods for options comparison, which encompass different degrees of detail and stakeholder involvement, is needed. Although there is some existing guidance on specific methods for options comparison (Dodgson *et al,* 2000), this does not reflect the particular needs and issues to be considered when dealing with contaminated land.

A range of methods has been used in practice, reflecting points on a spectrum rather than distinct and greatly differing approaches. For example, most methods have adopted an approach based on systematic analysis of several separate criteria. Stakeholder input to the comparison of options has typically involves the elicitation of numerical weighting factors for criteria[11], although the incorporation of stakeholder input has been undertaken in a variety of ways depending on the particular needs of the given situation.

A central aim of the options comparison guide is to foster the use of appropriate methods for the comparison of options for managing contaminated land. This appendix presents a set of methods that are recommended for consideration. These range from the simple to the complex. The methods have been drawn from practical experience in options comparison for contaminated land, and a review of methods described in decision science literature (Karaback, 2007). Although the set of methods is illustrative of the spectrum of available approaches, it is not exclusive. Other methods can be used if they are appropriate to a given situation.

All methods follow the general stages in options comparison that have been discussed in the Chapter 3 of the main document. They differ primarily in the method by which options are compared, the information they require and the extent and nature of stakeholder involvement they incorporate. So this appendix describes each method in terms of:

- scope and level of detail
- information requirements
- opportunity for stakeholder involvement
- the main steps in the method (defining objectives, identifying options, determining assessment criteria, assessing the options and comparing the options).

Appendix A2 presents worked examples of the application of these methods.

11 The broader role of stakeholders (and processes for identification thereof) in defining objectives and strategic requirements for land management. Setting the context for options assessment is described in more detail elsewhere in this document, and in the LMG (Hill *et al*, 2007)

A1.2 Direct Evaluation

A1.2.1 Scope, applicability and level of detail

This method simply involves assigning descriptions of option performance for a limited number of criteria, and attempting to determine whether there is a clearly preferable option.

It is suitable for contaminated land situations that are of limited significance, limited complexity and limited interest to stakeholders. It may be suitable for patches with low levels of contamination that exist on a larger site.

It may also be suitable at the initial stages of deciding how to manage a contaminated land situation. The method can reduce a large number of potential options into a shortlist for more detailed assessment, by indicating any options that perform very poorly in respect of important criteria.

The method is unlikely to provide a robust basis for preferring an option if several rate similarly, or if there are trade-offs between criteria that require a carefully analysis. It is also unlikely to be suitable if there is a significant degree of stakeholder interest.

A1.2.2 Information requirements

The direct evaluation method involves the minimum level of analysis necessary to be consistent with the general approach to options comparison described in Chapter 3. So the method has limited information requirements. It involves making use of the available information on the contaminated land situation, supplemented with expert judgement. No specific data gathering would be anticipated and it could be undertaken as a simple desk study.

A1.2.3 Stakeholder involvement

The method is primarily applicable to contaminated land situations in which there is limited involvement of stakeholders beyond owners/operators, with the possible exception of regulators. However, it is adaptable and could incorporate a degree of non-statutory stakeholder involvement. If this is the case, it is important to ensure that stakeholders appreciate the reasons for an assessment of limited detail.

A1.2.4 Main steps in the process

Problem statement

The problem statement should include a summary of the objectives, context and scope of the options comparison. A brief description of the contaminated land being considered is also useful. Information would be expected to be available from the characterisation stage of the SAFEGROUNDS process described in the SAFEGROUNDS LMGv2 (Hill *et al*, 2009a).

Any existing objectives would be defined by the earlier planning stage of the SAFEGROUNDS process (described in the LMGv2) and other specific objectives, necessary to carry out the key principles, would also be defined at the planning stage. The problem statement should refer to these, but is concerned with the specific objectives for the options comparison process. As such, the objective might be to deal with a contaminated land situation of limited significance", or "initial framing of a contaminated land situation.

Constraints and assumptions should be identified and documented. These are likely to arise from the limited scope of the appraisal.

Identify options

For situations where this approach might be applied, the options for managing the contaminated land would be reasonably evident. They would be identified using existing knowledge and perhaps a limited amount of research. Each should be documented with a brief explanation.

If this approach is being applied to a contamination of limited significance, options could be screened according to practicability at this stage. If the approach is being applied as an initial framing of a more complicated situation it is advisable to retain a wide range of options and perform limited screening.

Assessment criteria

Consideration of a limited set of assessment criteria is commensurate with the level of detail of this method. The assessment criteria will be specific to the problem, but should include factors related to: health and safety, environmental impacts, technical issues (including waste management and waste minimisation), social and economic factors and costs. If relevant other criteria could be added (eg security).

Particular aspects of each criterion are drawn out and described in the options assessment stage. However, criteria such as health and safety and environmental criteria should be split into costs and benefits. This is because there are usually costs incurred to achieve benefits (eg an increase in the health and safety of the public requires work that has a potential detriment to the health and safety of workers).

Assess options

The options should be assessed by a small number of experts (a minimum of one assessor and one reviewer) using existing information, supplemented by expert judgement.

The assessment of the options takes the form of populating a matrix of options and criteria with a simple description of the performance of each option for each criterion. If scores are assigned for each combination of option and criterion they should be clearly based on the description. It may be reasonable to adopt rankings when assessing options, provided there is clear understanding of the range of performance for all options in respect of a given criterion.

Compare options

The options are compared by inspection of the matrix and the descriptions therein. A rationale for the preference of one or more particular options is then developed by determining the most appropriate balance of pros and cons across the criteria under consideration. The reasoning is then documented.

This stage of the process could permit stakeholder involvement. For example, the populated matrix could be made available to representative stakeholders, who could be asked to state a preference based on the available information, and describe the basis for the preference.

The outcome of the process should be recorded. This could be in a single document or paper.

A1.3 Non-compensatory methods

A1.3.1 Scope, applicability and level of detail

Non compensatory methods are simple structured analysis techniques that centre on examining, criterion by criterion, whether options meet a defined standard. However, while a range of criteria can be considered the methods do not permit compensation, ie for strong performance on one criterion to compensate for weak performance on another.

The methods are suitable for contaminated land situations that are of limited significance, limited complexity and limited interest to stakeholders. They are most likely to be applicable to patches of contaminated land, although they can also be useful as a tool for screening a large number of options under consideration in respect of a more significant contaminated land situation.

They provide a more systematic and standard-based assessment of options than direct evaluation, but do not permit compensation between criteria like the more detailed methods described in this appendix.

Non-compensatory methods are of most use if there are clear and agreed standards to be met with specific criteria. The methods are unlikely to provide a robust basis for preferring an option if several rate similarly, or if there are complicated trade-offs between criteria.

A1.3.2 Information requirements

These methods require limited information. They would often be applied by an individual (with suitable review) or a small team, using experience and any available information on the contaminated land situation. Information gathering would typically be limited, although it may be necessary in respect of the particular assessment criteria, especially if the associated standards are quite specific.

A1.3.3 Stakeholder involvement

These methods are primarily applicable to situations where there is limited stakeholder involvement beyond owners/operators and, potentially, regulators. They could incorporate a degree of non-statutory stakeholder involvement if required, however the options assessment and comparison stage would need to be repeated with each group of stakeholders.

A1.3.4 Main steps in the processes

Problem statement

This stage in the process is essentially identical to that applied for the direct evaluation method.

Identify options

This stage in the process is essentially identical to that applied for the direct evaluation method.

Assessment criteria

These methods require a list of more specific criteria than the direct evaluation method. Also, a performance standard or level of expectation needs to be defined for each criterion. A large number of criteria can be adopted if needed. Although this will require more effort, the greater the number of criteria that are considered, the more likely it is that a single preferred option can be identified (as the only option to satisfy all criteria). Note that criteria can be quite varied in nature because they are examined sequentially rather than as a set.

There are no specific rules for the selection of criteria, although the basis for selecting each needs to be documented and explained. If stakeholders are involved in the process, it would be of benefit to obtain their views on the assessment criteria at this stage.

Assess and compare options using elimination by aspects

The best known non-compensatory method is elimination by aspects. In this method, criteria are first ranked according to their expected ability to exclude options (ie the criterion with the most demanding standard is taken first). The options are then examined, criterion by criterion, in each case excluding those that do not meet the relevant standard. The process continues until either a single option remains, or all criteria have been applied. If the latter, the list of criteria and associated standards can be reviewed, adding new criteria or tightening the standards. Alternatively, the remaining list of options can be taken into the decision making process as a set.

Assess and compare options using lexographic ordering

With the lexicographic ordering method, first it is necessary to prioritise the criteria for importance. This should be undertaken in consultation with stakeholders, if they are involved in the process. The options are then compared for the most important criterion. If there exists a single option that performs better than others then it is chosen, otherwise the process proceeds to the next most important criterion and so on until one option clearly outperforms the remaining options.

A1.4 Cost-benefit analysis

A1.4.1 Scope, applicability and level of detail

Cost-benefit analysis (CBA) aims to value the expected effects of an option in terms of the direct relationship between costs and benefits. Benefits are evaluated in terms of people's willingness to pay for them, and cost in terms of willingness to pay to avoid them. The method is widely used in business as at its centre is a clear monetary evaluation of the various aspects of a given issue. It can be applied at a range of levels of detail, although it requires a basic standard of information to express important criteria in financial terms. For sites that are likely to have a remediation strategy operating over ten years or more, a major issue is the appropriate choice of discount rates for benefits and costs that do not arise until later stages of the programme.

Its applicability to the management of contaminated land is hindered because in many

situations the main criteria are difficult or impossible to value definitively in monetary terms. Environmental and social factors can, in particular, be problematic to place a value on. Monetary valuations of radiological effect on human health have a track record of use in relation to judgments on worker and public safety (including in radiation protection). However, these have typically been used in relation to technical design and maintenance problems that have limited external social and environmental effects. Discussion on monetary valuation of environmental effects can be found in Eyre (1998).

For these reasons, the approach is unlikely to be well suited to strategic decision making. However, CBA can be an effective tool if the dominant factors are related to costs, as may be the case when considering a specific range of technologies for use.

A1.4.2 Information requirements

The approach has significant information requirements, as it is fundamentally quantitative in nature. However, the nature of the method means that the focus is likely to be on quantifiable criteria. Examples of factors likely to be considered include direct monetary costs (equipment hire/purchase, manpower, consumables etc), secondary effects (eg costs arising from inconvenience when enforcing the option to other site operations), waste management costs (primarily associated with the disposal of waste), and costs associated with worker radiation exposure and other hazards. Benefits will include the potential realisation of the land as an asset, reduction in radiological risks, and increase in amenity.

A1.4.3 Stakeholder involvement

While it is possible to involve stakeholders, the method is most suitable for situations of limited significance, limited complexity, and limited interest for non-statutory stakeholder involvement. The description that follows assumes a typical application in which the assessment is undertaken primarily by technical specialists. Should stakeholder involvement feature, the most appropriate form of involvement would be elicitation of valuations for important criteria.

A1.4.4 Main steps in the process

Problem statement

The problem statement should include a summary of the objectives, context and scope of the options comparison and a brief description of the contaminated land being considered. Overall objectives would be defined in the earlier planning stage of the SAFEGROUNDS process, described in LMGv2 (Hill *et al*, 2009a).

It is also necessary to define the specific task to be addressed by the CBA study. This may involve describing what needs to be done, when, where and possibly how. It is also useful to recognise the overall significance of the issue and the level of effort should be devoted to the CBA study. Given the monetary basis of the assessment, any relevant financial aspects (in particular any constraints) would need to be clearly defined. The organisations or groups most affected by costs and benefits should be determined. A related issue is the timing that costs and benefits would be realised.

Finally, it is advisable to define the specific analysis method to be used from the start: benefit-cost ratio, net present value, cost-effectiveness or some combination of these. These methods, and their applicability to considering options for the management of

contaminated land, are discussed in more detail below.

Identify options

CBA is often applied by considering a base case and a range of alternative options. The base case is usually selected to represent the existing situation and expected future conditions if no action is taken other than ensuring continued control of the existing situation; it is the do nothing option. Even if a strategy exists for the management of the contaminated land that negates a do nothing base case, it can still be used as an effective point of reference for other options that are consistent with the strategy. Alternatively, a base case that represents the minimal effort consistent with the requirements and objectives can be used.

Alternatives (ie options) are then identified that are capable of fulfilling the objectives and requirements defined in the problem statement. As CBA is a method most suitable for quite narrow technology selection problems, in most cases these requirements would be quite specific. For example, target concentrations of radionuclides in soil and groundwater would be expected to be an important factor. The identification of options can consider the capabilities of technologies, to remediate to such levels. All those with potential would be selected for consideration, with their other features being assessed in the options comparison stage.

Both the base case and alternatives should be described in a level of detail consistent with the scope and scale of the contaminated land situation. There should be care to ensure that all requirements for the full use of each option (activities such as enabling works, waste management actions etc) are identified so they can be captured in the monetary evaluation.

Assessment criteria

Like other multi criteria methods, a range of criteria are considered that represent factors of importance to the contaminated land situation. CBA attempts to value each of the factors linked to the criteria via the common currency of monetary cost or benefit. In principle the assessment can consider a large number of criteria, although the range and detail will be determined by the scope of the assessment.

The main constraint on the range of criteria that can be considered is their amenability to representation in monetary terms. In principle, a wide range of factors can be represented by using valuations that are based on the willingness to pay. However, problems are commonly encountered in relation to valuing social and environmental effects. For this reason, the application of CBA by the UK Government has evolved to more explicitly encompass non-monetary components related to environmental effects (DfT, 2007).

However many technical aspects can be considered in terms of cost, and adopted as criteria. Guidance has been developed on the valuation of radiological effects on health (NRPB, 1986 and DfT, 2006).

Assess options

The assessment of options is undertaken by establishing a valuation of each combination of criterion and option. Many valuation techniques arise in cost-benefit analysis and have been documented in the literature. Practical experience is also very valuable, especially in relation to criteria that are specific to contaminated land, such as

waste management costs and techniques for valuing radiological impacts.

Technical factors will generally be amenable to valuation and, if technologies are under consideration, are available from suppliers. Failing this, owner/operators are likely to possess experience that will permit reasonable valuation estimates for the technical aspects of the options.

As noted, social and environmental effects are more difficult to value. There is an extensive, though by no means conclusive, literature on the valuation of such criteria, although this is generally related to large infrastructure projects (primarily transport). The most widely applied methods are:

- the use of observed price information (eg house prices)
- the contrasting stated preference method.

The latter considers a direct individual (rather than market) valuation of impacts. This involves asking individuals about their willingness to pay, or willingness to accept compensation, for changes in the environment. In the context of contaminated land management, the latter approach is preferable, but this clearly requires substantially greater stakeholder involvement. In its absence, information on valuations by the general public may be available through other projects or in relation to other sites or facilities. For example, compensation funds have been established for radioactive waste repositories (including the LLWR in Cumbria).

In practice it is unlikely to be possible to value all the costs and benefits of options in monetary terms, and so most CBA studies will explicitly recognise items that are not possible to value within the scope of the study. These can then be set alongside those examined in the CBA and included in the later decision process.

Compare options

The preferred option typically provides the best balance of benefits and costs. The typical methods for evaluating the balance of costs and benefits are:

- benefit-cost ratio: the total discounted[12] benefits are divided by the total discounted costs. Projects with a benefit-cost ratio greater than one have greater benefits than costs. The higher the ratio, the greater the benefits relative to the costs. However, a simple benefit-cost ratio is insensitive to the size of net benefits and can favour options with small costs and benefits over those with larger costs but also larger benefits
- net present value: the total discounted costs are subtracted from the total discounted benefits. The greater the net benefits (or the lower the net costs), the more financially attractive the option. Other considerations, such as the scale of investment required, should also be considered
- cost-effectiveness: if a given amount of money is available, the discounted benefits that can be achieved with that amount of money can be compared. On the other hand, if a given objective is desired, the discounted costs required to achieve that objective can be compared.

12 *Discounting* is the process of finding the present value of an amount of cash that is to be spent at some future date. Further details of discounting can be found in HM Treasury (2003).

Typically, a cost-effectiveness analysis is likely to be suitable for assessing technology options for the management of contaminated land. It can be used even if the benefits cannot be valued in monetary terms and are instead expressed as requirements for the technology options (eg as clean-up levels). However, such an approach requires an outcome to be defined and is most applicable to comparing technologies for achieving a specific end state. If CBA is to be applied where significantly differing end states can be contemplated (ie at a more strategic level), the benefit-cost ratio and net present value are likely to be more relevant. However, as previously noted, there are likely to be problems with valuing the benefits of options. Government guidance on value for money (eg from the DfT, 2006) provides useful information.

Established approaches that are unlikely to be suitable for application to contaminated land situations include the internal rate of return (which gives a measure of the discount rate required for costs to equal benefits) and the payback period (the time it takes for the benefits to become equal to the costs).

These methods typically evaluate discounted costs, on the basis that this provides an accurate measure of true cost over a period of time. Care should be taken when selecting the discount rate (although government guidance is available), and it can often be informative to also undertake the evaluation with a discount rate of zero to give context to the actual costs.

Finally, it is noted that these approaches do not permit significant stakeholder participation in the comparison of options, which is essentially a mathematical exercise. Nevertheless, it is well understood that there is usually a need to reconcile the outcome of a CBA-based comparison with those factors that cannot be valued with confidence and are not included in the analysis. There is clearly opportunity for effective stakeholder involvement in this reconciliation stage before decision making.

A1.5 Trade-off analysis

A1.5.1 Scope, applicability and level of detail

This approach places emphasis on the development of options and to consider a relatively wide range of criteria, followed by identifying the main pros and cons and investigation of trade-offs. It can be most effective when used to determine important issues and differences in view rather than seeking to identify a preferred option. It has many similarities with the linear additive method described in the following section, but involves a broader consideration of each criterion rather than the aggregation approach used in the linear additive method. It differs from CBA by permitting more flexibility in criteria, and does not use a single measure of performance. However, it does involve rating performance on scales that permit compensation between criteria.

The approach is best suited to the determination of strategies for large areas of contaminated land or whole sites. In these situations, a wide range of criteria need to be considered at an early stage of deciding how to manage the contaminated land. It also allows for considerable stakeholder involvement.

The approach is very flexible and can be applied to more specific contaminated land situations, however it may be found to be insufficiently quantitative for problems involving detailed technology choices. Also, any risks and important uncertainties should be identified from the start. If issues of concern are identified during the process it may be necessary to change or modify the assessment to accommodate them.

A1.5.2 Information requirements

As trade-off analysis is primarily applicable to the consideration of strategic options, this method been developed not to require large amounts of detailed information to substantiate the assessment of contaminated land options. However, it can involve a considerable degree of care in the problem specification and definition of options and criteria so as to ensure that the study is sufficiently comprehensive in scope.

Relevant information is likely to have been generated in earlier stages in the SAFEGROUNDS process. This could be supplemented with existing information gathered by the owner/operator. Much of the information required for this approach can come from expert knowledge, perhaps gained through workshops. It may also be necessary to develop a briefing pack for stakeholders, which gathers information from specific studies undertaken to support the process.

A1.5.3 Stakeholder involvement

The method is flexible enough to permit stakeholder involvement at many stages – problem specification, determination of options and criteria, and comparison of options. Detailed methods for stakeholder involvement are not described here, but see Collier (2005a) *Community stakeholder involvement* for more details. Broadly stakeholder views can be gained through workshops and other consultation processes.

A1.5.4 Main steps in the process

Problem specification

A summary of the objectives, context and scope of the assessment is needed, with a description of the site or area of contaminated land being considered. Objectives defined at the planning stage of the SAFEGROUNDS process (described in LMGv2) are likely to be important if this approach is being used to determine an overall strategy for a site. If it is being applied to a more specific problem (eg determination of a particular technology), extra objectives may be needed to focus the assessment, which will probably be more practical.

Whether the approach is applied at a strategic or more specific level, it is important to consider carefully any constraints and assumptions to define the appropriate scope of the options comparison study. This will also inform stakeholders of the scope of the analysis and clarify any issues that are considered to be outside the scope of the appraisal, eg dependencies on national facilities for radioactive waste management.

If the assessment is intended to be just one stage of an iterative process to determine the management of the contaminated land, the sequence of stages should be clearly described.

Identify options

If the approach is being used to develop a contaminated land management strategy the options may be broadly defined. Indeed, it is possible that distinct and discrete options cannot be identified, in which case it is necessary to select representative strategies from the spectrum of choices. Care is needed when developing the options, and consideration should be given to the best manner of expressing them, for example objectives, time or actions. Clear descriptions are essential, perhaps making use of storyboards or visualisations to illustrate the strategy.

If the assessment is focused at technology identification, the problem statement will enable more specific options to be identified. It may be appropriate to use the problem statement to screen a generic list of technology options and then develop a more detailed description of the screened list.

While the options identification process is likely to be most appropriately led by the owner/operators (most familiar with the contaminated land situation), it is important that there is consensus that the identified options are sufficiently comprehensive and encompass stakeholder aspirations. For this reason, stakeholder feedback on the options should be sought, if possible before the options assessment stage.

Assessment criteria

This approach is orientated towards an appraisal of options in broad terms, so a broad suite of assessment criteria is typically considered. Social and economic factors will be important, but should not be over emphasised in respect of other criteria. However, it is likely that if the emphasis is on determining a strategy then technical issues would not be considered in great detail. If the emphasis is on the identification of a specific contaminated land management solution, however, more detailed consideration of technical factors would be likely.

The number of criteria that can be considered could perhaps reach 20 or so, and should, as far as possible, be defined at a similar level of detail across the criterion groups. This is important to ensure that the assessment and comparison stages do not include an implicit bias because a particular criterion is broader or narrower in scope than others.

Some description of the criteria will be needed to ensure that they are clearly understood. If possible, this should also include an indication of targets or expectations in performance, where these can be defined.

Assess options

The method of scoring is an important aspect of this method. For it to be accessible to non-technical specialists, yet still capable of capturing the performance of a range of options, using a standardised numerical (eg 1–10) or literal (very poor to very good) scale is most appropriate. The scores assigned using the scale should provide a shorthand to a more detailed description of the performance of the option.

The choice of scale is important as it indicates the level of certainty associated with the scores of the assessment. A coarse scale is appropriate if there is a significant degree of uncertainty in some aspects of options performance. A finer scale may be merited if the assessment is considering specific technical options, and may be required to distinguish large differences in performance of options and also allows non-linearity.

The options will typically be assessed by a small number of experts using existing information, supplemented by expert judgement. The outcome of the assessment would be assigned scores, each with an accompanying detailed description of option performance.

Compare options

An important feature of this method is that while a numerical or semi-numerical assessment is made of options performance, the analysis stage does not centre on the aggregation of scores across a range of criteria, but instead seeks to undertake a broad

assessment of the trade-offs between pros and cons. In this respect, it represents an intermediate point between direct evaluation and linear additive method.

As noted, a significant degree of stakeholder involvement is a main feature of this approach. In particular, an indication of the relative importance of criteria from stakeholders should be sought. The most convenient approach is to seek views in terms of numerical weights for each criterion (eg on a scale of 0–100), but preferences can also be stated more qualitatively (eg a simple hierarchy of criteria reflecting a view on their importance).

The scores are initially examined to determine which criteria are capable of distinguishing between contaminated land management options, and in particular where large differences in the performance of options lie. Following this analysis, stakeholder weights can be examined for the discriminating criteria to determine the options that perform relatively well or poorly. The outcome of the comparison is an indication of where the most important pros and cons lie. The characteristic pros and cons of each option can then be discussed with stakeholders and explored to determine the balance that best satisfies their views.

As the approach may incorporate numerical scores, further mathematical analysis can often be performed if required. For example, more perspective can be gained by applying the linear additive method using the scores and weights that have been gathered. This can add perspective to the evaluation of pros and cons with stakeholders.

At the conclusion of the analysis, the comparison of options needs to be documented alongside a description of the scope, options, criteria and assessment. Because the process of comparing options in this method relies on a substantial amount of qualitative assessment, it is likely that the rationale for the preferred option will need careful explanation. This can involve examining main themes, such as preferred criteria and how the options relate to them. While there is less of a numerical basis for the preference, there is greater freedom to express a more complex set of motivating factors.

A1.6 Linear additive method

A1.6.1 Scope, applicability and level of detail

The linear additive method is a systematic multi criteria technique in which a numerical approach is taken to comparing options. It comprises the same elements as trade-off analysis but differs by introducing a numerical approach to determining the overall performance of an option, rather than examining specific pros and cons. The method has clear similarities with CBA, but enables a greater range of criteria to be included by introducing a generalised numerical scale of performance in place of monetary valuations. It also enables stakeholder valuation of criteria to be expressed more directly than in CBA, permitting weights to be applied to criteria.

Theoretically, this method can permit a substantial number of options and criteria to be evaluated, as the approach involves aggregating weighted scores so a single measure of performance can be determined for each option. However, in practice it can be difficult to construct a large performance matrix and ensure that scores are assigned consistently.

As the approach is essentially numerical it is generally most applicable where scores can

be assigned with a degree of precision. It is also a prerequisite that performance against different criteria can be sensibly summed (once weighted). The method is most suitable for application to technology selection for contaminated land management, in which specific options can be determined and compared using tangible criteria. It can be applied to more strategic questions, however the level of uncertainty likely to be associated with strategic options may well mean that the resulting weighted aggregate scores need to be treated with care. No clear preference emerges from the analysis.

A1.6.2 Information requirements

This method requires a considerable degree of confidence in the assigned scores (although the outcome of the assessment may not be sensitive to the scores for some criteria). The scores can be based on any reasonable measure of performance for a criterion that is common to all options, but quantitative information (eg time or the total amount of contaminated effluent arising from the process) is always preferable. Factual information, describing the performance of options in terms relevant to the identified criteria, is valuable. Given that this method is most suited to the evaluation of technology options for specific contaminated land management requirements, such information can generally be obtained, often from suppliers or published literature.

Some criteria are inherently difficult to quantify, and a degree of expert judgement in the analysis may well be necessary. However, provided such information is clearly identified and explained, it can be incorporated into the analysis.

A1.6.3 Stakeholder involvement

The method can involve stakeholders at several stages – definition of scope, determination of options and criteria, and comparison of options. However, the main opportunity for stakeholders to provide input into the options comparison is by weighting criteria during the options comparison process.

Detailed methods for stakeholder involvement are not described here (for more details see Collier, 2005a), however, stakeholder views can be gained through workshops and other consultation processes.

A1.6.4 Main steps in the process

Problem specification

A summary of the objectives, context and scope of the assessment is needed, with and a description of the site or area of contaminated land being considered. Objectives defined at the planning stage of the SAFEGROUNDS process (described in LMGv2) are likely to provide an overall context when this approach is applied to identify a technology solution. More specific objectives will be needed, and can be defined with reference to strategic objectives and any other requirements (eg from regulators).

As this approach is most suited to the appraisal of technical options or usage there should be fewer specific assumptions and constraints to consider, with most being defined with reference to overall strategy for the management of contamination on the site. However, extra practical objectives or constraints may be introduced at this stage, for example to ensure an option can be used in practice.

Identify options

As this approach is most suited to an assessment of technologies the range of options to be assessed would typically be constrained by the requirements of the overarching strategy. SAFEGROUNDS has produced a list of technology options that provides a useful starting point (Mallett, 2004) and other compilations of options are available (for example <www.safegrounds.com/>). However, these would need to be screened for relevance to the specific contaminated land situation under consideration. But a clear list of distinct options can be established with reference to experience, with due regard for any emerging technologies.

If the approach is being used to determine the strategy for a whole site, it will be necessary to identify broader options, perhaps with a degree of overlap between them. These could be determined in the same manner as the options for the trade-off analysis method.

The list of options may be relatively uncontroversial in most applications of this method, although confidence in the completeness of the list could be improved by, for example, independent review. As this method is most suited to technologies for contaminated land management, it is unlikely that non-technical stakeholders can offer extra options, although it is sensible to keep them informed of the options that have been identified, and request comments.

Assessment criteria

The linear additive method requires a considerable degree of care in formulating the list of assessment criteria. While in principle the process of weighting options should remove any bias resulting from a poorly constructed set of criteria, it is best avoided from the start. So particular care should be taken to ensure that criteria are unique and defined at a similar level of detail. Because the analysis stage of this method involves the aggregation of criteria, it can, in theory, accommodate large numbers of criteria. However note that the greater the number of criteria considered, the less influential each is in determining the aggregated weighted score, and so a greater range in the value of weighting factors may need to be considered.

To ensure a consistent basis for scoring options, basic measures of performance should be defined for criteria (most usefully, a definition of what would be regarded as almost completely unacceptable, and completely acceptable).

Assess options

The linear additive method is most reliable when the set of criteria is well defined and the scores assigned to options are consistent and stable. As noted, this means it is most suited to quantifiable criteria, such as the volume of solid waste arising. The preference is to assign scores on the basis of factual information where possible, compensating for areas in which information is lacking by using expert judgement with well documented justification.

A consistent scoring method is needed, in which scores for each criteria are normalised to a common scale. To preserve the greatest amount of information, it is recommended that an absolute scoring approach be adopted. Other approaches – in particular ranking – have the potential to provide misleading results. For example, a particular criterion may be very highly weighted, yet all options perform similarly. If a ranking approach is adopted, some options will be inappropriately penalised.

While it may be that much of the scoring is based on factual information, it is nevertheless important to review scores and ensure their validity. It may be suitable to convene a workshop in which a range of experts review the scores and suggest scores in situations where expert judgement is required.

Compare options

The majority of the linear additive method is similar to trade-off analysis, but the options comparison process differs considerably. In trade-off analysis, the approach focuses on identifying and exploring the pros and cons of particular options, but there is no attempt to define an overall measure of performance across all criteria. Linear additive method applies stakeholder-assigned weights directly to scores, which are then aggregated to give an overall measure of an option's performance across all criteria.

The options comparison process is centred on the elicitation of a set of weights from stakeholders. These can be obtained in a variety of ways, but the result will either be sets of weights assigned by individuals or sets assigned by groups.

This approach is conceptually appealing and robust, provided that scores are reliable and the criteria and weights are genuinely representative of stakeholders underlying values. This can be challenging to achieve where large numbers of criteria are considered, so it may be necessary to weight groups of criteria (eg all those related to health and safety issues). However, it is challenging to develop an ideal performance matrix and there is always a possibility of residual bias. Also, it may not be clear to stakeholders what weights are appropriate in the context of the assessment (eg simple linear weighting method may not necessarily reflect their views).

One way of helping to give clarity to the weighting process can be to provide participants with guidance on how to determine the weights, rather than just to ask for a number on a scale of 0–100. It is very important that weights are elicited appropriately. The objective of the weighting process is to determine the relative importance of an increment in score across all the attributes (there is more discussion of this issue in Dodgson *et al* (2000) and other texts on multi-attribute methods). For example, it might be recommended that the stakeholder first identifies the most important criterion (or criteria, if more than one is equally important). These can be assigned the top weight, say 100. Then, the remaining criteria are considered and in each case, the question to be asked is: how many times less important is this criterion than the most important one?. If it is half as important, a weight of 50 is assigned, and so on.

The weights are then applied to each criterion to determine an aggregated weighted score for each option. For example for option i, the aggregate weighted score S_i is:

$$S_i = \sum_{j=1}^{n} w_j \, s_{ij}$$

where w_j is the weight for criterion j and s_{ij} is the score for option i and criterion j.

The aggregate weighted scores for each option can then be compared, with the highest indicating the best weighted performance for the given set of weights. Care should be exercised, however, as experience often indicates that differences between aggregate weighted scores for different options can be marginal, especially if a substantial number of criteria are considered, many of which do not significantly discriminate between options.

Many software applications that incorporate this basic method permit sensitivity analysis to be undertaken in which the robustness of a top scoring option can be examined in terms of the weights applied.

A1.7 Analytical hierarchy process

A1.7.1 Scope, applicability and level of detail

The analytical hierarchy process has the same basic structure as the linear additive method but provides an alternative approach to determining weights. It focuses on determining the relative importance of weights in a more systematic way than simply eliciting a preference and trusting that the response is genuinely representative of the underlying views.

As a numerical approach, which provides a performance rating that is an aggregated measure of performance for a range of criteria, the approach has similar applicability to the linear additive method. It is primarily suitable for the comparison of distinct and well defined options, such as particular technological solutions that are being considered for a contaminated land management strategy on a specific part of a site. Like the linear additive method, problems can be experienced if the options under consideration are broadly defined and may overlap, such as when developing a contaminated land management strategy for a whole site.

The process is included here because it provides a more structured way of determining weights than the linear additive method, which can provide greater confidence in the resulting sets of weighting factors. This may prove important if there is significant stakeholder interest in the contaminated land situation. The main drawback of this method is that it can be time consuming to apply with large numbers of criteria.

A1.7.2 Information requirements

The information requirements in respect of scope, options, criteria and scores are very similar to those described for the linear additive method. The extra information gathered that is specific to this method is concerned with preferences for criteria, and would be obtained from stakeholders.

A1.7.3 Stakeholder involvement

The main opportunities and forms of stakeholder involvement are similar to those described for linear additive method. The main difference is that this approach uses an alternative approach to eliciting weights. This process is likely to require facilitation, and so the method to involve stakeholders would primarily be through workshops.

A1.7.4 Main steps in the process

Problem specification

This stage in the process is essentially identical to that applied for the linear additive method.

Identify options

This stage in the process is essentially identical to that applied for the linear additive method.

Assessment criteria

This stage in the process is essentially identical to that applied for the linear additive method.

Assess options

This stage in the process is essentially identical to that applied for the linear additive method.

Compare options

During the comparison of options, the analytical hierarchy process requires those taking part to explicitly compare each criterion with every other to assign the weights. The value in this approach is that it helps to ensure that weights are determined more consistently.

The process involves comparing each pair of criteria, and assigning a numerical preference, indicating which criterion is more important. Typically, a nine point scale is used:

- Criterion A and Criterion B are equally important: score 1
- Criterion A moderately more important than Criterion B: score 3
- Criterion A strongly more important than Criterion B: score 5
- Criterion A very strongly more important than Criterion B: score 7
- Criterion A overwhelmingly more important than Criterion B: score 9

If Criterion B is more important than A, the reciprocal of the score is used (ie if Criterion B is overwhelmingly more important than Criterion A, score 1/9). Each pair of criteria is compared until a matrix is of preferences populated. An example is shown in Table A1.1.

Table A1.1 ***Illustration of a matrix of criterion preferences developed with the analytical hierarchy process***

	Health and safety	Environment	Technical	Social and economic	Cost
Health and safety	1	3	5	1	9
Environment	1/3	1	5	1/5	7
Technical	1/5	1/5	1	1/3	3
Social and economic	1	5	3	1	9
Cost	1/9	1/7	1/3	1/9	1

Weights are computed by calculating the geometric mean of each row, then normalising the geometric means. In Table A1.1, the weights are calculated as:

- health and safety 0.37
- environment 0.16
- technical 0.07
- social and economic 0.37
- cost 0.03

For this hypothetical example, health and safety and social and economic criteria are assigned the highest weights, but cost the lowest. The resultant weights (any number of sets may be developed) can then be applied to determine aggregated weighted scores in the same manner as the linear additive model.

A1.8 Multiple criteria decision analysis

A1.8.1 Scope, applicability and level of detail

Multiple criteria decision analysis is based on the linear additive method, but, like the analytical hierarchy process, involves a more structured approach to weighting, referred to as swing weighting. Multiple criteria decision analysis differs from the analytical hierarchy process by taking account of the potential for a criterion to actually discriminate between options when weights are assigned. For example, if all options are assessed to perform similarly in respect to worker safety, although the criterion might be important as an issue, it would not warrant a high swing weight because all options are essentially satisfactory. So a swing weight both reflects the overall weight, or importance, of the criterion, the range in the performance of different options against the criterion, and how much the difference matters.

This method is applicable to a broad range of contaminated land situations. It requires significant resources and is most likely to be relevant to whole sites or very significant areas of contaminated land. Typically, it would be applied in situations where the scope of the problem is reasonably well defined and it has been established that a thorough assessment of option performance is warranted, with substantial stakeholder involvement.

A1.8.2 Information requirements

The information requirements in respect of scope, options, criteria and scores are very similar to those described for the linear additive method. The extra information that is required for this method is concerned with the definition of swing weights. This would be obtained from stakeholders.

A1.8.3 Stakeholder involvement

The main opportunities and forms of stakeholder involvement are similar to those described for the linear additive method. The main difference is that this approach involves an alternative method of weighting. The elicitation of swing weights requires facilitation, and stakeholder involvement at this point would need to be primarily via workshops.

A1.8.4 Main steps in the process

Define objectives and scope

This stage in the process is essentially identical to that applied for the linear additive method.

Identify options

This stage in the process is essentially identical to that applied for the linear additive method.

Assessment criteria

This stage in the process is essentially identical to that applied for the linear additive method.

Assess options

This stage in the process is essentially identical to that applied for the linear additive method.

Comparing options

Multi criteria decision analysis centres on determining the importance of the range of option performance for a given criterion, and how much the range matters compared with other criteria. The swing weight reflects the difference between measured performance and the value of that performance to the stakeholder.

For example, for a given criterion, an improvement in performance may be real but not necessarily useful or much valued: an improving performance may not contribute a corresponding increment in added value. Such a criterion would be assigned a low swing weight. For a different criterion there might be a smaller difference in performance but which carries a lot of value to the person or group assigning the weight. This case would be assigned a larger swing weight. So, a criterion that is widely seen as very important (eg public health) could have a similar or lower swing weight than a low priority criterion (eg time) if all options had insignificant risks to the public but took widely varying times to apply.

The derivation of swing weights is a process that requires expert assistance. Generally, the procedure would be as follows (Dodgson *et al*, 2000):

The criterion with the biggest swing in preference is identified and assigned the top weight (say 100). This is referred to as the reference criterion. If there are many criteria being considered the most important might not be evident. It would then be necessary to use a paired-comparison process, comparing criteria two at a time and retaining the one with the bigger swing to be compared with the next criterion. The criterion emerging from this process is the reference criterion.

Any other criterion is then chosen and participants are asked to write down, without discussion, a weight that reflects their view of the significance of its swing in preference compared to that of the reference criterion. For example, if the criterion is judged to represent one tenth the swing in value as that of the reference criterion, it should be assigned a weight of 10.

Participants reveal their judged weights, which are discussed and a consensus on the weight is determined.

Any numbers can be used as swing weights so long as their ratios consistently represent the ratios of the valuation of the differences in preference between the top and bottom scores (whether 100 and 0 or other numbers) of the scale being used.

An alternative approach is to use a two stage assisted process to identify separately the swing and the weight. This can help simplify swing weighting approaches for assessments involving a wide variety of different scales for criterion assessment. Relevant stages are then as follows:

- specialists identify how important the scales used for each criterion are, relative to one another. Scoring scales can then be renormalised for the swing, irrespective of criterion importance. Often, this will be done by the same specialists that undertook the initial scoring
- weighting is then undertaken by stakeholders, in a manner consistent with methodologies previously outlined above, but focusing on the relative importance of the criteria.

The advantage of this latter method is that it allows stakeholders to express their raw preference for the weighting of criteria without having to consider at the same time the detailed implications of the range of, and approach to, option scores against different criterion. This is because the renormalised scoring scales for criteria carry with them the information on the swing during this process.

In either case, the resultant swing weights can then be applied in the same manner as the linear additive model.

A2 Worked examples

This appendix presents worked examples for the application of the options comparison methods described in Appendix A1. The worked examples consider hypothetical and stylised situations that are intended only to provide a basis for illustrating the method. The examples concentrate on showing the main themes of each method, in particular showing the options assessment and comparison stages.

The examples do not illustrate the finer points of developing a good problem statement (including study objective, physical and temporal scope, constraints, assumptions). The options and criteria considered are illustrative only, and in practice may not give a consistent and comprehensive assessment.

A2.1 Direct evaluation

Problem statement

A new area of contaminated land has been located on an existing site that has an established contaminated land management strategy. It is a small patch of about 10 m^3 that appears to have occurred from a spill. Radioactivity is present although radionuclides are uncertain. Initial characterisation shows that the concentrations are low by comparison with other areas of contamination on the site. The contaminated area is not close to access routes or occupied buildings. Regulators are notified of the find and the local community's environmental network is made aware of the situation.

Identify options

A risk assessment indicates the need to remediate the contamination. The owner/operators identify three options, based on their experience and the existing considerations for the site strategy for contaminated land management. These would be integrated with the strategy for the rest of the contamination on the site, and comprise:

- excavate and dispose
- immobilisation
- capping.

Assessment criteria

A basic set of assessment criteria are considered: health and safety, environmental effects, technical issues, social and economic factors and costs. Each is subdivided into pros and cons.

Assess options

The options are assessed by one of the owner/operator's contaminated land experts and reviewed by a colleague. In assigning scores, information on other contaminated land at the site is used as a point of reference. The outcome of the option assessment is presented in Table A2.1.

Compare options

The options are compared by inspection of the matrix as shown in Table A2.1 and the descriptions. The comparison is undertaken by a contaminated land expert of the owner/operator, who makes a recommendation, as follows:

- excavation will remove the hazard and use established methods, however it may result in unnecessary exposure to workers. It is not clear that excavation is necessary
- immobilisation could result in lower costs, less potential for exposure and less disruption, however work would be needed that may duplicate necessary work for other parts of the site
- capping the contaminated area will prevent the potential for exposure and migration and is likely to be lowest cost, but there might be migration in the future.

In conclusion, the preferred management strategy is to cap the area. Work then starts to examine the feasibility of incorporating this into the site-wide strategy for contaminated land.

This is documented, reviewed by management and regulators are notified along with the environment representative on the local site stakeholder group.

Table A2.1 ***Example of direct evaluation of a simple contaminated land situation***

Criterion		Excavate and dispose	Immobilisation	Capping
Health and safety	Pros	Removes the contamination	Contamination immobilised and isolated	Breaks the main exposure pathway
	Cons	Some worker exposure	Some residual hazard remains	Some residual hazard remains
Environment	Pros	Removes the contamination	Contamination immobilised and isolated	Migration of contaminants monitored and controlled
	Cons	–	–	Possibly some limited release into the environment in time
Technical	Pros	Simple approach with limited requirements	Various approaches can be considered	Simple, variety of sub-options
	Cons	–	Options require some plant/engineering	–
Social and economic	Pros		–	–
	Cons	–	–	–
Costs	Pros	Costs not major	Costs vary, some options may be less than excavation	Low cost compared with other options
	Cons	Costs may be unnecessarily spent (eg radioactive waste disposal)	Costs vary, some options may be more than excavation	–

Note: – indicates no significant factors identified in respect of the criterion.

A2.2 Non-compensatory methods

Problem statement

Contaminated land has been located on a site where a contaminated land management strategy has been defined. The strategy includes element levels (contaminant concentrations) giving an acceptable level of clean-up that should be achieved for various management options (eg capping, immobilisation, excavation). The contamination is a small patch but the concentrations are significant by comparison with other areas of contamination on the site. The contaminated area is close to access routes and occupied buildings. Regulators are notified of the find and it is scheduled for discussion with a local community's environmental network.

A preliminary assessment of the management of the contaminated land is required. The options comparison method selected is elimination by aspects.

Identify options

The owner/operator's experts identify three options, based on their experience and the existing considerations for the site strategy for contaminated land management. These include:

- excavate and dispose
- immobilisation
- capping.

Assessment criteria

A basic set of assessment criteria is considered: health and safety, environmental effects, technical issues, social and economic factors and costs. In each case, a specific criterion is identified with an associated required performance standard, shown in Table A2.2. The performance standards are defined based on information defined in the existing site strategy for contaminated land management. An important element of the existing standard is a set of clean-up levels (radionuclide and non-radioactive contaminant concentrations) that have been calculated.

Table A2.2 ***Example of performance criteria for evaluation of simple contaminated land situation by elimination by aspects***

Criterion	Performance standard
Worker health and safety	No significant increase in average worker doses
Public health and safety	Site-specific clean-up levels (dose criteria)
Environment	Site-specific clean-up levels (environmental criteria)
Technical requirements	Carried out within 10 years Does not adversely impact on decommissioning projects Does not increase site discharges Consistency with waste hierarchy
Social and economic effects	No adverse impact on jobs No adverse impact on local amenity
Costs	No prescribed performance criteria

Assess options

The options are assessed at a workshop by representatives of the owner/operator, and reviewed independently. During the assessment, information on existing contaminated land is used as a point of reference, in particular pre-calculated site-specific generic clean-up levels, which provide concentration targets for various management options. A compilation of contaminated land management options that had been previously developed is also consulted. For each criterion, options are rated as definitely meeting the performance standard (✓), definitely failing the performance standard (✖), or uncertainty as to whether the standard is met or failed (?).

Compare options

The criteria are ordered according to their ability to discriminate between options. The assessment indicates that excavation is not favoured due to its impact on the waste hierarchy, although it achieves relevant clean-up levels. There is uncertainty as to whether immobilisation will meet the clean-up levels and worker dose targets as important radionuclides are believed to be difficult to immobilise. Capping appears to achieve objectives, although there is some uncertainty as to whether environmental criteria are fully satisfied. This is the strategy that is provisionally selected, and a study commissioned to examine specific caps. The assessment and recommendation is documented and sent to regulators and local stakeholders.

For comprehensiveness, the ratings assigned to the other criteria are shown in Table A2.3.

Table A2.3 ***Example of use of a non-compensatory approach to preliminary assessment of a management strategy for a contaminated land situation***

Criterion	Excavate and dispose	Immobilisation	Capping
Consistency with waste hierarchy	✖	✓	✓
Worker doses	?	?	✓
Clean-up levels (dose)	✓	?	✓
Clean-up levels (environmental)	✓	?	?
Does not increase site discharges	✓	✓	✓
Does not adversely impact decommissioning	✓	✓	✓
Carried out within 10 years	✓	✓	✓
No adverse impact on jobs	✓	✓	✓
No adverse impact on local amenity	✓	✓	✓

A2.3 Cost-benefit analysis

Problem statement

An area has been identified on an operating nuclear site where an amount of contaminated material was believed to have been disposed of. The area is thought to include some lightly contaminated radioactive material (inadvertently disposed of) and asbestos. The area has not been subject to intrusive analyses, however, characteristics of the contamination have been estimated with reference to historical records.

A qualitative risk assessment is undertaken and action is taken to control the contaminated area. The site's contaminated land management team then undertake an initial assessment of management options. It is considered appropriate to use a cost-benefit approach, and regulators and other stakeholders are comfortable with this.

Identify options

Options are identified with reference to the objectives for managing the contaminated area and its main characteristics. An important receptor is soil outside the site boundary, which is now in agricultural use. A small number of dwellings are also nearby, and a nature park with a lake. The contamination can migrate by groundwater and air (as dust).

The options for managing the contamination are identified by the site's contaminated land management team following a review of technologies, and include:

A Further site investigation and removal of contamination.

B Simple capping (not fully impermeable).

C Impermeable capping, barriers and groundwater treatment.

D Monitored natural attenuation and access control.

Other options were screened out as being impractical or grossly disproportionate to the situation. The options are documented and presented to regulators and site stakeholders along with the basis for their identification.

Assessment criteria

Assessment criteria are identified, and a basis for expressing them in monetary terms is developed. The criteria selected to express benefits relate to the impacts of the options on:

- property value
- agricultural value
- amenity.

Together, these criteria are considered suitable to express the potential benefits to human health, the environment, and social factors.

Assess options

For each of the criteria, the basis for its conversion to monetary value is documented. For example, the impact on property and land costs is investigated directly, allowing for other activities on site that will affect values. Amenity costs are based on published information concerning willingness to pay for access to the lake and associated nature reserve.

The cost of enforcing each option takes account of the estimated extent of characterisation, and available estimates of the resource requirements to deploy each option. Also, an estimate of waste management costs is developed, as well as capital and operating costs,. These costs are calculated based on actual costs per unit volume, and estimated characteristics and volumes of contaminated material that could be associated with each of the remediation options.

Both costs and benefits are calculated on both an undiscounted and discounted basis. Tables A2.3 and A2.4 present the undiscounted values. Discounted values, and ranges that take account of uncertainties, are also documented.

Table A2.4 ***Benefits realised by the application of the option***

Option	Property (£k)	Agriculture (£k)	Amenity (£k)
SI and removal	125	50	50
Capping	50	0	25
Cap and treat	50	50	25
Monitor and control	0	0	0

Table A2.5 ***Costs incurred in the application of the option***

Option	Capital cost (£k)	Operating cost (£k/y)	Duration (y)	Waste management (£k)
SI and removal	500	One off action	0.5	200
Capping	50	10	30	0
Cap and treat	200	20	30	50
Monitor and control	0	10	50	0

Compare options

The benefit-cost ratio is considered the most appropriate measure of the performance of the options. There is no defined budget available for dealing with the contamination at this stage, and this method provides a good measure of the relative balance of benefits and costs.

The reference (undiscounted) benefit-cost ratios are calculated to be:

A SI and removal: 0.32
B Capping: 0.21
C Cap and treat: 0.15
D Monitor and control: no benefits on the assessed criteria

A further analysis was applied to take account of discounted costs and uncertainties. This appeared to make capping slightly more favourable, however, Option A remained preferred although it is noted that the benefit-cost ratio remains below 1 (indicated that there is a net cost of the action).

The contaminated land management team documents the work and reports it to the regulators and local community's environmental network, and comments are invited as to whether the study provides sufficient basis for selection of an option or whether further work is needed.

A2.4 Trade-off analysis

Problem statement

A site has reached the end of its use, and consideration is being given to its future management. Most of the site is free from contamination, but one area has substantial chemical contamination and some radiological contamination. The owners/operators are considering the most appropriate management strategy that will take the whole site to a suitable end state. It is decided to use a trade-off analysis approach. Regulators are informed of the study as is the local community's environmental network.

Identify options

The site management team identify four options, based on their experience and the existing considerations for the site strategy for contaminated land management. These include:

- mothball: immediately close the site and restrict access[13]
- restricted reuse of site: seek potential alternative uses for a restricted and controlled site, and manage contamination *in situ* consistent with use
- partial sale: sell all the uncontaminated land as rapidly as possible and retain the contaminated area for in situ management of the contamination
- clean-up for complete sale: remediate the whole site for sale as quickly as possible.

The options are published along with a short news story in the local newspaper, along with an invitation for people to offer views.

Assessment criteria

A basic set of assessment criteria are considered: health and safety, environmental effects, technical issues, social and economic factors, security and costs. These are broken down into a range of sub-criteria considered to be relevant to the contaminated land situation. The criteria are shown in Table A2.5. In each case, a definition is developed, with an indication of completely acceptable and nearly unacceptable performance.

Assess options

A desk study is undertaken to develop the options and describe their main characteristics. This information is compiled in a briefing pack for an options assessment workshop. The workshop involves technical experts drawn from the owner/operator's team, independent experts – including those from NGOs and CBOs, and a balanced range of local non-statutory stakeholders. The assessment of the options is helped by an independent expert selected by the entire group. Where there is a difference of views, a range of experts act as intermediaries for both statutory and non-statutory stakeholders. The outcome of the workshop is documented, focusing on the assigned ratings for each option and criterion, and a supporting record of the discussion and justification that led to the assignment of the score. Options are assigned scores on a scale of 1 (very poor) to 5 (very good). The scores are summarised in Table A2.6.

13 This option is recognised as likely to be unfeasible but is included as an option to illustrate minimal action.

Compare options

Stakeholders are invited to review the options assessment results, both by correspondence and in person at two stakeholder workshops. In each case their views on the importance of criteria is sought by asking them to rate the importance of each criterion on a scale of 0–100. The general outcome is that social and economic factors are considered to be most important, followed by health and safety, security, environment, technical and cost criteria. Preferences are expressed by stakeholders for the partial sale of the site or complete clean-up.

Following an assessment of the responses, a meeting is held by the owners/operator to consider the evidence and make a decision.

It was quickly concluded that the option of immediately closing the site is unacceptable. It is very poorly rated against several criteria that are important both from the perspective of stakeholders and the owner/operator. Restricted reuse of the site was considered to be potentially important; however practical difficulties are encountered in finding potential users of a site subject to the necessary controls. The complete clean-up option would result in higher worker exposures, more waste and more cost over a greater period of time compared with partial clean-up. However, the remediated land would be completely available for reuse, and could be sold without conditions, offsetting a significant portion of the costs of clean-up. The decision is taken to select complete clean-up as the option to be used.

The outcome, and a description as to why it is chosen, is published in local media.

Table A2.6 ***Examples of criteria adopted in a strategic study using trade-off analysis***

Criterion group	Criteria
Health and safety	Worker safety (radiological) Worker safety (other) Public safety (long-term) Public safety (transport)
Environment	Visual affect Contaminant concentrations Natural resource use Noise
Technical	Project risk Time Waste generation Flexibility
Social and economic	Local employment prospects Burden on future generations
Security	Vulnerability to disruption Vulnerability to theft
Cost	Estimated cost to enforce strategy Land value realised Continuing costs

Table A2.7 ***Example of scores assigned to several options using the trade-off analysis approach***

		Mothball	Restricted reuse of site	Partial sale	Clean-up for complete sale
Health and safety	Worker safety (radiological)	❺	❹	❹	❸
	Worker safety (other)	❺	❹	❹	❸
	Public safety (long-term)	❷	❷	❸	❺
	Public safety (transport)	❺	❺	❹	❸
Environment	Visual affect	❸	❸	❹	❺
	Contaminant concs.	❸	❸	❹	❺
	Natural resource use	❺	❺	❺	❹
	Noise	❺	❺	❹	❸
Technical	Project risk	❶	❹	❺	❺
	Tme	❺	❸	❹	❸
	Waste generation	❺	❺	❹	❸
	Flexibility	❺	❺	❹	❸
Social and economic	Local employment prospects	❶	❶	❹	❹
	Burden on future generations	❶	❷	❸	❺
Security	Vulnerability to disruption	❹	❺	❹	❺
	Vulnerability to theft	❹	❺	❹	❺
Cost	Estimated cost of enforcing strategy	❹	❹	❸	❷
	Land value realised	❶	❷	❹	❺
	Continuing costs	❸	❸	❹	❺

A2.5 Linear additive method

Problem statement

A site has reached the end of its use, and consideration is being given to its future management. Remediation options are being considered for a substantial area of the site which contains contamination. The owners/operators have adopted an overall strategy to clean-up the site for eventual sale. Methods of achieving this are being examined, and it is decided to use a linear additive method for comparing options. Regulators are notified, as is a working group of the local community's environmental network concerned with the clean-up of the site.

Identify options

The site management team identify three options, based on their experience and the existing considerations for the site strategy for contaminated land management. These include:

- excavate all contamination
- excavate the most significant contamination and cap/landscape other areas
- immobilise the most significant contamination and cap/landscape other areas.

Preliminary risk assessment studies show that all options could, in principle, meet the criteria for the release of the site from control. However, the excavate and cap and the immobilise and cap option would require further planning controls and possibly some reassurance monitoring.

The options are published along with a short news story in the local newspaper, along with an invitation for people to offer views. Those involved in a previous strategic assessment are sent information.

Assessment criteria

A basic set of assessment criteria are considered: health and safety, environmental effects, technical issues, social and economic factors and costs. These are broken down into a range of sub-criteria considered to be relevant to the contaminated land situation. The criteria are shown in Table A2.7. In each case, a definition is developed, with an indication of completely acceptable and nearly unacceptable performance. Where possible, numerical measures are assigned, for example, time was considered to range from >10 years (nearly unacceptable) to one year (completely acceptable).

Table A2.7 ***Examples of criteria adopted in a strategic study using trade-off analysis***

Criterion group	Criteria
Health and safety	Worker safety (radiological) Worker safety (other) Public safety (long-term) Public safety (transport)
Environment	Visual affect Contaminant concentrations Natural resource use Noise
Technical	Project risk Time Waste generation Flexibility
Social and economic	Local employment prospects Burden on future generations
Security	Vulnerability to disruption Vulnerability to theft
Cost	Estimated cost to enforce strategy Land value realised Continuing costs

Assess options

A desk study is undertaken to develop the options and describe and quantify their main characteristics in terms of the criteria being considered. Where possible, preliminary scores are assigned and have an associated justification. This information is compiled in a briefing pack for an options assessment workshop.

The workshop involves technical experts drawn from the owner/operator's team, many independent experts including those from NGOs and CBOs, and a balanced range of local non-statutory stakeholders. The assessment of the options is helped by an independent expert selected by the entire group. Where there is a difference of views, a range of experts act as intermediaries for both statutory and non-statutory stakeholders. The attendees review the scores and the evidence on which they had been based. Where no scores have been assigned in the briefing pack, the attendees make a judgement and document the justification. The scores are summarised in Table A2.8.

The outcome of the workshop is documented, focusing on the assigned scores for each option and criterion, and the record of the discussion and justification that supports them.

Compare options

Stakeholders are invited to review the options assessment results, both by correspondence and in person, by attending an independently facilitated workshop. A summary of the options assessment is made available. Stakeholders are invited to submit weights for each criterion, which are used in the evaluation of the scores. An example of the sets of weights, and the weighted aggregate scores that are calculated, is shown in Table A2.9.

The sets of weights are analysed to determine their influence on the ranking of options according to their weighted aggregate scores. A sensitivity analysis is also undertaken to determine how sensitive the overall ranking of options is to different potential combinations of weights.

It is concluded that the option of immobilising and capping the contaminated land is never ranked highly. Generally, the option of excavating all potential contamination ranks highest, however, if a high weight is placed on technical and cost factors, and a low weight on environmental and social/economic factors, the option of partial excavation and capping is ranked highest. The owner/operator's view is that on balance, the option to excavate all contamination should be adopted, with extra work that will seek to minimise waste volumes arising by sorting and segregating the excavated material. The decision is published, with a full description of the options comparison process.

Table A2.8 ***Example of scores assigned to several options for a linear additive method approach***

		Excavate all	Excavate and cap	Immobilise and cap
Health and safety	Worker safety (radiological)	55	70	90
	Worker safety (other)	70	70	80
	Public safety (long-term)	100	80	60
	Public safety (transport)	65	75	90
Environment	Visual impact	90	70	70
	Land quality	90	60	35
	Natural resource use	50	45	60
	Noise	60	60	70
Technical	Project risk	70	50	25
	Time	50	60	40
	Waste generation	25	55	100
	Flexibility	30	60	70
Socio and economic	Local employment prospects	80	60	30
	Burden on future generations	100	50	10
Security	Vulnerability to disruption	100	70	35
	Vulnerability to theft	100	70	35
Cost	Estimated cost to enforce strategy	10	55	30
	Land value realised	100	60	20

Table A2.9 *Example of weighted aggregate scores calculated with a linear additive method*

	Weighting set A	Weighting set B	Weighting set C
Worker safety (radiological)	70%	40%	90%
Worker safety (other)	70%	40%	90%
Public safety (long-term)	90%	100%	70%
Public safety (transport)	90%	100%	70%
Visual impact	60%	100%	50%
Land quality	60%	100%	60%
Natural resource use	30%	80%	30%
Noise	60%	80%	40%
Project risk	50%	20%	80%
Time	90%	20%	80%
Waste generation	20%	50%	70%
Flexibility	70%	20%	80%
Local employment prospects	100%	30%	40%
Burden on future generations	50%	100%	20%
Vulnerability to disruption	70%	40%	60%
Vulnerability to theft	70%	50%	60%
Estimated cost to enforce strategy	20%	5%	100%
Land value realised	20%	5%	80%
Weighted aggregate scores			
Excavate all	**73**	**76**	65
Excavate and cap	66	65	**66**
Immobilise and cap	54	57	55

A2.6 Analytical hierarchy process

Problem statement

The problem considered is the same as that described in Section A2.5, however it is assumed that discussions with stakeholders has led to problems establishing a clear and consistent understanding of the implications of weighting. For this reason, an analytical hierarchy process is used.

Identify options

The options considered are the same as described in Section A2.5.

Assessment criteria

The criteria are the same as described in Section A2.5.

Assess options

The scoring of options is undertaken in the same manner as described in Section A2.5. The results are shown in Table A2.8.

Compare options

A group of stakeholders is established from the full list of consultants. Volunteers are invited to attend a workshop to examine the options, and efforts are made to ensure that the attendees are representative of the mix of stakeholders to the problem. The workshop is independently assisted, and the attendees are taken through the process of determining weights using the analytical hierarchy process. An example of one of the attendee's weighting matrix is shown in Table A2.10.

Table A2.10 ***Example of the determination of weights using the analytical hierarchy method***

	Health and safety	Environment	Technical	Social and economic	Security	Cost
Health and safety	1	3	7	1	5	9
Environment	1/3	1	7	1/3	1	9
Technical	1/7	1/7	1	1/9	1/3	5
Social and economic	1	1/3	9	1	3	9
Security	1/5	1	3	1/3	1	3
Cost	1/9	1/9	1/5	1/9	1/3	1

Using the matrix in Table A2.10, the calculated weights were:

- health and safety 39 %
- environment: 17%
- technical: 5%
- social and economic: 26%
- security: 11%
- cost: 3%

The scores assigned to criteria are combined to generate a measure of performance for each criterion group. This was done by taking the geometric mean, mean, minimum score and maximum score. The resultant weighted aggregate scores (see Table A2.11) all indicate that the option of excavating all contamination is most preferred for the weights shown in Table A2.10.

Table A2.11 *Weighted aggregate scores, calculated by various methods*

Method	Excavate all	Excavate and cap	Immobilise and cap
Geometric mean	76 (1)	66 (2)	52 (3)
Mean	78 (1)	66 (2)	53 (3)
Minimum score in group	63 (1)	59 (2)	37 (3)
Maximum score in group	97 (1)	71 (2)	64 (3)

Note Ranks in brackets

A detailed analysis of all the weights generated by stakeholders revealed a very strong preference for the option of excavating all contamination. The owner/operator's view is that the option should be adopted, with extra work that will seek to minimise waste volumes arising by sorting and segregating the excavated material. The decision is published, with a full description of the options comparison process.

A2.7 Multiple criteria decision analysis

Problem statement

The problem considered is the same as that described in Appendix A2.5, however it is assumed that stakeholder involvement is continuous, with a relatively small number of stakeholders through workshops and other methods. The stakeholders have a diverse set of views and there is a need to understand the implications of these views in detail. Reflecting the importance of weighting, and the opportunity to work closely with a range of important stakeholders, a MCDA approach is adopted.

Identify options

The options considered are the same as described in Section A2.5.

Assessment criteria

The criteria are the same as described in Section A2.5.

Assess options

The scoring of options is undertaken in the same manner as described in Section A2.5. The results are shown in Table A2.8.

Compare options

A group of stakeholders representing all constituencies is established and invited to attend a workshop to give their views on the main factors to inform decision making and to compare the options. The workshop is independently assisted. The MCDA approach is explained with reference to hypothetical examples. The process is based on that applied by CoRWM (Phillips *et al*, 2006), although other variations are equally valid.

The derivation of swing weights is undertaken by developing an initial ordering of the

criteria according to the expected swing in value. As an introduction, the trainer explains each criterion, its basis, uncertainties, and the range of scores that have been determined for each of the options by specialists at the stage of assessing options. Swing weights are developed for each of the criteria, working group by group.

For example, for the health and safety group, the criterion assigned the greatest weight (100) was agreed to be public safety (long-term) as the options performed quite differently, and the improvements in performance were considered to have the greatest value. Other criteria in this group were then assigned weights relative to public safety (long-term), using a pair wise comparison:

- worker safety (radiological) 50
- worker safety (other) 20
- public safety (long-term) 100
- public safety (transport) 70

This process was repeated for each group of criteria. The group sought to agree a consensus set of swing weights, but could also record alternative views if some did not agree with the majority.

The next stage is to compare the criterion groups themselves, and assign swing weights at this level. For each criterion group, the criterion assigned a swing weight of 100 is compared with all those of other criterion groups.

- health and safety 90 (public safety, long-term)
- environment 75 (land quality)
- technical 50 (time)
- social and economic 100 (burden on future generations)
- security 5 (vulnerability to disruption)
- cost 20 (land value realised)

The full set of raw weights generated is shown in Table A2.12. First these are recalculated by multiplying the criterion weights by the weight assigned to the relevant criterion group to calculate revised weights for individual criteria. The recalculated weights for each criterion are then summed for each criterion group, to generate a re-calculated weight for the whole criterion group.

Table A2.12 ***Calculation of swing weights for the reference weighting set***

Group	Criterion	Raw criterion weights	Raw criterion group weights	Recalculated criterion weights	Recalculated criterion group weights
Health and safety	Worker safety (radiological)	50	90	45	226
	Worker safety (other)	20		18	
	Public safety (long-term)	100		100	
	Public safety (transport)	70		63	
Environment	Visual affect	70	75	52.5	139
	Land quality	100		75	
	Natural resource use	10		7.5	
	Noise	5		3.8	
Technical	Project risk	20	50	10	100
	Time	100		50	
	Waste generation	70		35	
	Flexibility	10		5	
Social and economic	Local employment prospects	80	100	80	180
	Burden on future generations	100		100	
Security	Vulnerability to disruption	100	5	5	9.5
	Vulnerability to theft	90		4.5	
Cost	Estimated cost to enforce of strategy	50	50	10	30
	Land value realised	100		20	

The recalculated weights can then be applied to the scores for each option and an aggregated total score calculated. For the reference swing weights, the calculated aggregate weighted scores (normalised to a scale of 0–100) were:

- excavate all 78
- excavate and cap 64
- immobilise and cap 51

The workshop attendees then review the scores to determine, for example, the contribution of particular criteria, and to examine which criteria differentiate the options significantly. The most significant criterion in this case is the burden on future generations, followed by land quality and long-term radiological safety.

Sensitivity analyses are then undertaken to explore the effects of changing scores or weights. A main input to this stage is the alternative sets of swing-weights generated by the workshop participants. These can be analysed to determine alternative scores.

The analysis confirmed that there is a strong preference for the option of excavating all contamination. The decision is published, with a full description of the options comparison process.